Laboratoire d'analyse et d'architecture des systèmes du CNRS

Activity Report 2009-2014

and

Scientific Project 2016-2020

June 2015

Université Fédérale
Toulouse Midi-Pyrénées

Contents

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This report presents the activities carried out during the period January 2009-June 2014. It also briefly sketches the Scientific Project of the Laboratory for the period 2016-2020. It is available for download from the Laboratory website: www.laas.fr.

It is complemented by a companion document

Scientific Production 2009-2014

that lists the bibliographical references used in this report and that is also available for download from the Laboratory web site.

I- Presentation of the Laboratory

1 Introduction

Located in Toulouse, LAAS-CNRS was created in 1968. It was originally named ***Laboratoire d'Automatique et de ses Applications Spatiales***, relating the obvious links existing with the installation of CNES at the same period. Since 1994, its name is: ***Laboratoire d'Analyse et d'Architecture des Systèmes***, reflecting the extension of its activities beyond Automatic Control (Computer Science, Robotics, Microelectronics) as well as the application domains of the research results, while keeping the same acronym. Actually in practice, the laboratory is known for years as LAAS-CNRS**.**

LAAS-CNRS is one of the major CNRS laboratories and is attached to two institutes INS2I and INSIS. During the period the laboratory was also closely connected to the **University of Toulouse** (UT) and in particular, it was associated by convention with the six founding members: UT3PS, INSAT, INPT, UT2J, UT1C, ISAE. This means that CNRS researchers and faculty members work closely together to cover the various research topics addressed by LAAS. More precisely, the Lab. is linked to three sections of the **CoNRS** ***(Comité National de la Recherche Scientifique)*** — 6, 7 and 8, and to four of the **CNU** (***Conseil National des Universités)* —** 27, 28, 61 and 63.

2 Scientific Strategy

2.1 The Activity Profile

Research activities being developed cover a wide spectrum of the fields of Science and Technology of Information and Communication and of Systems Engineering. They address various kinds of complex systems, generally heterogeneous, and at different scales, for devising advanced conceptual an theoretical works, proposing methodologies for modeling, designing and controlling them, as well as developing demonstrators and tools for exemplifying and supporting these results. Among the several platforms available at LAAS that make such developments possible, it is worth pointing out the micro and nano manufacturing platform from the RENATECH network.

For years, research, innovation and transfer activities have been closely linked. Indeed, LAAS has a strong history of relationships with industry. This is exemplified by a continuous implication into a large number of direct and collaborative projects with international, national and regional industries of various sizes. This commitment is also evidenced by the fact that LAAS was selected among the first "Carnot Institutes" labeled in 2006; the label was renewed in 2011, for five years.

Considering its mission and the close links to the University of Toulouse partners, LAAS is very much involved into training activities: for example, during the considered period, the Lab. hosted more than 1000 trainees and 580 PhD students; a total of 342 PhD theses were defended, thus a yearly average of 62.

LAAS has definitely a strong involvement into activities supporting research both at international (e.g., **IEEE**, **IFAC**, **IFIP**), national (**CoNRS**, **ANR**, **ALLIANCES, Ai Carnot**, etc.) and regional levels; the latter has been significantly developing during that period due to the emergence and actual elaboration of the University of Toulouse, in particular the evolution from **PRES** (*Pôle de Recherche et d'Enseignement Supérieur*) to **COMUE** (Communauté d'Universités et d'Établissements) into which CNRS is explicitly involved.

Based on these various dimensions, it is not surprising that LAAS-CNRS features an activity profile mainly oriented towards academic research and a rather well balanced distribution among the other facets depicted in Table 1.

Table 1: Activity Profile

Facets	Academic Research	Interaction with Environment	Research Support	Training
%	51	17	11	21

2.2 Scientific Positioning

To anticipate the interdisciplinary challenges of emerging and future systems, LAAS has identified and implemented two strategic axes:

- **ADREAM** (Architectures for Dynamic Resilient Embedded Autonomous Mobile systems): this axis addresses the challenges raised by the emergence of Ambient Intelligence, Internet of Things and Cyber-Physical Systems as well as the production and optimized usage of Alternative Energies.
- **ALIVE** (AnaLysis and Interactions with the liVing and the Environment): in that case, technologies (mostly micro and nano), but also to some extent software-implemented algorithms, have been focused to target for health care (analysis, diagnosis, medication) and environmental concerns (water, air).

The development of the first axis was boosted by the construction of a new instrumented and energy optimized building (Figure 1).

Figure 1: The Photovoltaic Windowed Façade and Roof of the Georges Giralt Building

ALIVE has also benefited from a newly extended experimentation platform for supporting biological and chemical analyses.

The related relevant research encompasses a large body of the activities and skills developed at LAAS:

Table 2: Scientific Themes and Keywords

Themes	Keywords
IC	Architectures and Algorithms for Dependability, Formal Techniques for System Description and Verification, Modeling, Prototyping and Experimentation, Security and Privacy, System and Requirements Engineering, Verification, Validation, Testing and Assessment
RC	Communication Networks, Protocols and Communication Services, Internet of Things and Machine-to-Machine, Software Services and Architectures, Performance Evaluation, Quality of Service, Autonomic Computing and Networking, Ontologies, Network Computing, Traffic Engineering (Models and Tools)
ROB	Motion Planning, Task Planning, Visio-auditive Perception, Human-robot Interaction, Multi-robot Cooperation, Humanoid Motion Generation and Control, Human Motion, Control Architectures, Sensor Integration, Learning, Sensor-based Robot Control, Autonomous Mobile Manipulation
DO	Constraint Programming, Continuous and Discrete Optimization, Control Theory, Diagnosis, Fault Detection and Isolation, Hybrid Systems, Operational Research, Robustness, Scheduling and Logistics
HOPES	Nanotechnologies, Micro and Nano Systems, Optoelectronics (Components and Systems), Photonics, Optical Sensors, Sensor Networks, Microwave Components, Integration of Microwave Systems, Opto-microwaves, Electrical Noise and Reliability, Wireless Communications
N2I	MEMS, Lab-on-chip, Energetic Nanomaterials, Nanofluidics, Atomic Scale Modeling, Smart Sensor Integration, Wearable and Embedded Systems
MNBT	Physics and Advanced Integration of Nanomaterials, Biosensing, Chemosensing, Living Cells Analysis
GE	Active and Passive Power Devices, Energy Conversion, Power Integration, Microstorage, Wide Bandgap Semiconductors, Energy Harvesting, Radiation Hardening, Robustness (EMC and ESD), Predictive Modeling (electrothermal, ESD, EMC), Renewable Energies

- ADREAM: resilience and security of computing systems, communication networks (wired or wireless), Human-robot interaction, humanoid motion, control theory, diagnosis and optimization, smart sensors, sensor networks, advanced integration of nanomaterials, wearable systems, power devices, energy conversion, renewable energies, etc.
- ALIVE: lab-on-chip, microfluidics, biosensing and chemosensing, atomic scale modeling, molecular motion, advanced diagnosis, living cells analysis, etc.

2.3 The Scientific Themes

To address the challenges targeted by the two strategic and multi-disciplinary axes, the research activities develop skills in the four major disciplines that have constituted, for years, the hallmark of the laboratory: **Computer Science**, **Robotics**, **Automatic Control**, **Micro and Nano Systems**. Previously, the laboratory was organized into four scientific **domains** (or **areas**, ***pôles*** in French) — SINC (*Systèmes informatiques critiques*), RIA (*Robotique et intelligence artificielle*), MOCOSY (*Modélisation, optimisation et commande des systèmes*) and MINAS (*Micro et nano systèmes*) — that directly matched these disciplines. In order to provide more visibility to the research and results being achieved within these areas (especially those related to MINAS), **eight scientific themes** were identified that embody the main research orientations that were developed during the past years:

- **Crucial Computing** (*Informatique Critique* – **IC**),
- **Networks & Communications** (*Réseaux et Communications* – **RC**),
- **Robotics** (*Robotique* – **ROB**),
- **Decision & Optimization** (*Décision et Optimisation* – **DO**),
- **Microwaves & Optics: from Electromagnetism to Systems** (*Hyperfréquences et Optique : de l'Electromagnétisme aux Système*s – **HOPES**),
- **Nano Engineering & Integration** (*Nano Ingénierie et Intégration* – **N2I**),
- **Micro Nano Bio Technologies** (*Micro Nano Bio Technologies* – **MNBT**),
- **Energy Management** (*Gestion de l'Energie* – **GE**).

Table 2 depicts the main keywords identifying the research activities being conducted in each scientific theme.

3 The People

LAAS-CNRS remains among the largest academic research labs in France. Its personnel — 660 persons as of June 30, 2014 — has only slightly evolved (this number was 635 in 2009, thus an increase of less than 4%). Table 3 shows the variations for several typical categories. The main change is attached to the relative distribution of permanent staff among CNRS researchers and Faculty (UT) members that has significantly evolved during the considered period.

Table 3: Evolution of Lab's Personnel
[Emeritus and non titular (e.g., affiliates) members not included]

Period milestones	Permanent		Temporary	
	Research CNRS - UT	Support ITA - BIATSS	Research - Support Eng. & Tech.	PhD - Postdoc
01/01/09	87[1] - 104	87 - 6	7 - 29	264 - 45
30/06/14	88 - 119	90 - 11	22 - 38	242 - 38

[1] Including 1 INSERM

Another significant variation in Table 3 concerns temporary positions, in particular, Research Engineer *vs.* Postdoc; this is due to a more precise classification of Postdoc positions that is now enforced. Also worth pointing out is the high number (and even increased about 30%) of contractual support staff (CDDs).

In addition, the Lab. hosts annually about 200 students (Master programs) from various universities and engineering schools.

3.1 A Truly International Lab.

With more than 1/4 of Lab. personnel (≈ 170 persons) originating from 45 foreign countries, the Lab. gathers a truly international population, as shown on Figure 2 that depicts the geographical distribution of foreign members.

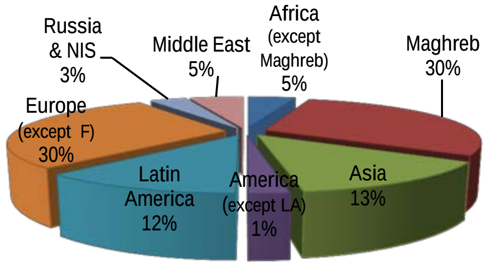


Figure 2: Geographical Distribution of Foreign Members

3.2 An Integrative Lab.

Indeed, as was planned in the project of the previous period, the Lab. has integrated most of the members (essentially faculty members) of two laboratories — **LATTIS**[1] (INSAT & UT2J) and **LOSE**[2] (INPT): a total of 18 professors and assistant-professors have joined the Lab. in 2011. For LATTIS, they have been integrated into existing research teams (see § 4) according to their research activities:

- One person working on artificial muscles in robotics has joined the ROB theme (Gepetto team).
- Three persons have integrated the IC theme, with two persons working on safety issues joining TSF, while one working on systems engineering joined the ISI team.
- Two persons, working on sensor networks, have joined the NII theme (N2IS team).
- Two persons, working on electromagnetic Compatibility have integrated the GE theme (ESE team).
- One person, working on Nonlinear Dynamics and Chaos, has joined the DO theme (MAC team).

The EMI experimentation zone, located at the Computer Science Engineering department of INSAT, has been incorporated as a part of the Characterization platform.

The integration of the LOSE members (9 faculties) gave birth to a new research team (OSE: Optoelectronics for Embedded Systems), part of the HOPES theme. In that case, the related personnel remained located at INPT-ENSEEIHT.

3.3 A Renewed Personnel

Table 4 details the yearly flow of permanent personnel over the period.

Table 4: Yearly and Global (Δ) Flow of Personnel

	2009		2010		2011		2012		2013		2014		Period		
	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	Δ
Researchers	1	0	5	3	4	6	4	6[1]	3	1	2	2	19	18	*1*
ITAs	3	5	3	1	3	4	2	0	4	4	4	4	19	18	*1*
Faculty	2	3	4	3	22[2]	3	3	7	5	5[4]	1	0	37	21	*16*
BIATSS	1	1	0	0	0	0	2	1	4[3]	0	1	1	8	3	*5*

[1] Including one INSERM; [2] Integration of LATTIS and LOSE faculty members; [3] Integration of OSE BIATSS; [4] Convention with ISAE discontinued.

The main change, as noted earlier, is related to the integration of LATTIS and LOSE members. Table 5 depicts the global flow of CNRS and UT personnel and the current status. In particular, the figure for incorporation of CNRS researchers clearly shows the attractiveness of the Lab.

Table 5: Global Flow of CNRS and UT Personnel (detail)

a) Research: Researchers (C); Faculty members (E/C)

C - E/C	CNRS	UT3PS	INSAT	INPT	UT2J	UT1C	ISAE	ENAC	UT	Total
In	19	14	11	9	2	1	0	0	37	56
Out	18	11	4	1	0	0	4	1	21	39
Delta	*1*	*3*	*7*	*8*	*2*	*1*	*-4*	*-1*	*16*	*17*
30-06-14	88	66	34	12	5	2	0	0	119	207

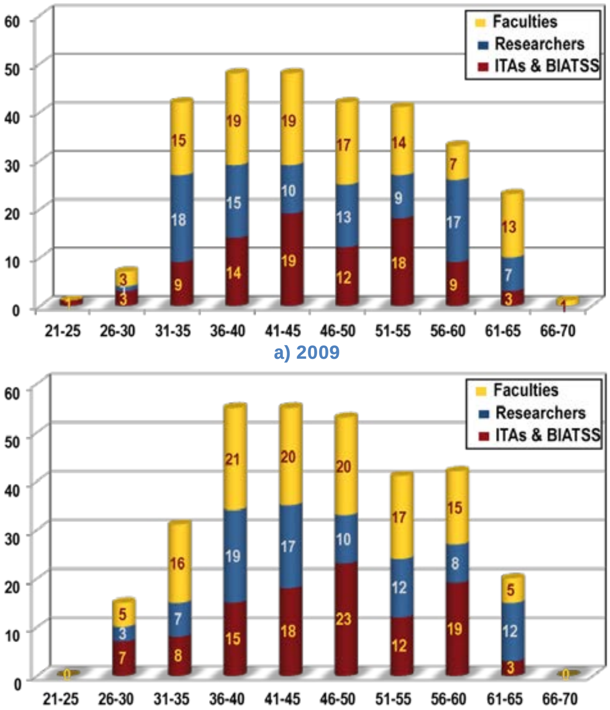
a) Support Staff

ITA - BIATSS	CNRS	UT3PS	INSAT	INPT	UT2J, UT1C, ISAE, ENAC	UT	Total
In	19	4	0	5	0	9	28
Out	18	2	0	1	0	3	21
Delta	*1*	*2*	*0*	*4*	*0*	*6*	*7*
30-06-14	90	5	1	5	0	11	101

During the period, the convention with ISAE that affected 4 faculty members to the Lab. was not renewed; accordingly, these persons are no longer LAAS members. The tables also indicate a significant "turn-around" of permanent members over the considered period: almost 100 for research and 50 for support personnel.

3.4 Anticipating the Future

In spite of the increase in the number of support staff (essentially from University — see Table 3) the concerns that were anticipated in 2009 (Figure 3-a) about the renewal of the support staff are exacerbated by the shift in the age distribution and are reflected by the fact that 19 members in this category belong to the 56-60 age-range (Figure 3-b). It is also worth pointing out that while the number of CNRS researchers was maintained over the period, the next years might be more difficult in particular as 12 researchers are now in the 61-65 age-range. A similar difficulty might apply to faculty members, to a less extent however, due to the significant increase in this category during the period (both via integration and recruiting).



a) 2009

b) 2014

Figure 3: Age Pyramids

4 Organization and Life of the Laboratory

Figure 4 illustrates the current organization of the Lab.

4.1 The Scientific Themes & Research Teams

As shown on Figure 4, most Scientific Themes are composed of several basic research entities. Today, the basic operational research entity of the Laboratory is a research **team**. The laboratory has currently 22 teams.

Each **research team** is composed of researchers (CNRS, faculty, post-docs and PhDs) sharing a set of focused scientific subjects and objectives. Each researcher belongs to a single team. A team is directed by a leader and a scientific committee that meets at least 6 times per year. The team manages its own resources and

[1] *Laboratoire Toulousain de Technologie et d'Ingénierie des Systèmes.*
[2] *Laboratoire d'Optoélectronique pour les Systèmes Embarqués.*

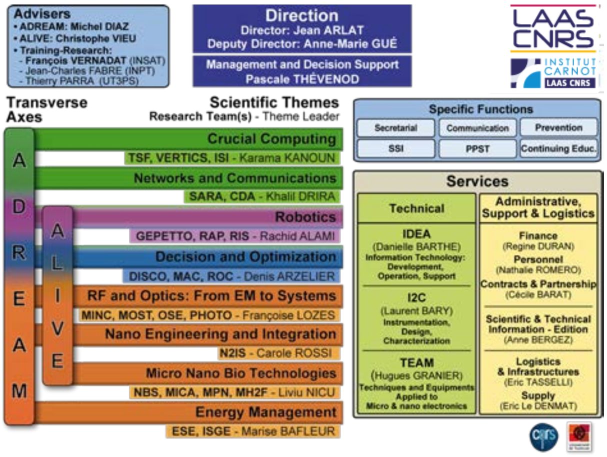


Figure 4: LAAS-CNRS General Organization

external projects and contributes to the common Lab. budget. The size of a team is variable and its lifetime is five years, renewable according to evaluation.

A **scientific theme** gathers in a consistent way, connected and/or complementary research topics that can be carried out by distinct teams. Each theme has a leader and a scientific committee that meets at least 6 times per year. One research team belongs to a single theme. This maintains the focus on a set of well-identified and characterizing topic for each theme. Accordingly, the themes gather a set of rather homogeneous members. This is exemplified on Table 6.

Table 6: Distribution of Personnel among the Themes and of Permanent Members among CNRS & CNU Sections (June 30, 2014)

Themes	IC	RC	ROB	DO	HOPES	N2I	MNBT	GE	Total
Total	64	56	82	78	63	39	55	47	484
CNRS	12	7	15	16	9	7	16	6	88
Faculty	21	14	10	24	18	10	6	16	119
PhDs	24	33	51	36	32	19	29	19	243
Post-docs	7	2	6	2	4	3	4	6	34
Distribution by Sections (CoNRS; CNU) of Permanent CNRS & Faculty Members									
Sections 6, 7; 27, 61	33	21	25	40	1	1	0	0	121
Sections 8; 28, 63	0	0	0	0	26	16	22	22	86

This level of structuration into themes proved also useful and efficient to facilitate the integration of the faculty members from the LATTIS and LOSE labs. This organization change and the related identification of more focused research topics facilitated the grouping of activities previously developed into distinct teams. The number of teams has significantly grown (5 additional teams) since the last period.

For all these reasons, we have opted for a detailed description of the activities of the Lab. at the level of the Scientific Themes (see subsequent Chapters) and for this level to be considered for the evaluation.

4.2 The Services

Technical support is provided by a number of engineers and technicians. This personnel is currently organized into three common technical services:

- **IDEA**: Information technology: Development, Operation (*Exploitation*), Support (*Assistance*).
- **I2C**: Instrumentation, Design (*Conception*), Characterization.
- **TEAM**: Techniques and Equipment Applied to Micro & nano electronics.

The first two services, initially grouped into a single entity (II or 2I: Informatics & Instrumentation), were set in 2012 due to the size of the service (more than 40 persons: 38 permanent and 4 contractual (CDD) positions) and the wide range of activities covered, so as to allow for more flexible operations and management. The partition was made according to the respective core skills, namely:

- for IDEA, computers and networks,
- for I2C, electronics and instrumentation.

Still, close links are maintained in particular around several platforms (e.g., Robotics & Design) that are run jointly. It is also noteworthy that, following the retirement of its head in 2012, the "Information System" (database support and tools) service was merged into IDEA; two persons thus joined the IDEA service.

In addition, the Lab. features **6 common administrative, support and logistics services**. A specific cell, under the responsibility of the director, addresses the issues related to **Communication**. Also, the **secretarial** functions attached to the direction (two titular persons) and the theme/team/technical entities (7 persons, including 3 CDDs), and the prevention assistants (*assistants de prevention*) are under the responsibility of the director.

In the sequel, we briefly review the missions and activities of the services and of the communication cell that support the activities of the researchers and ensure the interface between the research activities and the environment at large, including the external administrative services. The activities of the technical services will be further described in line with the platforms they contribute to.

4.2.1 IDEA

The IDEA service gathers 23 people — including 1 contractual agent (CDD). The **first major mission** is the exploitation and management of the information technology (IT) resources and of the networking infrastructure of the laboratory, and assistance in their usage. Table 7 lists the IT resources and networking infrastructure available.

Table 7: IT Resources & Networking Infrastructure

IT Resources
• 1500 personal workstations, including 370 laptops
• 16 physical servers for services that cannot be virtualized (redundant firewalls, DNS, mail servers)
• 3 redundant and secure virtualization architecture supporting 72 virtualized servers
• 2 secure redundant networked storage servers (NAS) providing 30TB of storage space available for users
• 2 dedicated servers (50TB of disk space) to backup user and system data from common storage space, as well as the workstation data
Networking Infrastructure
• Optical fibers (1G or 10G links) interconnect the 8 buildings, 2 routers manage the routing of the traffic routing inside and outside the laboratory; Internet access is available via RENATER
• 175 switches provide access to 3816 ports
• 33 WIFI access points distributed all over the laboratory; they give access to 3 virtual networks (SSID)
• 3 communication servers, 1 IP gateway and 720 ip phones

Examples of services provided include: installing workstations, troubleshooting, data backups, Internet access and mailing, data security, video conferencing, fixed and mobile telephony. In 2013, 7345 "requests for assistance" were processed.

The **second mission** is concerned with the development and maintenance of the information system of the laboratory, as well as the related Web applications.

The service also provides **management and technical support to three platforms**: Robots, Networks and Design & Simulation. In addition to the support provided to these platforms that are exploited by several research projects, it is worth noting that the service provides support to a large number of other projects. In 2013, 11 such projects were supported for more than 1 p.m share each.

4.2.2 I2C

The I2C service gathers a wide range of skills encompassing electronics, instrumentation, mechanics, optics, and more recently biology — in support to the ALIVE axis. It is composed of 28 people (including 3 CDDs).

I2C staff maintains instrumental means that are available via several platforms and facilities: Robots, Design & Simulation, Characterization (electrical, microwave, optical, biological & chemical zones). The total surface for these four zones is about 1200 m^2 and the related equipment available is worth 7 M€. The major evolution concerns the latter zone that constitutes the specific facilities devoted to the ALIVE axis. Indeed, it was extended from 140 m^2 to 380 m^2, to accompany the development of ALIVE. This significant extension accompanied the relocation of the platform in the area hosting the original cleanroom facility of the laboratory.

The **Electronics** facility supports various kinds of realizations, including: design and routing of PCBs, cabling and prototyping (for Micro & Nano Systems and Robotics domains), management of self-service measuring instruments and of the electronic components shop (about 1300 references available). During the period, due to increased demand for support, the self-service offer was significantly developed (now, an area of 40m^2). Major evolutions concern the development of skills and equipment for high-density integration (e.g., Surface Mounted Devices or even Ball Grid Array components).

The Mechanics facility supports the design of parts and assembly. It is equipped with various tools and relevant machines, among which, a computer numerical controlled (CNC) milling machine, two lathes (CNC & manual) and a high-speed/high-precision machining center. The design and programming of the manufacturing are made under CATIA software. During the period the major evolution concerned the acquisition of a CNC laser engraver (≈ 80 k€ worth).

The I2C service also significantly contributes to the research team projects: about 60 such projects are supported annually; this represents a total of 18 ETPs.

4.2.3 TEAM

The TEAM service is composed of 36 members (including 3 BIATSS and 7 CDDs). It provides technology support to researchers for micro and nano components prototyping.

It is in charge of operation and development of the micro and nano technology platform (a 1500 m^2 cleanroom that is part of the national RENATECH network) that gathers all the manufacturing resources and equipment of the laboratory in the field and that is worth more than 30 M€.

TEAM staff is organized around technical zones with a leader, and technical project coordinators. Each member of the service exercises its expertise in specific zones. This encompasses the management, development of the zone, renewal of equipment and processes and the training and coaching of users.

In addition, TEAM staff is involved into scientific projects led by LAAS researchers. They contribute as technical project coordinators. Building on the in-deep knowledge of the means and processes of the cleanroom, this role is essential to assist LAAS researchers in their projects developed on the platform. In practice, more than 60 projects are supported yearly[3].

4.2.4 Communication

The main role of the Communication cell, currently composed of two titular agents, is to implement the Lab. communication strategy in line with the strategy of the CNRS and of the Midi-Pyrénées Regional Office, e.g., dissemination of scientific and technical culture, that is an integral part of researchers agenda since the 1982 law on Research orientation and programming.

Other examples of missions include: providing support for conferences and manifestations, organizing the internal communication, handling corporate communication and outreach to the general public, particularly, young people and the media.

4.2.5 Finance

The service is composed of 6 persons (including 1 CDD[4]). It is in charge of accounting activities and of managing the finances and the budget of the laboratory.

More than 5000 administrative acts (orders and invoice processing, travel expenses, conference registrations, etc.) are executed yearly. Due to the changes that occurred and the increase in the constraints imposed during the period (eOTP[5]-based accounting, stricter rules for justification), the load of the service has been severely impacted.

Nonetheless, the service is making all efforts to manage the financial resources handled by the Lab. that amount to about 14 M€/year.

4.2.6 Personnel

The service is composed of four persons (including 2 CDDs). It is in charge of the management of the laboratory's human resources, of the temporary or permanent personnel individual files, of staff training, of visitor procedure and of reception staff.

Reception, information to visitors and working-hours access control functions are ensured by two contractual persons. They also handle in and out mailing activities.

[3] Assistance is also provided to external academic and industrial projects as part of RENATECH (see Figure 9).
[4] One additional CDD is replacing a permanent staff member, currently on-leave.
[5] *Elément d'Organigramme Technique de Programme*.

The load of the service and especially the activities devoted to the hosting of new members — permanent or temporary (Postdocs, PhDs, Master students) have been significantly increased and complicated, since the laboratory has been labeled "ZRR (*Zone à Régime Restrictif*)" in August 2013. Indeed, this has resulted in a more stringent and lengthier process: to be granted the right to work at LAAS, all people have to be screened [6]. This process leads to an additional administrative overhead and has a significant impact on the hiring of all categories of personnel. We had to modify our Rules of Procedure (*Règlement Intérieur*) accordingly (see Appendix 5). From September 25, 2013 (when our first demand for access under the ZRR directive was submitted) to June 30, 2014 (≈ 9 months), 446 demands were submitted — thus an average of ≈ 50 demands per month. It is noteworthy that 204 concern EU citizens (among which 157 are French).

4.2.7 Contracts & Partnership

The service is composed of three persons (including 1 CDD). It is in charge of the negotiation and management of contracts, as well as, IP protection and valorization activities.

Just to give some figures, over the period, the service has contributed to the management of 58 European projects. On the average, each year, about 100 proposals were handled and submitted to national project calls (more than 80% correspond to submissions to ANR calls). In addition, one has to consider a yearly average of 90 contractual documents (direct collaborations, consortium and confidentiality agreements, extensions, etc.), as well as more than 35 proposals submitted yearly to Regional calls (Midi-Pyrénées Regional Council, University of Toulouse, RTRA STAE).

The creation of the Midi-Pyrénées SATT [7] (Toulouse Tech Transfer — TTT) in the first quarter of 2012 induced new types of interactions and different procedures for the valorization of our research results. By the end of June 2014, 15 files were being processed by TTT for the Lab.; five of them consisted in supporting maturation activities.

4.2.8 Scientific & Technical Information - Edition

The service is currently composed of 5 persons. It is in charge of all publications of the laboratory, scientific information, documentary research and audiovisual realizations as well as computer graphics and publishing.

It manages the library funds that gather 10,000 books, an archived collection of about 500 Journals and thesis manuscripts or conference proceedings.

In cooperation with UT3PS, INSAT and INPT, the Lab. contributes to the access to IEEEXplore, which is essential for all research teams. The Lab. participates also to inter-library sharing.

Researchers are increasingly encouraged to post their publications on HAL. The Lab. has a specific collection "HAL-LAAS". Currently, about 2,000 documents are available on-line. Figure 5 shows the evolution of documents posted and accessed over the period.

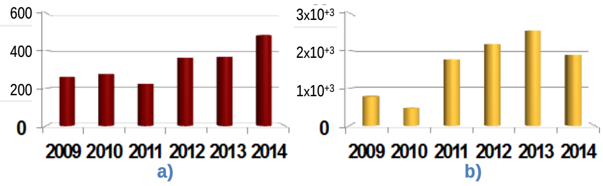


Figure 5: Documents posted on (a) & accessed from (b) HAL

For what concerns Edition, the service ensures the design (using advanced computer-assisted publication applications) and local printing of most of the documents produced yearly by the Lab., in B&W (1,800,000) and in color (46,000). In addition, about 200 posters and 2,000 leaflets are produced per year.

4.2.9 Logistics & Infrastructures

The service is composed of four persons. It is in charge of building caretaking and maintenance as well as and guarding, housekeeping and maintenance.

LAAS facilities are made of 8 buildings representing 21,000 m^2 of offices and experimentation space, spread on almost 8 acres (4 ha) including green surfaces and parking areas. To these main premises should be added the accommodations (460 m^2 — offices and experimention space) for OSE team at **INPT-ENSEEIHT**, and the experimentation space (about 50 m^2) located at **INSAT**.

During the period, the service accompanied two major actions: one building was completely refurbished (now hosting the ALIVE biochemical experimentation platform) and one new instrumented building (1,700 m^2) featuring photovoltaic electricity production, optimized energy management and advanced sensing capabilities, was constructed.

4.2.10 Supply

The service is composed of two persons. It ensures the management of orders, receipts and inventory. It runs a "store" that is open to Lab. members and handles about 1,000 referenced items (stationery, computer peripherals, etc.). The service also handles fast-delivery mails and manages the maintenance of the pool of printers (about 100).

4.3 The Governance

The steering and animation of the Lab. relies on several bodies that meet regularly (Figure 6). The statutes of the laboratory have been revised in January 2012 to accommodate the evolution in the organization proposed in 2011 (areas, groups -> themes, teams).

The **Laboratory Council** (CL) composed of 25 members (12 elected) is the core entity. The CL holds at least a meeting every month.

Two other Councils meet alternatively every month — the **Restricted Direction Council** (CDR) and the **Direction Council** (CD):

- The CDR gathers the Direction, the responsible for Management and Decision Support, the Advisers for the two Strategic Axes and the principal Adviser for Training-Research, the leaders of the scientific themes and of the technical services.
- The CD gathers in addition the leaders of the research teams and of the other services.

The **Scientific Council (CS)** of the Lab. is formed by the CDR and the team leaders.

[6] Previously, under the ERR (*Etablissement à Régime Restrictif*) rule, French and European citizens were not screened.
[7] *Société d'Accélération du Transfert de Technologies*, an instrument of the *Programme des Investissements d'Avenir* (PIA).

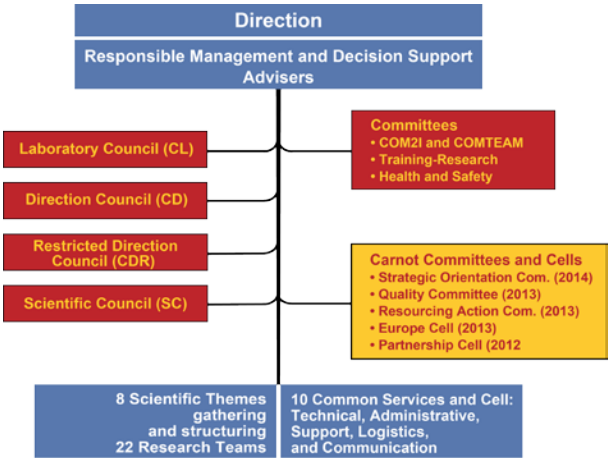


Figure 6: The Governance Bodies

Requests for technical support from the teams are examined by two *ad hoc* commissions (**Com2I** [8] and **ComTEAM**). They meet at least annually to allocate the IDEA, I2C and TEAM personnel according to the technical support demands proposed by the research teams.

The **Training-Research Committee** (CER) is an important link between the Lab. and the academic institutions connected to LAAS. This extends also to connections with the Doctoral Schools. In particular, the CER has developed procedures to handle the various steps of the recruiting of faculty members.

The **Health and Safety Committee** meets twice a year to discuss the relevant issues and related interventions**.** *The Document Unique d'Évaluation des Risques* (DUER), incorporating the issues raised and the actions taken or on-going, is regularly discussed and updated.

As noted, the entities shown on right part of Figure 6 (yellow background) are mostly dedicated to activities connected to the Carnot label. In addition, **general assemblies** are held, normally twice a year and whenever needed (e.g., for the renewal of the Direction).

Upon request from the Direction, some *ad hoc* committees work on specific aspects: Website revision, ADREAM and ALIVE platform installations, office dispatch, electronic newsletter, LAAS webzine, special events (e.g., new building foundation stone, inauguration, dedication), Georges Giralt conference series, etc.

These entities are complemented by the councils of the themes, teams and services that also meet regularly.

Such an organization allows, we believe, for an appropriate elaboration and discussion of the decisions, and a suitable internal information about the activities and the scientific strategy of the Lab.

4.4 The Budget

For years, how to balance "incomes" and recurrent costs has been an issue for LAAS-CNRS and for many other research Labs, probably. Accordingly, the Lab. has developed a strategy for withholding project resources to complement the recurrent endowments.

Such a levying has been an essential dimension for vitalizing the Lab. (*per capita* endowment to

[8] The Com2I (inherited from the service 2I), handles the requests to IDEA and I2C, thus ensuring a consistent allocation of their personnel.

Compositions of the Councils of the Lab.

Laboratory Council: J. Arlat, A.-M. Gué. ***Elected members***: L. Blain, S. Charlot, A. Delagarde, J. Guiochet, P. Joseph, J. Launay, J. Manhes, R. Marchand, C. Mouclier, P. Owezarski, P. Ribot, L. Salvagnac; ***Nominated members***: G. Almuneau, D. Barthe, L. Bary, S. Charlot, M. Devy, G. Garcia, H. Granier, L. Perez, N. Romero-Alias, H. Tap, P. Thévenod

Direction Council (Restricted): J. Arlat, A.-M. Gué; P. Thévenod, F. Vernadat, M. Diaz, C. Vieu; ***Theme leaders***: K. Kanoun, K. Drira*, R. Alami*, D. Arzelier*, F. Lozes, C. Rossi, L. Nicu, M. Bafleur; ***Team leaders***: M. Kaâniche, H. Demmou, B. Berthomieu, D. El Baz, P. Danès, P. Souères, C. Artigues, L. Travé-Massuyès, T. Bosch, O. Gauthier-Lafaye, O. Llopis, P. Pons, J.-Y Fourniols, C. Thibault, P. Ménini, F. Cristiano, K. Grenier, J.-M. Dilhac, F. Morancho; ***Service leaders***: D. Barthe, L. Bary, H. Granier; R. Durand, N. Romero-Alias, C. Barat, A. Bergez, E. Tasselli, E. Le Denmat.

NB. Members of the Restricted Council appear as underlined.

* Indicates Theme leaders that are also Team leaders.

researchers, support of strategic scientific orientations and coping with raising infrastructure expenses).

4.4.1 Coping with the Evolving Context

The trend in the financing modalities of the research has significantly modified the respective balance between the recurrent endowments to the Lab. (globally, a significant decrease compared to the previous period and at best stagnation the most recent year) and the Lab own resources based on more numerous projects — for most of them smaller, and with no increase in total amounts.

One of the first consequences of this evolution concerns the "crumbling" of the funding which results in a real difficulty for mutualizing these resources either for developing a scientific orientation within the Lab. or for coping with infrastructure costs due to the limited amounts obtained via the recurrent subventions. In practice the amounts that can be levied and the purposes they can be used for is diminishing and shrinking due to the strict encapsulation of resources in specific eOTPs attached to each project, that need to be justified individually.

In addition, during the period (2012), the CNRS Regional Office (*Délégation Régionale* - DR) had to adjust its policy about levying on contracts: several (direct and EU) contracts that previously were not levied are now supporting a 10% charge.

The Lab. had to dynamically adapt its strategy to these new circumstances: it was no longer possible to support individual endowment to researchers, instead, theme and technical services were each given a global endowment. Also, the levying rates initially planned in 2011-12 had to be revised to accommodate this new situation. It is difficult to develop and anticipate a robust/reliable budget in such an ever-moving context. The subsidies obtained from the Carnot label were mainly used for resourcing (supporting research projects) and professionalization actions.

4.4.2 The Incomes

The global budget (incl. Endowments from CNRS and UT partners[9], Staff salaries, Grants & Fellowships for PhDs and Own Resources) amounts to **35.4 M€** in 2013. Table 8 shows the variation and gives the average amounts over the period (2014 excluded).

[9] Actually, endowments are received from UT3PS, INSAT and INPT.

Table 8: Global Budget over the Period

	2009		2010		2011		2012		2013		Average	
	M€	%	M€	%	M€	%	M€	%	M€	%	M€	%
Endowment CNRS	2.15	6.5	2.33	6.3	2.2	6.5	1.93	5.4	2.1	5.9	2.14	6.1
Endowment UT	0.16	0.5	0.21	0.6	0.26	0.8	0.26	0.7	0.25	0.7	0.23	0.7
Salaries CNRS	11.90	35.7	12.1	32.5	12.34	36.3	13.22	37.2	13.22	37.4	12.56	35.8
Salaries UT	6.24	18.7	6.05	16.3	7.13	20.9	5.75	16.2	5.95	16.8	6.22	17.7
Salaries (Grants)	2.19	6.6	1.78	4.8	1.9	5.5	3.09	8.7	3.34	9.5	2.46	7.0
Own Resources	10.68	32.0	14.67	39.5	10.2	30.0	11.29	31.8	10.50	29.7	11.47	32.7
TOTAL	33.32	100	37.14	100	34.03	100	35.54	100	35.36	100	35.08	100

Indeed, the whole set of figures is not yet consolidated for 2014. However, the Endowments received from CNRS and UT are available. In particular, for CNRS it amounts to 2,104 k€ which is in the range of the average amount received during the five past years. The table also shows that LAAS-CNRS own resources amount to about 1/3 of the global budget.

Table 9 focuses on the part of the budget excluding the Salaries share. It also details the "Own Resources" part: Carnot, Europe, ANR, RTB, PIA (two EquipEx, one LabEx and several projects — see § 5.6.2 – The PIA), Region, other public funding (CNES, DGA, MINEFE, etc.) and direct contracts with industry (including CIFRE conventions). The average yearly operational budget amounts to 13 M€ (except for 2010 that reflects a somewhat singular context).

Table 9: Operational Budget over the Period

Years / Resources	2009		2010		2011		2012		2013		Average	
	M€	%	M€	%	M€	%	M€	%	M€	%	M€	%
TOTAL	12.99	100	17.21	100	12.66	100	13.49	100	12.85	100	14.60	100
CNRS (Total) [1]	2.54	19.6	2.65	15.4	2.28	18.0	2.07	15.3	2.26	17.6	2.36	16.2
UT	0.16	1.2	0.21	1.2	0.26	2.1	0.26	1.9	0.25	2.0	0.23	1.6
Other Fundings	10.29	79.2	14.35	83.4	10.12	79.9	11.16	82.8	11.04	80.4	12.01	82.2
Carnot	0.18	1.4	0.21	1.2	0.24	1.9	0.46	3.4	0.37	2.9	0.29	2
Europe	1.12	8.6	2.75	16.0	0.80	6.3	0.87	6.4	0.98	7.7	1.30	8.9
ANR	1.16	8.9	4.09	23.8	2.63	20.8	2.80	20.8	2.40	18.6	2.62	17.9
RTB	2.44	18.8	1.36	7.9	1.25	9.9	1.02	7.6	0.40	3.1	1.30	8.9
PIA [2]	—	—	—	—	—	—	0.70	5.2	1.82	14.1	1.26	8.6
Region	1.39	10.7	0.65	3.8	0.74	5.8	0.83	6.1	0.54	4.2	0.83	5.7
Other (Public)	2.49	19.2	2.89	16.8	2.81	22.2	3.10	23.0	2.22	17.3	2.70	18.5
Industry	1.51	11.6	2.40	13.9	1.65	13.0	1.38	10.3	1.61	12.5	1.71	11.7

[1] The amounts shown here include the additional funding provided over the year period by CNRS, e.g., for cooperative actions, etc. It is also worth pointing out a new procedure set in 2013 for handling requests for hiring temporary personnel (*Contrat de courte durée* - CCD): for the requests granted by the institutes, the corresponding salaries are directly supported by the institutes and not by the Lab. via the CNRS endowment received as was the case before; we have estimated this support (not handled by the Lab. and thus not included here) to ≈ 50 k€ for both 2013 and 2014.

[2] Related funding only available since 2012, thus, the average applies on the last two years.

Indeed, after a very successful year 2010, in many respects (including CNRS support, Europe funding and direct industry collaborations), a dramatic drop occurred in 2011 especially, but also in 2012. This is to be related to the significant investments deployed towards the series of calls concerning PIA instruments launched in 2010 and 2011. Such an implication was actually rewarded in 2012 and 2013, but had a negative impact then on other investment targets during that period, especially Europe and direct industry contracts.

Concerning Europe, the period saw the transition between FP7 and Horizon 2020 programs. It is noteworthy that six projects were signed in 2013 for a total funding of 2.6 M€ for the Lab., to which it is important to add an ERC Advanced Grant.

The Carnot contribution is actually impacted (with a two-year delay) by the partnership with Industry, but only direct contracts are eligible. Moreover, since the second Carnot phase, launched in 2011, a flat basis was implemented which improved the Carnot contribution in 2012. The low figures for industrial contracts [10] observed that year impacted the Carnot contribution for 2014 (reduction to 311 k€). Hopefully, the progress made in 2013 will result in an improved Carnot contribution (361 k€) for 2015.

The table also shows the significant share taken by national collaborative research projects into the budget. This is mainly obtained via ANR funding, but also encompasses FUI projects labeled by the competiveness clusters.

One dramatic evolution during the period was the reduction attached to the RENATECH platform: in 2013 the amount received was reduced by 80% from the support obtained in 2009. This trend is really worrying: should such low figures be maintained, then, there is a real risk of obsolescence for the platform, which would jeopardize the significant investments already made. Hopefully, the PIA funding for EquipEx LEAF (mainly deployed in 2013 for 847 k€) actually contributed to the equipment of the RENATECH platform.

Another big share of the PIA funding obtained during the period relates to EquipEx ROBOTEX for a total of 725 k€ (mostly obtained in 2012). In 2013, besides LEAF, most of the funding received is distributed among 6 projects, including LabEX GANEX (see § 5.6.2 – The PIA).

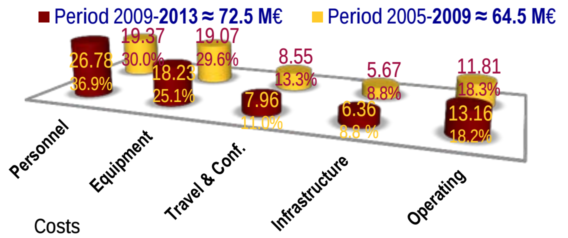
4.4.3 The Expenses

The expenses spent in 2013 raised to about 13 M€. Table 10 details the distribution according to various cost categories: Personnel (salaries paid on contracts), Equipment, Travel and conferences/events organized, Infrastructure (Electricity, etc.) and Operating costs.

Table 10: Expenses over the Period

Years / Costs	2009		2010		2011		2012		2013		Average	
	M€	%	M€	%	M€	%	M€	%	M€	%	M€	%
Personnel	6.09	37.7	6.05	36.7	5.12	37.4	4.85	36.9	4.68	35.9	5.36	36.9
Equipment	3.80	23.5	3.94	23.9	3.18	23.3	3.38	25.7	3.93	30.1	3.65	25.1
Travel/Conferences	1.91	11.8	1.91	11.6	1.33	9.7	1.16	8.8	1.65	12.7	1.59	11.0
Infrastructure	1.22	7.6	1.48	8.9	1.24	9.1	1.24	9.4	1.18	9.1	1.27	8.8
Operating Costs	3.12	19.4	3.12	18.9	2.80	20.5	2.53	19.2	1.60	12.2	2.63	18.2
TOTAL	16.14	100	16.50	100	13.67	100	13.14	100	13.03	100	14.50	100

Globally, the variations in yearly expenses rather matched the corresponding incomes. As already observed for the previous period, due to the consequence of the project-oriented funding, salaries paid to PhDs, Post-docs or engineers hired to work on these projects contributed to a significant share of the expenses. As shown on Figure 7, for the period, this share concerns almost 40% of the costs, i.e., much higher than the 30% observed for the previous one.



Note: Amounts are in M€. As figures for 2014 are not consolidated, we consider rather two overlapping periods.

Figure 7: Distribution of the Expenses for the Two Periods

[10] This concerned essentially large enterprises; the amount for contracts with SMEs was maintained well above the value of 2010.

Alternatively, the Equipment share was reduced which is a real concern for the capacity of the laboratory to invest for the future.

5 Realizations of the Laboratory

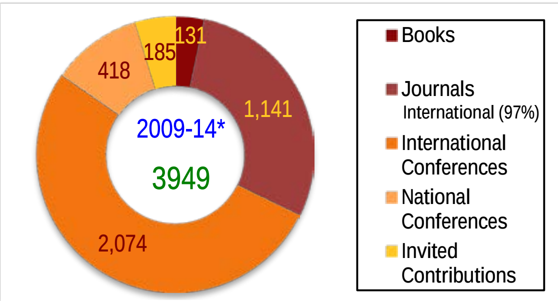
5.1 Scientific Production

The production of scientific publications that are meant to publicize widely our research results is an essential dimension of LAAS-CNRS activities.

Peer reviewed Journals, Books and Conferences with Program Committees are the usual vehicles for disseminating these results to the scientific community. In the domain of TICs, in addition a large number of papers are published via selective Conferences and Workshops. For some of them the acceptance rate can be lower than 20%.

The publications are produced simultaneously on paper version and on numerical form. They are listed in the publication repository held in the Lab. (accessible via the website) and whenever possible, are made available upon request. It is worth pointing out that many of them can be accessed on-line via the HAL multidisciplinary open archive[11].

Figure 8 shows the main scientific production over the period ranging from 2009 to 2014. The encouragements for favoring Journal publication proved to be successful: among the nearly 4,000 publications counted, about 30% are in this category; about 200 articles were published yearly during the period. Also worth pointing out: **in** this category, almost all papers were published in International Journals.



Books: Authored, Edited or Chapter (A, E, & C) contributions;
Invited Contributions: Journals and conferences included.

Figure 8: Distribution of Scientific Publications during the Period (* first semester only for 2014)

Table 11 focuses on International publications. During the five first (full) years, in average ≈ 635 international publications were produced yearly. In total, almost 3,500 such contributions were made during the whole period.

Table 11: International Publication during the Period

International Publications	2009	2010	2011	2012	2013	2014[1]	Total
Books (A, E & C)	25	22	17	20	17	8	109
Journals	186	187	207	209	217	102	1,108
Conferences with	395	386	360	339	323	155	1958
Other Conferences[2]	18	19	20	33	13	13	116
Invited Contributions	8	39	32	36	49	21	185
Total	632	653	640	640	619	299	3,476

[1] Incomplete year (first semester only); [2] This category (events with no widely available Proceedings) was not accounted for in the previous figures shown.

[11] http://hal.archives-ouvertes.fr/LAAS

On the basis of the figures provided for the previous evaluation, Table 12 compares the scientific production over two consecutive 4 ½-year periods.

The figures show an overall increase of 12% in the documents produced and point out the significant increase (40%) in Journal publication and also the important increase (65%) in the number of HDRs defended during the recent period.

Table 12: Comparison of Publications for two Periods

Publications	2005-2009[1]	2010-2014[1]	Delta (%)
Books	100	102	2%
Journals	617	944	53%
Conf. Int.	1549	1563	1%
Conf. Nat.	351	181	-48%
Invited Contributions	57[2]	177	—
PhDs	222	273	23%
HDRs	17	28	65%
Total	2,913	3,268	12%

[1] First semester only for 2009 and 2014; [2] This category was not thoroughly compiled during that period.

We now refer the number of publications to the number of permanent members. Here we focus essentially on selective publications (Books, Journals, International Conferences and Invited contributions) from Table 12.

Table 13: Comparison per C & E/C

a) Definition of Two Scenarios for ETP Assessment

Period	C = 1 & E/C = 1	C = 1 & E/C = 1/2
2005-2009	ETP = 187	ETP = 136
2010-2014	ETP = 206	ETP = 147
Delta (%)	*10%*	*8%*

b) Yearly Number of Publications per C & E/C

Period	Publications (Selective Set)	Scenario C = 1 & E/C = 1	Scenario C = 1 & E/C = 1/2
2005-2009[1]	2,323	2.76	3.81
2010-2014[1]	2,844	3.06	4.30
Delta (%)	*23%*	*11%*	*13%*

[1] First semester only for 2009 and 2014.

We consider the average values for the numbers of researchers (C) and UT faculties (E/C) over the two periods. We consider two scenarios for computing the average personnel figures (ETP), based on the widely assumed fact that a faculty member can only devote 50% of its time to research activities (Table 13-a). On this basis, the average yearly number of selective publications per C & E/C is given by Table 13-b.

5.2 The Experimentation Platforms

A large fraction of LAAS-CNRS research activities relies on the development of demonstrators or prototypes that require important experimental and technological facilities. During the period the related infrastructure and equipment were significantly improved and enhanced.

Seven main platforms can be identified:

- Micro & Nanotechnology,
- Characterization,
- Design & Simulation,
- Robotics,
- Networking,
- ADREAM,
- ALIVE.

5.2.1 The Micro & Nanotechnology Platform

The platform supports the research activities developed in micro and nanosystems. Established in 2007, thanks to the support received in the framework of the 2000-2006 CPER and from the Basic Technological Research (RTB) Program, the platform is one of the 6 platforms of the French National network on Nano manufacturing (RENATECH). A 7th platform, located at CEA LETI, is also associated as part of the RTB program.

The platform benefits of 1500 m^2 of cleanroom facilities[12] consisting of:

- 180 m^2 labeled class 100: in particular, photolithography room, electron beam lithography, under wet benches zone;
- 900 m^2 labeled class 10000: (characterization, laser lithography, electroplating, chemistry, thin film deposit, plasma etching, MBE, ion-implantation equipment, furnaces, assembly);
- 420 m^2 labeled class 100 000 (facilities and back-end machines).

Some major recent equipment acquisitions

- 2010 - MBE (Molecular Beam Epitaxy) III-V: Realization of photonics components [≈ 1,530 k€]
- 2011 - FIB (Focus Ion Beam): Realization of nanostructures [≈ 990 k€]
- 2012 - ALD (Atomic Layer Deposition): Deposit of atomic scale metal or dielectric layers [≈ 300 k€]
- 2013 - SPD (Surface Preparation Deposition): Functionalization of surfaces (grafted self-assembled layers) in vapour phase [≈ 430 k€]
- 2013 - Laser Writing: Integration of 3D structures via photo-induced processes [≈ 720 k€]

In addition to the 36 engineers and technicians of the TEAM service that are in charge of the management and development of the infrastructure, equipment and processes on the platform, the people (researchers, PhDs and postdocs) involved in the related research activities span the 11 teams of the 4 Micro and Nano Systems themes.

Being part of RENATECH, our cleanroom facilities are open to academic laboratories, as well as to industrial enterprises and especially SMEs. Figure 9 shows the evolution of the number of external projects supported and personnel hosted in that context. Of course, these projects come in addition to the (usually much heavier and complex) internal or cooperative projects developed by LAAS researchers; during the period, about 300 distinct projects were supported by the platform.

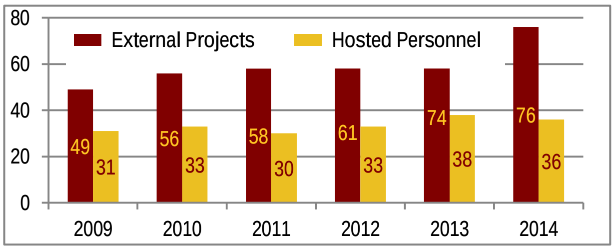


Figure 9: Evolution of the Number of Supported Projects

An action has been initiated in 2013 to integrate tools for the management of the cleanroom: one of the tools being integrated is developed at Chalmers University (SE).

The number of supported projects has significantly increased over the past decade. The availability of the extended platform in 2007 has boosted the number of these projects (both internal and external). Concerning the latter, during the evaluation period, this number has raised from 50 in 2009 up to 74 in 2013. In average, about 20% of these external projects are with industry.

LAAS, and especially the cleanroom facility and related process, has been instrumental from the beginning with the support of the DR in the initiative launched by CNRS concerning the usage of analytical accounting for facilitating the management of cooperative projects using platform resources (see also § 7.5.2). The procedure should be in place and started later this year and deployed more widely later on.

Figure 10 illustrates one of the major equipment facilities available.

Figure 10: The Cleanroom – Photolithography Zone

5.2.2 The Characterization Platform

The platform combines and organizes all the micro and nanosystems characterization facilities available at LAAS-CNRS in the following domains: electrical, microwave and optical analyses. It is managed by 9 engineers and technicians (including 2 BIATSS, involved part-time) of the I2C service and spans an area of more than 700 m^2, distributed into several zones.

The **electrical zone** covers an area of 160 m^2. Specific benches and probe stations are used for the electrical characterization of semiconductor devices, micro and nanosystems. Typical measurements and equipment include: I-V & C-V plots, parametric tests, Hall effect measurement, DLTS (Deep-level transient spectroscopy), impedance-meter, curve tracers, etc. It also includes facilities for ESD tests and measurements.

In the 250 m^2-**microwave** zone, test benches and probe stations for characterizing the "S" parameters and also for measuring the phase noise and the low and high frequency noise. Several setups have been developed for RF MEMS reliability using in particular one cryogenic probe station. One anechoic chamber certified in the range 1-40 GHz is available for the study of antennas. During the period the zone was extended by the facilities (including a 3x2 m Faraday cage) for testing (DPI: Direct Power Injection, BCI: Bulk Current Injection) the electromagnetic compatibility of integrated circuits, available at the DGEI Dpt. at INSAT.

In the **optics/photonics** zone (230 m^2), the equipment available ranges from materials optical characterization — including Fourier Transform

[12] A virtual visit is available from: http://www.cnrs.fr/cnrs-images/multimedia/laas/360/00_lagasse.html

InfraRed (FTIR) spectroscopy, to the characterization of passive (e.g., resonant-grating filters) and active (VCSELS, photonic crystal lasers, detectors) components: I-V and light vs. current of VCSEL and edge emitting laser sources, divergence diagrams, spectral analysis, in visible & Near-IR ranges.

Two major evolutions connected to the ADREAM axis are worth mentioning:

- The "Photovoltaic Electricity Management" area was significantly expanded by the opening in 2012 of the "Georges GIRALT" building, with more than 70 m² of setup (linked to the research-oriented panels deployed on the terrace and roof of the building) — see also (§ 5.2.6).
- The Antenna Measurement room was extended to 120 m² (50 m² in 2010), to include equipment for the measurement of wireless sensors and networking, that are part of the challenges addressed in the frame of ambient intelligence studies.

Some major recent equipment acquisitions

- 2010 - Cryoprober chamber: measurement of microvawe devices from DC to 67 GHz [≈ 450 k€]
- 2010 - 4-Port Vector Network Analyzer (67 GHz amx) [≈ 70 k€]
- 2011 - Atomic Force Microscopes, Molecular-scale imagery, for a) electrical and b) biological (in particular in liquids) analyses – the latter equipment is set in the ALIVE platform [≈ 280 k€]
- 2012 - DC measurement for power devices for wide bandgap devices e.g., GaN components) [≈ 70 k€].
- 2013 - IR camera [≈ 70 k€]

As is common practice for the micro and nanotechnology platform, since 2012, the Characterization platform accepts external requests and a procedure for handling such demands was established. In particular, support was provided to both local research labs. (e.g., IRAP, CEMES, Laplace) and industrial enterprises (e.g., Essilor, Continental, Exem, a LAAS start-up).

Figure 11 shows some of the equipment available on the characterization platform.

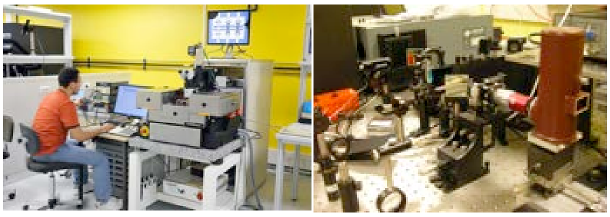


Figure 11: Equipment of the Characterization Platform

5.2.3 The Design & Simulation Platform

The platform is meant to simulate the behavior of systems in the fields of mechanical, chemical, electromagnetic, thermal at various scales: nanometer, micrometer and millimeter. In particular, this is an essential activity prior to chips/systems manufacturing in the cleanroom facility.

The platform currently consists of:

- 17 high-performance workstations: Intel quad-core 64 bits processors, with extended RAM from 8 to 32 GB,
- 1 high performance computing cluster (26 Xeon intel quad-core 64-bit processors),
- 11 major software packages (HFSS, ADS, COMSOL, OrCAD, etc.).

The main extension over the period concerns: in 2010, the acquisition of new software licenses for high frequency simulation (AWR) and in 2012, a significant massive memory upgrade.

Two engineers from the IDEA and I2C services manage this platform; this includes: user training, help with development, archival work, administration of hardware and software systems, etc.

5.2.4 The Robotics Platform

The platform supports the research activities on robotics of the laboratory since 1995.

The platform now covers an area of 250 m^2 on two specifically equipped experimentation rooms: motion capture systems, ambient cameras, 3D sensors, safety systems (gantry, net), etc. It has significantly been enhanced both from the extension made available by the opening of the "Georges GIRALT" building (a new area of 180 m^2) and likewise in equipment, via the 2007-2013 CPER and the ROBOTEX EquipEx. It constitutes one important support for the ADREAM research program. In particular, a studio apartment zone has been deployed for interactive experimentations involving humans and robots. Also, a net-protected area is devoted to multi-drone experimentations.

The platform hosts a fleet of a dozen of robots (Figure 12): 3 humanoid robots (HRP-2, Nao and soon, Romeo), 4 indoor wheeled multi-sensor interactive robots (Rackham, Jido et 2 PR2), 3 outdoor rugged terrain autonomous exploration vehicles and several UAVS (quadcopter drones).

Five staff members of the technical services — IDEA (2 software-oriented) and I2C (3 hardware-oriented & one mechanics-oriented) — are involved in this platform. The objectives are to maintain and prepare the evolutions of hardware and software architectures of the robots fleet as well as providing training and assistance when robots are deployed.

The platform provided support to about 15 research projects involving about 10 robots of the fleet, both

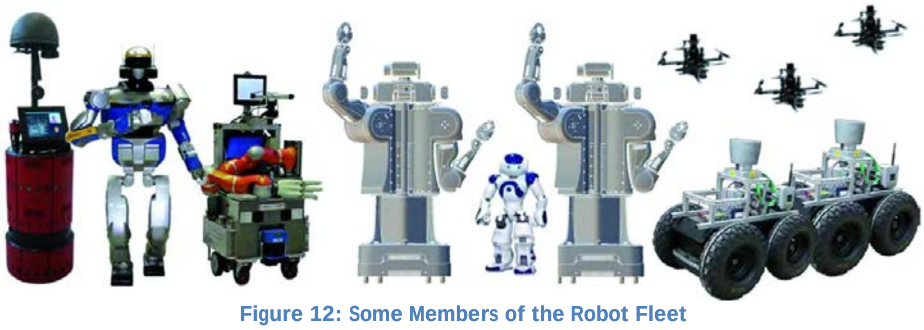


Figure 12: Some Members of the Robot Fleet

indoor and outdoor, as well as the associated software components. Two notable examples of such projects include: the 2007-2014 DGA funded *Programme d'étude amont* "Action" with ONERA (cooperation of heterogeneous aerial, ground and underwater autonomous vehicles for task monitoring) and the 2011-2014 FP7 SAPHARI project on safe and autonomous physical human-aware robot interaction.

Some major recent equipment acquisitions

- 2009 - Humanoid robot, Nao [≈ 10 k€]
- 2010/13 - 2 Willow Garage PR2 robots: Human/robots interaction [≈ 560 k€]
- 2011 - Mobile robot equipped with 2 Kuka manipulation arms [≈ 400 k€]
- 2011/13 - 6 Quadcopters: 1 Astec Pelican, 5 microkopters & safety net [≈ 60 k€]
- 2012/13 - 2 Segway-based rovers with multisensor devices (stereo cameras, laser telemetry, differential GPS [≈ 400 k€]
- 2014 - Humanoid robot, Romeo [≈ 230 k€]

5.2.5 The Networking Platform

"Laasnetexp" is a multi-technologies, multi-services experimentation Internet platform in place for several years for supporting research in metrology of computer networks. It has the form of a network domain, independent from the Lab. operational network, and directly connected to RENATER and GEANT, the National and European telecommunication networks for research, respectively.

It is mainly used for experimenting and validating protocols, architectures and network mechanisms aiming at enforcing quality of service in heterogeneous large-scale networks, security, and communication in dynamic networks. Concerning security, the research concerns the analysis of malevolent activity on the Internet via the deployment of "honeypots" both on the open DMZ zone of the operational network and on the experimental network Laasnetexp.

Figure 13 shows the architecture and interconnections of Laasnetexp and illustrates the deployment of honeypots.

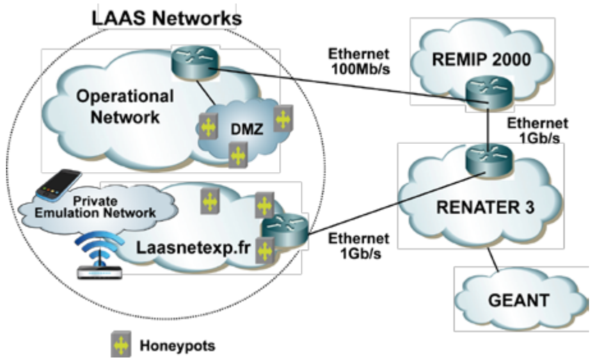


Figure 13: Deployment of Honeypots on Laasnetexp

The launch and development of the ADREAM research program on ambient intelligence and cyber-physical systems has opened new orientations to the Network platform towards the provision of services for supporting the deployment of machine-to-machine (M2M) communications and Internet of Things (IoT) applications. New support facilities are devoted to wireless communication systems, smart antennas and cooperating sensors, management of portable mobile systems, and M2M protocols compliant to the open source standards of the European Telecommunications Standards Institute (ETSI). Thanks also to the availability of the ADREAM cross-platform, the emulation environment has been complemented by an actual environment for experimentation on mobile embedded systems, smart objects and sensor networks.

5.2.6 The ADREAM Platform

The experimentation platform that supports the ADREAM research program (see Chapter X) is mainly the instrumented building that was inhabited in February 2012. Various topics are addressed, such as embedded systems, network sensor networks, Internet of things, M2M communication, software services, companion robots, security and privacy, and electrical energy production and optimization.

Figure 14 illustrates some of the experimentation facilities located inside this new building.

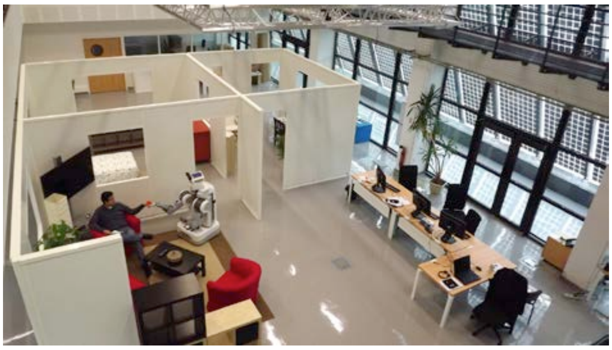


Figure 14: A Global View of the Experimentation Platform of the Georges Giralt Building

The building also hosts the characterization zone grouping the equipment for qualifying electrical energy conversion systems and especially photovoltaic systems. This dedicated zone features 8 test benches, allowing the connection of photovoltaic modules deployed on the roof of the building (see Figure 1). The benches can be connected to local electrochemical storage devices that will shortly complement the equipment. This will allow for coping with the transient production of the photovoltaic cells and optimize energy consumption.

Many sensor devices are spread in the building; almost 7000 data are recorded in a time frame of 1 to 5 mns:

- 650 measurements for the heating and air conditioning system,
- 3700 measurements for the advanced lighting system,
- 6 centralized Enerdis stations collecting 500 data about the production and consumption of energy,
- multiple temperature measurements and meteorological data.

The complementary competences of several themes are gathered in a research action aimed at exploiting these data and optimizing the energy management at the level of the building.

5.2.7 The ALIVE Platform

Due to the emergence and development of the ALIVE axis — see Chapter X, the equipment and experimentation facilities devoted to chemical and biological analyses have been significantly enhanced to support the increased number of related research activities (in particular, bio-detection, cellular and molecular engineering). These facilities are now considered on their own (apart from the Characterization platform) and constitute a platform *per se*: the ALIVE platform.

This extension was made possible by the refurbishing of the area devoted to the original cleanroom facilities.

This platform now covers an area of 400 m^2 distributed over 2 rooms. In particular, it incorporates a L2 cellular biology lab. The activities supported include:

- molecular and cellular biology **(**e.g., nano-channels, nano-pores, AFM metrology),
- microbiology and enzymology,
- cellular culture (e.g., culture on micro/nano-structured substrates),
- micro- & nano-fluidics (blood and corporal fluid engineering),
- dedicated experimentations (e.g., DNA technologies for nano manufacturing).

Figure 15: The ALIVE Platform for Biological & Chemical Analyses

5.3 Academic Reputation and Involvement

5.3.1 Journal Editorial Boards and Conference & Workshop Committees

Table 14 summarizes the key roles played during the period by Lab. members in international Journals, Conference and Workshops.

Table 14: Key Roles in Journals, Conferences & Workshops

International	Journal		Conference & Workshop Committees					
Categories	Editorial Board		Steering		Tech. Prog.		Organizing	
Role	GE	AE	C	M	C	M	C	M
Participations	17	64	3	28	82	562	117	40

GE: Guest Editor; AE: Associate Editor; C: Chair; M: Member

During the period, Lab. members have contributed to the editorial boards for about 80 international journals, spanning the full spectrum of the disciplines covered by our research activities. Another notable figure is the lead contribution to the organization of more than one hundred scientific events.

5.3.2 Involvement in the Community

From 2009 until now, several researchers and faculty members from the Lab. have been engaged in high-level functions in the interest of the community, of the CNRS and of our academic and industrial partners.

Hereafter, are listed some that are external to LAAS-CNRS and not directly linked to the education departments to which we are connected (see § 6.2). We also identify the main contributions by ITAs and BIATSS personnel.

Main Contributions to CNRS Instances

- 3 members of the Scientific Councils for the ST2I Dpt and for INS2I & INSIS.
- 7 members of the CoCNRS (in Sections 06, 07, 08), and 2 who are respectively currently leading Section 08 and CID 54.
- 3 Advisors for INSIS (2), and INS2I (1).
- 2 coordinations of INSIS WGs: Materials & Components for Nanoelectronics (2011) and Micro & Nanotechnologies for Energy (2012-13).

Main Contributions to other National Instances

- Pilot for the Workshop "Society of Information and Communication" for the elaboration of the SNR (National Strategy for Research) — 2013-14.
- One member of the Permanent Commission of the National Council of Universities (CNU), President of Section 28 (Dense Media and Materials) and Several members in other CNU sections (27, 60, 61, 63) — currently 4.
- Participation to WGs into 3 National Inter-organism Alliances for research coordination: ALLISTENE, ANCRE, AVIESAN.
- Member of the Scientific Council of RENATECH.
- Member of the Technology Academy.
- Responsibilities into 7 French Research organizations set-up by CNRS (GDRs): Robotics (3 WGs: Interactions persons/robotics systems; Humanoid robotics, Robotics & neurosciences); MOA (Mathematics of Optimization Applications); MACS (Modeling, Analysis et Control of dynamic Systems); ASR (Architecture, Systems et Networks) until 2013; M&MNS (Microfluidics & Micro-Nano Systems); *Ondes* (Waves); GPL (Programming and Software Engineering).

Main Contributions to UT Instances & Regional Committees

- **UT3PS**: one member in the Board, the Scientific Council, the CSR (*Commission Stratégie Recherche*), CEVU (*Conseil des études et de la vie étudiante*), 5 members elected in the Council of the MST2I [13] Cluster; Vice Director of the Faculty of Sciences and Engineering (FSI); VP for European Affairs; the Chairman of the Scientific Council of the Education & Research unit for Physics, Chemistry & Applied Sciences.
- **INSAT**: VP and 5 members of the Board; VP and 2 members of the Scientific Council; Directors for International Relations, and for Industrial Partnership.
- **UT**: CNRS representative in the Steering Committee of the Thematic Strategic Action (*Aéronautique, Espace, Systèmes embarqués*) of IdEx UNITI.
- Steering Committee of the RTRA STAE (*Sciences et Technologies pour l'Aéronautique et l'Espace*)[14].
- Scientific Council of CESEC[15] (*Chaire d'Enseignement pour les Systèmes Embarqués Critiques*).

[13] *Mathématiques, Sciences et Technologies de l'Information et de l'Ingénierie*; LAAS-CNRS is part of this cluster that gathers 6 research units, 3 associated teams and 5 federations.

[14] www.fondation-stae.net

[15] This Chair launched in January 2013 is funded by the Airbus Group and is operated jointly by INSAT, INPT-ENSEEIHT & ISAE.

Involvement of ITA and BIATSS Personnel

National WGs

- Member of the Steering Committee of CNRS RENATIS[16] (National Network on Scientific and technical Information) until 2010.
- Participation to the network Doccitanist (IST professionals in Occitania).
- Leading contribution to the CNRS WG "Determination of full cost and tariff applicable to the RENATECH platforms".
- Steering Committee and Topic Manager of the CNRS project PLUME[17] (Promoting economicaL Useful and Maintained softwarE For the higher Education And THE Research communities).
- WG on the definition of the AGATE application set up by CNRS for managing days-off deposit and validation.
- Participation to the refinement of the CNRS application (ASSAV) for managing access demands for ZRR classified laboratories.

Regional WGs

- Coordination group on PSSI (Security Policy of Information Systems).
- Several members contribute to the Steering Committee of CAPITOUL (Community of Administrators for Informatics in Toulouse), local branch of the CNRS Federation of Network and System Administrators (ASR) in Education & Research.
- Steering Committee of COMPIL (Collective action in Midi-Pyrénées of Informatics developers)

5.4 International Relations

When considering research activities in public domain, international positioning and connection at various levels (joint publications, exchanges, research projects, etc.) are very much part of the natural behavior for an academic Lab.

Clearly, openness and reach out have been very long standing attitudes for LAAS-CNRS members.

Already very much active, in the context of EU funded projects (see § 5.7), LAAS is pursuing its efforts to develop further international partnerships. Beyond the long-standing connections already established (e.g., Latin America, Maghreb or Japan), recently targeted countries include: Taiwan, USA, India, and China.

This strategy involves several facets: hosting foreign students (China), as well as the establishment of international partnerships. Good examples of the latter include SMARTMEMS (Smart Micro- & Nano- Systems) LEA (Associated European Lab.) with IMT in Bucharest (RO), iCeiRA (International Center of Excellence in Intelligent Robotics & Automation) with NTU (TW), jointly with UPMC & Inria, IFCAM (Indo French Center For Applied Mathematics) with 8 Indian institutes and 11 French universities. The Lab also participates to two CNRS Associated International Labs: LIA ATLAB (ATomically precise nano-engineering LABoratory) with UT Dallas (US) and LIA 1059 WIDELAB on Wide Band Gap technologies with CNM (ES) and AMPERE (FR).

It is also worth noting the consolidation of the partnership with Japan via the signature (May 2014) of a Cooperative Agreement with NICT (National Institute of Information & Communications Technology) on Sensing and Sensor Networks, Communications (physical layer and M2M), Security & Privacy.

Another important dimension of international attractiveness can be exemplified via the nationality of the PhD students.

Indeed, many foreign students are willing to prepare a PhD abroad and the choice of the laboratory depends upon the reputation of the hosting Lab. and research groups. During the period, LAAS hosted 584 PhD students; a bit more than half of them are foreigners originating from 51 countries. The spectrum of countries was expanded during that period compared to the previous one, with countries being increasingly represented, e.g., China (20), Italy (11) & India (7), or new countries appearing: Russia (4) & USA (2). Figure 16 shows the related geographical distribution. Nevertheless, about 2/3 is covered by 11 nationalities (representing each at least 9 students): Tunisia (46), Algeria (37), Lebanon (22), China (20), Viet Nam (19), Morocco (18), Italy & Romania (11 each), Spain (10), Mexico & Brazil (9).

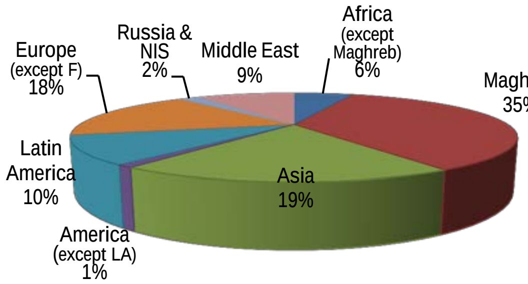


Figure 16: Geographical Distribution of Foreign PhD Students

Another way to illustrate the attractiveness of the Lab. is via the hosting of foreign scientists who are willing to spend some time at LAAS. Usually, they are hosted within a research team for a time period that can vary from a couple of weeks to several months (in some cases up to one year). They work in cooperation with the host team and benefit from the skills and infrastructure available at LAAS-CNRS. During the 2009-2014 timeframe, 211 foreign visitors have been hosted, whose 178 have made sojourns longer than 1 month.

We hope that the classification of LAAS as ZRR in 2013 will not impair the openness that is necessary to continue such a level of fruitful international recruitment and hosting.

Another relevant facet of our international connections and of the "reaching out" aptitude of LAAS members concerns their sojourns made when invited in foreign labs. and institutes. This goes beyond the numerous opportunities to exchange with colleagues during conferences and workshops organized abroad, but this is sometimes connected, in practice. During the considered period, 118 members of LAAS have made sojourns abroad, including 44 stays of at least one month.

5.5 Cooperation and Contribution to Federative Actions

5.5.1 Collaborations between the Themes

The scientific themes of the Lab. constitute a large multidisciplinary framework. However, collaborations and

[16] http://renatis.cnrs.fr
[17] https://www.projet-plume.org/en

synergies exist among several of them. They allow them to enrich their research activities by considering related topics and to benefit from complementary core competencies.

Sustaining such a form of inter-theme cooperation, in complement of cooperative projects involving external research groups, is clearly essential to a research Lab. As will be developed further in Chapter X, ADREAM and ALIVE procure two objective scientific contexts for developing such collaborations. A few examples can be given at this stage:

- IC and RC cooperate on issues related to security monitoring and analysis on the Internet via honeypots (joint PhD — see also Figure 13).
- DO and ROB cooperate on research problems posed by the distributed control of several drones for carrying out a cooperative task (joint Post-doc).
- MNBT and N2I develop activities benefiting from the complementary of their own skills on either the manipulation of cells (joint Post-doc) or the design of a lab-on-chip integrating cancer biomarkers for blood analysis (joint PhD).
- IC and ROB joined their effort for several years to address dependability issues in robot systems for critical applications (various joint PhDs and projects).
- DO and GE have cooperated on issues related to the optimized control and regulation of converters in power supply systems during the start-up phase.

The Lab. is proactively encouraging and supporting such cross-fertilizing activities by allocating them a significant share (≈ 2/3) of the amount received from the Carnot funding — see § 7.5. During the 2009-2014 period, in average, a yearly amount of 190 k€ was invested to support inter-theme research activities contributing to the ADREAM and ALIVE research programs.

5.5.2 Collaborations with other UT Labs

The University of Toulouse hosts a large number of laboratories[18]. LAAS is developing joint activities with several of them in various contexts.

The “Investments for the Future Program” (*Programme d’Investissements d’Avenir - PIA)* has noticeably influenced the period.

LAAS has been mobilized to contribute to this initiative. In particular, building on the strengths and soundness provided by the two strategic axes (ADREAM and ALIVE), LAAS has proposed and led two LabEx (Laboratory of Excellence) proposals, in coordination with other labs of the site for the second call in 2011:

- **ORCHESTRA** (Open Resilient Cyber-physical Human-aware systems: from Embedded Sensors & actuators to adaptive autonomous Robots and Ambient services): on the design of services for cyber-physical environments and ambient intelligence and on their acceptance from the various viewpoints: usage, ethical, legal; this crosscutting project united complementary skills from the partners gathered: IRIT, ONERA, UT1C (IFR MNR & IDET-Com), UT2J (MSHST).
- **BIOTED** (BIO-integraTED technologies): on the challenging combination of top-down and bottom-up approaches for developing advanced nanotechnologies for and through biology; the partners gathered around LAAS were: IPBS, ITAV and IMRCP.

Besides the fact that these two proposals were not retained[19], they instigated a real synergy at the Lab. level on these topics (and thus boosted the ADREAM and ALIVE axes) and contributed to the outreach of the related topics in the Toulouse community. Indeed, further actions have been developed and concretized as spin-offs of these initiatives.

In particular, the collaborations are developing within the neOCampus[20] initiative launched in 2013 by UT3PS. It addresses challenges (ambient intelligence, smart and sustainable campus) that encompass many facets of our ADREAM strategic project. It is worth noting that our instrumented/energy-optimized building is part of the experimentation facilities used in that context. This structuring initiative gathers 7 labs (CESBIO, ECOLAB, IRIT, LAAS, LAPLACE, LMDC, PHASE). It provides supports (internships, PhDs) to develop cooperative actions in this domain. Clearly, several joint projects currently developed in that context among IRIT and LAAS, emerged during the preparation of ORCHESTRA. In particular, 3 co-advised PhDs are funded in this context (1 LAAS-LAPLACE and 2 LAAS-IRIT).

The RTRA STAE is another body that encourages and supports collaborative and interdisciplinary initiatives (research projects, topical working groups) among the 30+ laboratories that are connected via the RTRA. In that context, LAAS has participated to almost 20 supported initiatives. In particular, at the initiative of LAAS, a WG, SYCYPH, has been launched at the end of 2013 on the topic of Explicit Mutidisciplinary Design of Distributed, Adaptive, Resilient, and Human-aware Cyber-Physical systems. This action, gathering also IRIT, CLLE, TSE & IDET-Com, is definitely a follow-up of ORCHESTRA.

Similarly, the BIOTED project led to a fruitful prospective analysis of the potential interactions with the community of oncologists. This shared reflection gave birth to a flagship project around the development of miniaturized tools for therapeutic monitoring (therapeutic companion) and pharmacological research. This strategic project is the first milestone of a close and long term partnership with the Cancer Research Center of Toulouse (CRCT) in the context of Toulouse *Oncopôle*. It will start in October 2014 with 5 co-supervised PhD thesis that will be partially funded by the IdEx of Toulouse.

Research federations constitute another well-structured form for developing fruitful local collaborations. LAAS is actively involved into 2 such structures: FERMaT (FR 3089)[21] and SH&HD (FED 4146)[22]. It is worth pointing out that **SH&HD** was led (previous period) and is now co-led by a Lab. member and that

[18] More than 60 are formally linked to the CNRS.

[19] LAAS is nevertheless involved into several PIA projects — see § 5.6.2.

[20] www.irit.fr/neocampus

[21] *Fluides, Energie, Réacteurs, Matériaux et Transferts* - www.federation-fermat.fr

[22] *Système Habitat et Habitant, pour un objectif de développement Durable*.

the activities carried out are very much linked to the energy facet of our ADREAM program. In the same context, the Lab. is also contributing to **FédESOL**[23] (*FR 3344*) set up by CNRS in 2010 to coordinate and promote research on solar energy nation-wide. In the sequel, we further develop the FERMat Research Federation.

The major objective of **FERMaT** is to initiate and support interdisciplinary research projects within a wide range of Engineering Sciences, in Toulouse and Midi-Pyrénées. The core of the Federation is composed of teams from six laboratories in Toulouse: LGC (Laboratory of Chemical Engineering), IMFT (Institute of Fluid Mechanics of Toulouse), LISBP (Laboratory of Biological Systems Engineering and Processes), CIRIMAT (Interuniversity Research Centre for Materials Engineering), LAPLACE (Laboratory plasma and Energy Conversion) and LAAS-CNRS. Other laboratories (mostly located in Midi-Pyrénées) are associated with a smaller contribution.

The involvement of LAAS-CNRS lies within 4 FERMaT themes: Microfluidics and microreactors, Porous media and colloids, Engineering for life sciences, and Materials & Applications.

During the reference period, 7 collaborative projects have been carried out under the auspices of the Federation. Among them, we emphasize the following ones, by identifying also the Labs involved and the respective number of individual contributors — permanent research/faculty members (20) and joint PhDs or Post-Doc (6):

- Model of nanofluidic devices: LAAS-CNRS (1), IMFT (1), LGC (1), LMDC (1); 1 PhD and 1 Post-doc.
- Elaboration of multifunctional coatings: CIRIMAT (5), LCC (1), LAAS-CNRS (3).
- Elaboration and exploitation of energetic nanomaterials (nanothermites): LAAS-CNRS (2), CIRIMAT (2); 2 PhDs.
- Realization of low resistivity interconnections with double-wall carbon nanotubes: CIRIMAT (1), LAAS-CNRS (1); 1 PhD.
- Consequence of chronic stress on the intestinal mucus barrier: LAAS-CNRS (1), LISBP (1); 1 PhD.
- Modeling and observation of biofilm growth: LAAS-CNRS (1), LISBP (2).

These six activities span four themes of the Laboratory: NII (5 contributors), MNBT (2), DO (1).

5.6 Prizes and Salient Points

5.6.1 Prizes

During the period, the regular distinction of researchers, faculty members, as well as engineers, from several viewpoints, including prestigious prizes, selective grants, best paper awards, is worth pointing out. A selection of such international and national distinctions is as follows:

- **2009**: Jean-Claude Laprie[24] (DR) received the Grand Prize in Informatics from the French Academy of Sciences, and Jean-Bernard Lasserre [25] (DR) the Lagrange Prize (presented by the SIAM and Mathematical Optimization Society); Céline Casenave (PhD student) was awarded the Amelia Earhart Fellowship presented annually by Zonta International to PhD woman candidates for outstanding works in aeronautics and space.
- **2010**: Dimitri Peaucelle (CR) was awarded of the IFAC National Member Organization Prize and Karama Kanoun (DR) received the IEEE Computer Society Golden Core Member; the best paper award of the IEEE RAS & EMBS International Conference on Biomedical Robotics and Biomechatronics (BioRob'2010) was granted to Manish Narsipura Sreenivasa, Philippe Souères & Jean-Paul Laumond.
- **2011**: Didier Henrion (DR) was awarded a Grant in System Control by the Simone & Cino del Duca Foundation of the *Institut de France*; Christian Artigues, Emmanuel Hébrard & Pierre Lopez were recipients of a Google Grant on SAT-based Scheduling and Thierry Bosch (PR INPT) of the Jean Ebbeni Award in Laser Optics from the French Society of Optics; Magali Brunet was awarded the CNRS Bronze Medal; Amélie Béduer (PhD student) was Laureate of the *L'Oréal*-UNESCO For Women in Science Awards *in* Nanophysics.
- **2012**: Yves Deswarte[26] (DR) received the IFIP TC-11 Kristian Beckman Award in Computer Security; Georgia Deaconu (PhD student) was Laureate for the Amelia Earhart Fellowship; Sébastien Plissard (CR)[27] and colleagues from Delft & Eindhoven Universities of Technology, were awarded the Newcomb Cleveland Prize for a paper on Semiconductor Nanowire Devices published in *Science*, already featuring more than 700 citations.
- **2013**: Jean-Paul Laumond [28] (DR) was awarded an Advanced ERC Grant for a project on anthropomorphic actions and Matthieu Herrb (IR) was proposed by INS2I to receive the CNRS Cristal in Robotics & Security; Jean-Yves Fourniols (PR INSAT) received, jointly with SME MyFox, the Syntec Digital Award for innovative secure home automation monitoring solutions.
- **2014**: Frédéric Blanc (AI INSAT) was laureate this year of the National Instruments contest in the category "Instrumentation/Electronic tests" for a Testbench for innovative gas sensors.

To these distinctions some **additional honors at Regional level** are worth pointing out: Léopold Escande Prize for best PhD (Manish Narsipura Sreenivasa, Nicolas Perrin, Florian Burgarin, Mayra Figueiredo-Fernandez), UPS Physics Award of *Académie des sciences, inscriptions et belles lettres* of Toulouse (Florence Capy), Midi-Pyrénées Inn'ovations (Françis Bony & Julien Perchoux for the Epsiline Startup), Cercle d'Oc Award (Alain Costes), Association of INSAT Engineers Prize (Arthur Bit-Monnot for his internship project), etc.

The **Novela Festival** organized annually by *Toulouse Metropole* since 2009 to promote science and knowledge among the wide public, has also rewarded several of these achievements.

[23] *Fédération de Recherche sur l'Energie Solaire - www.fedesol.cnrs.fr.*
[24] Deceased in 2010.
[25] J.-B. Lasserre also became a SIAM Fellow in 2014.
[26] Deceased in 2014.
[27] S. Plissard was recruited by CNRS and joined LAAS in 2013.
[28] J.-P. Laumond was also titular of the Liliane Bettencourt Chair on Technological Innovation at *Collège de France* in Paris in 2012-13.

5.6.2 Salient Points

The PIA

LAAS has been very much active in the proposals for the PIA. It is currently involved into 10 major projects in that context:

- EquipEx LEAF (Laser procEssing plAtform for multiFunctional electronics on Flex).
- EquipEx ROBOTEX (National Network of Experimental Platforms in Robotics).
- LabEx GANEX (Network of Labs joining efforts on Gallium Nitride semiconductors).
- CORALIE, as part of the EPICE Platform of the CORAC Program.
- SVC (Secure Virtual Cloud) in the Cloud Computing Program.
- DIGIDIAG (miniaturized micro-nanofluidics lab-on-chips) and VIBBNano (Video Imagery for Biological and Bioinspired Nanosystems), both part of the Nano-Biotechnologies Program.
- TOURS 2015 (innovative components for advanced energy mastering, led by STMicroelectronics).
- OPEN FOOD SYSTEM (disruptive technology for digital cuisine, led by the SEB group) and ROMEO 2 (large bipedal humanoid companion robot for robot-human-environment interactions, led by Aldebaran Robotics), as part of the Structuring Projects of the Competitive Clusters (PSPC)

In addition, it is worth pointing two participations in the PFMI (Mutualized Platforms for Innovation Program via DécidAIE (innovations for intensive, still environment-quality-security-aware agriculture) and FAHRENHEIT (improved mastering of thermal phenomena at component & system levels).

An Increasingly Attractive Lab.

A shown on Table 4, during the period the Lab has attracted a large number of CNRS researchers (19) and faculty members (37); among the latter, it is worth pointing out that 17 are young researchers recruited via entrance examination.

The publications produced by these recruits prior to joining LAAS-CNRS clearly evidence the ability of the laboratory to attract bright new members.

Two proposals put forward by the Lab. for hosting distinguished professors made it possible to host:

- Prof. Mark Hopkinson, U. Sheffield, GB — Pierre de Fermat Chair 2011 (*Midi Pyrénées* Regional Council).
- Prof. Gene Cooperman, Northeastern U., Boston, MA, US — Attractiveness Chair 2013 (IdEx UNITI).

During the period, the Lab. has been very active in proposing candidates for *Honoris Causa* (HC) to academic partners of the University of Toulouse (UT) associated to LAAS. Table 15 identifies the recipients[29].

It is also worth pointing out that, during the period, LAAS has successfully integrated the faculty members from LATTIS and LOSE.

[29] Our proposal for 2015, Prof. Yves Chabal, UTD, TX, US, with whom ATLAB LIA (see § 5.4) is on-going, has been confirmed by UT3PS Board.

Table 15: HC Recipients proposed by LAAS over the Period

Year	Recipient	Affiliation, Country	UT Entity
2010	Prof. Jean-Jacques Quisquater[1]	UC Louvain, BE	INPT
	Prof. José Claudio Geromel	U Campinas, BR	UT3PS
2011	Prof. Ravishankar K. Iyer	UIUC, IL, US	UT3PS
2013	Prof. Ian Walmsley[2]	Univ. Oxford, GB	UT3PS

[1] J.-J. Quisquater had been awarded one of the first Pierre de Fermat Chairs in 2004, following a proposal by LAAS.

[2] This proposal was made jointly with LCAR (*Laboratoire Collisions Agrégats Réactivité*).

A Unique Innovative Building and a Renovated & Expanded Working Place

The Georges Giralt building has allowed for a significant extension of our experimentation facilities for supporting research activities related to Robotics, Ambient Intelligence, Assistance to persons and Energy Management. The building is the cornerstone for supporting the ADREAM research activities. The support received via the 2007-2013 CPER for the construction of the building and for equipment attached to the ADREAM research project sum up to 7.2 M€. Table 16 details the CPER contributions to this funding.

Table 16: Funding of ADREAM Project (Amounts in k€)

EU (FEDER)	Midi-Pyrénées Région	Toulouse Métropole	CNRS	Total
3,200	2,500	1,000	500	7,200

In addition to these facilities the building features offices hosting more than 70 working places.

The original windowed façade (Figure 1) makes the building a unique and attractive piece of architecture. The photovoltaic electricity production and energy consumption optimization capabilities of the building constitute also an important aspect for the mastering of infrastructure expenses.

In addition, another building installed in the 80's was totally refurbished. In order to provide more spacious working places, this has also allowed for extending the experimentation facilities devoted to the research activities concerning the ALIVE axis.

5.7 Projects

Collaborative research projects are also representative of the openness and dynamics of the Lab.

5.7.1 EU projects

During the period LAAS has been contributing to 58 EU funded projects.

In substance, let us mention that these projects span various Programs: EDA (3), EUREKA (8), FEDER-SUDOE (1), FP6 (11), FP7 (35). While the whole amount was not received during the period, the total funding for these projects sums up to 18.4 M€.

LAAS was/is coordinating 11 of these projects; the corresponding funding is 5 M€ — one of them being an ERC Advanced Grant, started in January 2014.

Table 17 shows the yearly distribution of on-going projects.

Table 17:Distribution of On-going EU-funded Projects

EU Funding Year	2009	2010	2011	2012	2013	2014
# On-going Projects	27	21	24	24	27	27

The yearly distribution is rather homogeneous (more than 20 projects were active each year). It is also worth noting that 27 projects are currently on-going and that 20 of them will still be active in 2015.

5.7.2 National Institutional Projects

LAAS was also very much active at National level. During the period, 250 collaborative projects have been carried out with 3 main categories of funding: ANR, Midi-Pyrénées, Other institutions (MINEFI, OSEO, DGA, STAE, etc.).

Table 18 shows the distribution among these three categories during the evaluation period.

Table 18: National Projects with Pubic Funding

Funding	ANR	M-P Region	Others	Total
# Projects	130	65	55	250

Figure 17 describes the yearly distribution of the on-going projects in these three categories.

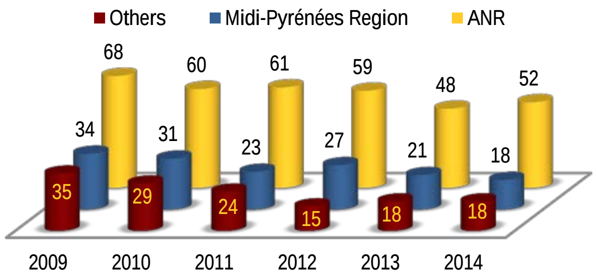


Figure 17:Distribution of On-going National Projects

The figure reveals a trend in the reduction of such projects over the recent years: the total number that was above 120 for the first 2 years of the period has decreased below 90 for the past two years (2013 and 2014). This trend is also evidenced by considering the number of projects initiated during two consecutive 5-year time periods (Table 19).

Table 19: National Projects Initiated

Public Funding Period	2005-2009	2010-2014	Delta (%)
# Projects Initiated (Total)	136	112	-18
ANR	69	57	-17%
Midi-Pyrénées Region	37	27	-27%
Others	30	28	-7%

The overall decrease (18%) is significant an concern all categories. The main decrease concerns the Midi-Pyrénées Region category. The decrease concerning ANR, also considerable, reflects the escalation observed in the selectivity of the ANR call. While much less impacted, the “Others” category was also decreasing.

Nevertheless, it is worth pointing out that several on-going actions (e.g., see § 5.6.2 and § 5.7.1) are providing alternative funding opportunities.

6 Training and Interaction with Academic Environment

6.1 Training and Recruiting

6.1.1 Training Through Research

In partnership with the three main associate partners, namely, UT3PS, INSAT and INPT, LAAS-CNRS is host laboratory for three Doctoral Schools: EDSYS (Systems — 225 registrations during the period), GEET (Electrical, Electronics &Telecommunications Engineering — 229), MITT (Mathematics, Computer Science, Telecommunications — 71). It is also connected with a fourth one: SDM (Sciences of Matter — 23).

LAAS is also the “support lab.” for the Master course in Engineering (CMI) Electronics, Electro-technics & Automatic control (EEA) at UT3PS.

The Lab. is highly involved into two Inter-university Training Centers, co-founded by UT3PS, INPT, INSAT & LAAS-CNRS: AIME (*Atelier Interuniversitaire de Micro-nano-Electronique*) and AIP-PRIMECA (*Atelier Inter établissements de Productique et Pôle de ressources Informatiques pour la MECAnique*).

LAAS is also regularly invited by these Schools and Universities to participate to various councils on the evolution of training. To strengthen links and exchanges, the Lab. participates to their “open days”, via posters and demonstrations. LAAS also encourages the students and the faculty staff to visit the laboratory. Specific training seminars are organized at LAAS and are an opportunity for the community to benefit from focused talks by scientists involved into these topics.

During the course of the evaluation period, LAAS hosted 584 PhD students and 520 Master II or Engineer internships. Also, 360 L1- or M1-level students have been received at LAAS for internship periods or for attending training modules.

A multi-annual educational engineering experiment on nanotechnologies at school has been developed in collaboration with researchers in education science of UT2J. The ambition is to involve all disciplines for building lectures, workshops and visits on Nanotechnologies, covering issues such as concepts, applications, and controversies. Over 4 years, this action has impacted 700 14-year-old pupils and it has represented 750 hours of contact with the pupils.

The PhD students have two representatives in the Laboratory Council and are represented in the Scientific Council of their teams. To ensure a smooth integration, the laboratory organizes each year a “welcome day” for new PhD students (other newcomers are also invited to join).

An annual reporting collects various indicators relevant to events attached to the conduct of the theses (duration, dropout, publications, etc.). If we except the thesis carried out in a co-supervision framework, the average duration of the PhD theses is 3.53 year.

At their initiative, and supported by the Lab., PhD students have launched two types of informal gathering:

- ***Réunion et Rencontre* Sessions**, (aka, Bi-R Sessions) are organized every couple of weeks at the end of the working day on Fridays. They are convivial meetings aimed at promoting exchanges among LAAS members, especially PhD students from different themes and teams. This series was started mid-2013 (10 sessions took place in 2013 and 8 more by mid-2014).

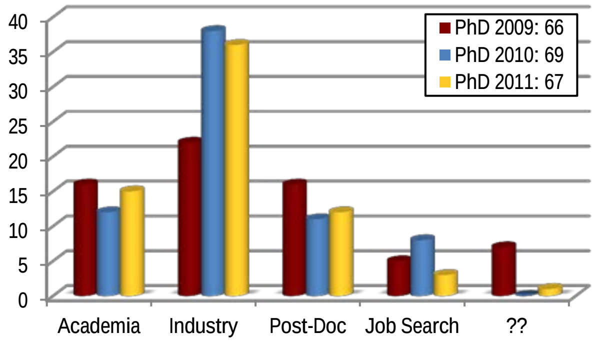


Figure 18: Future of PhD Students

- **PhD Students Coffee Sessions** are scheduled during the mi-day break: students briefly expose (via a short 10mn-talk — poster-based support is also allowed) the topic of their research, their work, their progress or results and the (tentative) perspectives and applications. This series was launched at the beginning of 2014; five sessions were organized during the first semester. This is probably a good “training” to plan participating to the now widespread form of contest “Your Thesis in 180 Seconds”…

The future of our PhD students is also specifically monitored. Specific statistics are made 2 years after the defense. Figure 18 illustrates these data for the defenses in the period 2009-2011.

6.1.2 Links with the Academic Partners

At the level of the laboratory, the Training-Research Committee (CER[30]) provides assistance in specifying and monitoring issues related to higher education, especially concerning our associated partners (description of position profiles, recruitment process, training programs, etc.). To ensure a good thematic coverage and a good representation of the different institutions within the CER, the 21 members (faculty or researchers) are nominated equally by the scientific themes and the Direction. With the support of elected members within various CNUs, the CER organizes annually a meeting of information on careers in higher education and research as well as on the qualification procedures and the applicable selection criteria. In coordination with the other actors of the site, the laboratory and the research teams encourage and support the mobility of PhD students during their thesis, their participation to Summer schools and the organization of the conferences of Doctoral Schools.

6.1.3 Continuing Education

For many years, LAAS is engaged in a process of continuing education for its members. The first Training Plan was developed in 1994 (since the Lab. has identified a correspondent for training).

The on-going training plan covers the period 2010-2014. An update of this plan is elaborated annually, from the census of needs identified primarily by the service leaders.

The training can be accomplished in various frames:

- Internal training sessions offered in connection to the platforms and the working environment, e.g., RENATECH (micro and nanotechnology), Computer Networks (IT Security), Health and Safety, etc.
- Training programs for skills development via the CNRS Regional Office and the Skill Development Department at UT3PS.
- Personalized training sessions dispensed by independent training organizations, for which support is provided for registration fee or for travel expenses when the fee is paid by the employer (CNRS, UT3PS, INSAT or INPT).

Concerning the first item, it is worth pointing out that access to the Lab. platforms is conditioned to the fulfillment of specific training sessions. Accordingly, technical services provide the required training to the laboratory staff and also to the PhD and internship students. For example, usage of the micro and nanotechnology facilities is conditioned by a 20 h-training session, provided by the TEAM service staff. On average, and by including all the technical services, 1250 h of training are offered each year to 200 people.

Each year, about 80 Lab. members (including 60% ITA or BIATSS personnel) are benefiting from external training programs.

6.1.4 Integration of Persons with Disabilities

The Lab. has a voluntary approach for the integration of disabled personnel.

During the past four-year period:

- two ITAs and one research fellow were recruited via the CNRS “*Campagne Handicap*”;
- three PhD students were recruited via doctoral contracts for disabled students;
- one post-doctoral student was also recruited via such a plan.

For these personnel, the laboratory has been taking care, with the help of their employer (namely, CNRS or UT3PS) of adapting their working environment to their disability, and also of their training.

6.2 Involvement of the Members of the Laboratory

During the period, several members of the Lab. have contributed or are contributing at different levels to the direction and/or various instances of the institutions of the UT site:

- **Doctoral Schools**: Direction of GEET and vice-direction of EDSYS.
- **Inter-university Training Centers**: Direction of AIME (until 2011) and AIP-PRIMECA (2 successive directors during the period); other LAAS members are also contributing to both Boards.
- **Direction of UPSSITECH**[31] (*Université Paul Sabatier, sciences, ingénierie et technologie)*
- Direction of Education Departments and Schools:
  - **UT3PS**: Electronics, Electro-technics & Automatic control (EEA), Interactive Robotic Systems (UPSSITECH), Electric & Industrial Computing Engineering (IUT A);
  - **INSAT**: Electrical Engineering & Computer Science;
  - **INPT-ENSEEIHT**: Electronics and Signal Processing;
  - **UT2J IUT Blagnac**: Networks & Telecommunications.

[30] *Commission Enseignement-Recherche.*

[31] The Engineering School of the UT3PS.

- **UT3PS Master Programs**: Coordination of the EEA Master (EEA) and responsibility for 4 M2 specializations: Electronics for Embedded Systems & Telecommunications (ESET), Real Time Systems Engineering (ISTR), Smart Systems & Microsystems (SMI), Engineering of Modeling of Physical Processes (IM2P2).
- **Specialization Classes in Engineering Schools**:
  - **INSAT** (2): Automatic Control & Electronics, Computer Science & Networks;
  - **INPT-ENSEEIHT**: Electronics & Signal Processing.

Several members of LAAS coordinate and contribute to various pedagogical multiannual programs developed as part of the inter-School CESEC training program. They are also involved in the National Coordination for Training in Microelectronics and Nanotechnology as well as the Conference for Teaching Technology & Sciences of Information & Systems. The National Days of the Doctoral Network in Microelectronics are chaired by a member of LAAS. Members of LAAS regularly contribute to the program of about fifteen thematic schools in France and abroad.

7 Valorization and Innovation

With its large number of permanent researchers and doctoral students, and a long-standing partnership with the business community, LAAS-CNRS is located at the crossroads of scientific challenges, innovation and markets. This is exemplified by the Label Carnot that was attributed to the Laboratory in 2006 and renewed in 2011.

7.1 Contracts with Industry Partners

LAAS has established strong collaborations with industry; during the period almost 400 projects involved at least an industry partner: e.g., this includes 43 of the 58 EU projects and 144 of the 250 National Institutional projects. To provide some clue about the related connections with industry, let us mention that the 68 cooperative projects with an industry partner carried out in 2013 involved a total of 191 companies.

EU projects provided us with opportunities to cooperate with some major companies in various application domains; these include: Audi (DE), Ericsson (SE), Fujitsu Siemens Computers (DE), IBM (IL), Infineon (DE), KLM (NL), Kuka (DE), Telefunken (DE), Volvo (SE).

Nation-wide, among the period, several key industrial actors are our major and recurrent partners: Airbus Group (35 projects with one or more group entities), Thales (34), Freescale Semiconducteurs France (18), ST Microlectronics (9), Renault (7).

Some known or emerging companies of various sizes are also worth pointing out among our close or recent partners. Actia, Aldebaran Robotics, Essilor, Innopsys, i-Trust, SigFox, Sterela, are among these.

Among the various options for collaborating with industrial partners, direct contracts form the reference type of cooperation for the Carnot program. For example, for the last full year (2013), we had 37 contracts involving 33 different enterprises.

Two (often cross-fertilizing) options are of particular interest to establish fruitful links with industry:

- The CIFRE [32] program: the framework provides a convenient and efficient way to establish a close partnership between Research Labs and Industry.
- The setup of a “joint cooperative Lab.”: such a structure gathers, on a specific agreed research agenda, one (or several) industrial partner(s) and one (or more) academic research Lab(s).

7.1.1 CIFRE Program

LAAS has been using the CIFRE opportunity since the beginning of the launch of this program in 1981. A total of 209 PhD students have been (or are currently) supported since then. During the period 01/01/2009 - 30/06/14, a total of 77 CIFRE-supported PhD students have been hosted. The number of such PhDs started during that period amounts to 45. Table 20 provides the yearly distribution.

Table 20: Yearly Distribution of CIFRE PhDs

CIFRE Year	2009	2010	2011	2012	2013	2014[1]	Average
PhD Hosted	41	38	37	32	35	29	35
PhD Started	9	8	8	7	9	4[1]	8

[1] Accounts only for the first semester.

7.1.2 Joint Labs with Industry Partners

LAAS was a pioneer as CNRS Lab. in setting up (together with other Labs from the site) a joint research Lab. in 1991: MIRGAS. Since then, a dozen of such joint Labs have been set-up.

Possibly due to the emergence of new or augmented support opportunities provided by the various programs developed over the past years (growth of the ANR agenda, takeoff of the competitiveness clusters initiatives linked to the FUI framework, etc.), we have experienced more difficulty in maintaining or renewing these opportunities.

Over the period, two major such close cooperation frameworks with industrial partners have to be mentioned:

- AIRSYS (*Architecture et IngénieRie des SYStèmes*): a close cooperation with Airbus started in 2006, gathering also IRIT and ONERA (until 2012). The road map has been renewed in 2012 (until 2015) to include 4 domains: avionic platform, cockpit & flight control, systems engineering and maintenance.
- BIOSOFT: an ANR–supported LabCom set up at the beginning of 2014 between LAAS and Innopsys[33]; the objective is the development of flexible technological processes (e.g., soft-lithography) directly applicable to the industrial production of biosensing systems.

Another project of joint Lab. with Essilor is now well underway and should be started before the end of 2014. In addition, in 2014, exchanges have been started with Thales Airborne Systems for setting-up a portfolio of joint research topics.

7.2 Contribution to the Eco-system

The laboratory is very much involved into actions related to innovation beyond the various contracts that link it to several industry domains; for example:

[32] *Conventions Industrielles de Formation par la REcherche* proposed by ANRT (Association Nationale de la Recherche et de la Technologie) - www.anrt.asso.fr

[33] www.innopsys.com

- Member of the Board of the Carnot Institutes Association, major implication into the TIC-MNT Alliance and contributions to various WGs (Europe, Quality, Industrial sectors, etc.).
- Co-animation of six DAS (Strategic Activities Domains) of the Competitiveness Cluster Aerospace Valley, one for Era 2 (Embedded Systems, until March 2013) and 5 for Era 3 from April 2013: ESE (Energy & Electromechanical Systems), G2MCO (Maintenance Engineering & Maintaining Operational Conditions), SEEL (Embedded Systems: Electronics & Software — 2 persons, SSTA (Safety & Security of Air Transportation), UF (Factory of the Future).
- Member of the WG "Automobile & Transports" of Systematic: the Paris Region Systems & ICT Cluster.
- Member of the Scientific Council of the FRAE[34].
- VP of "Higher Education-Research" College of Arboritech [35] (Innovation and Training Center in Arboriculture - Montauban 82)
- LAAS is hosting the Midi-Pyrénées office for CAP'TRONIC-JESSICA France[36] and for the GIPI[37]; LAAS members contribute to the respective Boards; 1 for the first one and 3 for the latter.
- LAAS has set — since 1990 — an Affiliate Club[38] of industrial partners; today, the Club counts more than 80 members whose 2/3 are SMEs.

7.3 Start-Ups

The laboratory supports the approach of its researchers, engineers, technicians and PhD students in creating their own business and assists them during the first years of their existence by providing technological and local support, and hosting them during the incubation phase. CNRS is a member of the regional *Midi-Pyrénées* incubator and of the Board of Toulouse Tech Transfer (society for accelerating technology transfer), entrepreneurship projects can naturally be supported by these structures.

Of particular note is the intensification in the process of business creation in past years. Among the start-ups launched by LAAS-CNRS members, recent ones are:

- **3dis Technologies**, 3D Interconnection Technology (2014).
- **WideSens**, Wireless Sensor Networks (2013).
- **i Habitation**, Domotics for New Facilities or Renovation (2012).
- **Seeks**, Free Cooperative Search Engine (2011).
- **Naïo Technologies**, Technological Developments and Robotics for Agriculture (2011).
- **Exem**, Electromagnetism Monitoring for Radio Communications (2010).
- **Epsiline**, Anemometry by Laser Technology (2009).
- **Mapping Consulting**, Consulting Agency Specialized in Innovation Ecosystem (2009).
- **EHTech**, Sustainable Technology for Energy Harvesting (2009).

[34] *Fondation de Recherche pour l'Aéronautique et l'Espace* - www.fnrae.org
[35] www.arboritech.eu
[36] www.captronic.fr
[37] *Groupe d'Innovation Pour l'Industrie* - www.gipi.org
[38] www.laas.fr/club-affilies

It is noteworthy that the link with these start-ups often continues well beyond their creation, whether they were born in the laboratory or outside its walls. Two recent highlights concerning previously founded start-ups deserve to be stressed:

- **Kineo CAM**, the company created in 2000 has rapidly become a key player on Motion Planning and was acquired by ***Siemens PLM Software*** in 2012.
- **QoS Design**: launched in 2004 the firm focusing on Simulation/Optimization of Networks just signed (Sept. 2014) an ***Agreement with Tunisie Telecom and CNRS*** to develop future cooperation: among the plans, a proposal for a LIA involving LAAS-CNRS.

7.4 The Emergence of the Toulouse Tech Transfer (TTT) SATT

The TTT SATT was launched at the beginning of 2012 and started operating in mid-2012. UT, CNRS and CDC are the shareholders. The missions of TTT are essentially geared towards: i) the valorization of innovative research results (preparation and registration of patents, maturation of results for climbing the TRL scale) and ii) the provision of support to the creation of start-ups. During this early period, TTT has mostly focused on the first objective.

For LAAS, this has resulted in new procedures, as well as different information channels. Explicit coordination actions have been set in order to facilitate the interactions between TTT, the researchers, the Lab. and the relevant academic authorities.

Among the 15 CNRS-linked Labs of the site that have benefited of the support from TTT, LAAS features the largest number of actions. Indeed, at the end of June 2014, the 15 support actions devoted to LAAS represent a large share (> 1/4) of the 54 on-going support actions. These supports include 5 maturations (among a total of 16 currently on-going); they concern four scientific themes: ROB, DO, MNBT, N2I (2).

TTT assigned mission is also to support the submission of patents. In our case (being a CNRS UPR), this is being carried out in conjunction with the CNRS DIRE and FIST. In that respect, too, specific adjustments had to be made to facilitate the coordination of the decision loops concerning the patents being submitted. During the period considered for this report, 41 patents have been registered. While it is still an early stage to have a precise picture in the long term, so far, no positive impact with respect to patents submissions is to be reported (Table 21). Among these patents about half of them (53%) are co-owned with partners, the rest are issues from Lab. own results.

Table 21: Distribution of Patents Registered

Year	2009	2010	2011	2012	2013	2014[1]
# Patents Registered	13	9	8	5	4	2

1 Accounts only for the first semester.

7.5 The Carnot "Profile"

On the grounds of its significant and long term involvement in collaborative research with industry (e.g., CIFRE contracts, series of Joint Labs), which is also objectively reinforced by its Affiliate Club, set in the early 90's and gathering today more than 80 members,

Figure 19: Use of the Carnot Contribution — 2009-2011 (Carnot 1) & 2012-2015 (Carnot 2) — Amounts are in k€

the Lab. has been labeled "Carnot institute[39]" since 2006. The governance of the Carnot institute is mapped to the management of the Lab.: direction and responsible for management and decision support.

The Carnot contribution (see § 4.4.2) constitutes a non-negligible share of the Lab. resources and it revealed as good lever to develop both **resourcing**, in particular for reinforcing our strategy to support our transverse axes (ADREAM and ALIVE) and **professionalization**, for improving our abilities in developing collaborative research activities.

Another share, but more limited, is devoted to **integration** activities within the Carnot network currently grouping 34 Carnot institutes. Hereafter, we briefly describe activities being carried out with respect to these three targets.

The pies of Figure 19 indicate the distribution of the Carnot contribution (amount shown in green) among the three main identified activities over the years.

The figure also shows (as explained already in § 4.4.2) the significant impact on the funding received induced by the change (between Carnot 1 and Carnot 2 phases) in the calculation of the Carnot contribution (allowance of a flat-funding).

Indeed, the increased amounts made it possible to develop further each of these activities. In particular, this has allowed significantly increasing our investment in professionalization actions while sustaining a substantial level in resourcing activities.

It is also worth pointing out that the decrease in Carnot contribution received in 2012 and 2014 has actually been recovered as evidenced by the amount confirmed for 2015, which refers to the flow attached to direct contracts on-going in 2013.

7.5.1 Resourcing

During the period, a significant share was devoted to support cutting-edge research actions at the crossroads of two complementary targets: promoting inter-theme actions and implementing our strategy attached to the development of ADREAM and ALIVE.

Indeed, experience shows that it is not so easy to obtain funding (e.g., via collaborative calls) for research projects gathering teams belonging to the same Lab., even if the teams are actually mixing the complementary competencies necessary to address the challenges raised by the project. In practice, inter-Lab. projects are usually favored. So, this form of support proved very much useful to reinforce our strategic axes.

Three internal calls for proposals were made during the period — in 2010, 2013 and 2014 — for which three forms of personnel (PhD, Postdoc, Research Engineer) were eligible for funding, in addition to some related travel and equipment resources:

- **2010**[40]: The decision to support 2 positions (a PhD and a Postdoc, for 2 years) was made for this call; also, three other projects from the previous call in 2008 were on-going until 2011 (2) or 2012 (1).
- **2013**: Four Post-docs ADREAM (2) and ALIVE (2) and one Engineer for a transverse project on advanced nano manufacturing for the RENATECH platform (1 year each).
- **2014**: Two PhDs — one for ADREAM and one for ALIVE. Both are starting in October 2014.

For helping us in developing and implementing our Carnot roadmap, we have established a COS (*Comité d'Orientation Stratégique*) that gathers 12 external members both from industry and academia. Due to the mid-term evaluation process that ran in 2013, the first meeting of the COS occurred in 2014. The 8 external members present contributed then to finalizing the selection of the 2 final PhD-projects among a pre-selection of 4 proposals made by the members of the CDR, among the 11 proposals submitted.

7.5.2 Professionalization

Three main aspects are worth pointing out:

- prospective contacts and interactions with industry;
- continuous quality improvement;
- support to contractual and communication activities.

Prospective Contacts and Interactions

This range of activities is very much linked to the actions developed via the Affiliate Club. They include:

- organization of seminars and workshops on specific topics of interest to the Club members that are selected jointly within the Board;
- assistance in establishing connections between the industrial members together [41] and with the researchers of the Carnot institute.

Several events have been co-organized with several competiveness clusters, Aerospace Valley, *Agri Sud Ouest Innovation*, DERBI, Water, and other associations, including: ANRT, GIPI, MPI, Robotics Place, etc. More details on the seminars and workshops organized in that context can be found on the Club Website.

[39] In that context, the Lab. is identified as "*institut Carnot LAAS CNRS*" or "iC LAAS CNRS", in short.

[40] The funding to support these actions (for several of them spanning three years) was relying on (a significant part of) the Carnot contribution to be obtained in the subsequent couple of years. This explains why the next call was made in 2013.

[41] An example is the creation in 2012 of the Sensing Valley Cluster that has resulted from the identification of common interests by 12 SMEs members of the Club — www.sensingvalley.com.

One recent significant action concerns the strong participation to the ICS forum held in Toulouse on September 16-18, 2014[42]. The action and presence of the Lab. was double: a) promotion of the event within the Carnot Association for the presence of a stand of the Carnot Institutes (that gathered 5 iCs, including iC LAAS CNRS) and b) installation of a stand for the Affiliate Club, that helped 3 SME members and the Sensing Valley SME Cluster to be present at this event around the Lab.

During the period, the main impact of the synergies explored and established concerned the agricultural domain that was not, so far, much targeted by the activities developed by the Lab. This has encompassed various levels of exploration and refinement of research results developed by several themes of the Lab including, smart sensors (HOPES, N2I, MNBT), diagnosis for supporting decision making (DO), security and privacy of the data processed (IC), terrestrial autonomous vehicles and UAVs (ROB). It is worth pointing out that these activities perfectly sustain the scientific challenges explored within ADREAM.

Continuous Quality Improvement

In order to improve further our procedures, in particular for what concerns the management of our actions in connection with industrial partners, we have started a **“**continuous quality improvement” plan[43]**.** This effort, started in July 2013, is relying on the support of a company (SYNOOSYS) and is expected to last about 2.5 years. It is developed according to 8 main phases.

The first three phases (diagnosis, training, launch) were carried out in 2013. This initial step has resulted in the cartography of the main relevant activities involved: ten processes have been identified and the related working groups and objectives defined.

The fourth phase (on-going) is devoted to the definition in our context of the procedure and record models that are necessary for these processes in compliance with the ISO 9001 standard. It is developing during 2014.

The next four phases will be carried out in 2015; they concern:

- training the internal auditors that are mandatory to sustain the continuous improvement;
- adoption and stabilization of the procedures by implementing them and applying them;
- finalization of the quality improvement system with respect to its consistency with the standard requirements;
- conduct of a pre-audit, no later than the last quarter of 2015.

Support to Contractual and Communication Activities

During the period two main actions were carried out to support our contractual activities:

- Development of a tool to assess the full cost of the projects.
- Reflection on and implementation of an analytical accounting process.

The first action started at the end of 2011 as part of the Carnot Partnership cell. It has resulted in early 2014 into a spreadsheet-based support tool specifying: a) for ANR projects, the financial set up identifying the eligible expenses and b) for direct projects, a quotation for the industrial partner.

The second effort is targeting our technological platforms (especially the RENATECH platform) for assessing the full cost of a product/service. It is a long-term initiative of the Lab. that was also supported by the CNRS Regional Office in Midi-Pyrénées. After two years of efforts and interactions, in 2014, LAAS is now acting as a pilot site for implementing this process. It is planned that this opportunity will be deployed nation-wide in 2015.

Also, in that context, a share of the Carnot contribution was exploited to support contractual agents. In particular, it has benefited to enhance the human resources devoted to manage our contractual actions from both viewpoints of project submission and justification of expenses: two CDDs could be supported in that context for the Contracts & Partnership (1) and Finance (1) services. During the evaluation period, another CDD was also supported until 2013, which made it possible to further develop our Carnot-related communication.

7.5.3 Integration

The iC LAAS CNRS has been very much active in contributing to the Carnot network. Since 2011, it holds a seat in the Board of the Association.

The Lab. has been involved into various actions. Among them one can identify the contribution to the joint work carried out within the framework of the TIC-MNT Alliance that resulted into a White Paper on smart objects[44].

During the past year, several members of the Lab. have been involved into working groups set up to anticipate the specific ANR call "*Valorisation-instituts Carnot*" that is exclusively open to iCs and meant to lead to the structuring of the offer of the iCs to respond to the needs of the economic sectors, especially from the SMEs and MMCs[45].

While this is still an on-going effort, it is worth pointing out that iC LAAS CNRS has been contributing to working groups concerning 6 (among the 15 identified) economic sectors, namely: automotive; aircraft construction; renewable energies; industries & technologies for health (medical devices); digital (HW; SW, usage); mechanical industries & processes (including future production systems).

8 Communication and Interaction with the Socio-Cultural Environment

LAAS commitment in communicating and interacting with the public at large, i.e., beyond the scientific community, are numerous. Popularizing science and our research activities is definitely part of our genes. Several contributions can be highlighted in that context.

[42] While this event took place beyond the period covered, the related organization issues were started more than one year ago.
[43] In compliance with **the** ISO 9001 version 2008 standard.

[44] See: http://www.internet-of-things-research.eu/pdf/AiCarnot-White_Paper-Smart_Networked_Objects_and_Internet_of_Things.pdf
[45] Medium Market Companies; in French: ETIs (*Entreprises de taille intermédiaire*).

An emblematic action is the "Doors Open Day" organized annually as part of the Science Festival (Fête de la Science). For the past couple of years, more than 700 persons have come to visit the Lab. The visit includes demonstrations of some of our timely research results and also special experiments for the children organized by PhD students.

In addition to the seminars that are organized regularly by each scientific theme, a series of seminars focused on cyber-physical systems and the ADREAM project was organized at specific milestone dates attached to the experimental building that host the project:

- Laying of the foundation stone (June 2010).
- Inauguration (July 2012).
- Dedication to Georges Giralt (Oct. 2013).

On each of these occasions videos were recorded that are available from the Lab. Website. Also several reports (press, TV, radio, photo) covering these events were made.

We also engage in many actions to share our results and explain our activities outside the Lab. Such a dissemination is made via various media supports. Figure 20 illustrates the media coverage obtained for the past years[46].

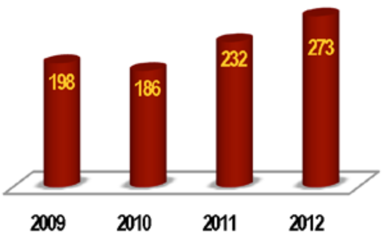


Figure 20: Media Coverage (TV, Radio, Press, Websites, etc.)

TV broadcast (news, reports) and videos (demonstrations, posted conferences) are among the most impacting actions; we can mention:

- France 5: *C dans l'air, Les robots,* March 2012.
- Public Sénat: *Bibliothèque Médicis, Le cerveau*, May 2012.
- AB Encyclo TV: The World of Tomorrow, Ambient Intelligence, Feb. 2014.

Contributions to large audience radio broadcasts are also worth pointing out. Some highlights are:

- France Inter: *Le téléphone sonne, Les nanotechnologies*, Oct. 2009; *La tête au carré, La robotique,* Jan. 2012.
- France Culture: *Des robots et des hommes, Robo Sapiens, une espèce en voie d'apparition*, Nov. 2010
- Wiki radio CNRS, *Le CNRS innove à Toulouse* (Futurapolis), April 2013

Some original multidisciplinary exhibitions mixing sciences and art that contributed to various editions of the Novela Festival[47] are also worth emphasizing:

- **Luminescent Harp** (2010): A colorful laser-based snake-shaped instrument jointly elaborated with Toulouse Beaux-arts School for the 50th anniversary of laser discovery (Figure 21). The Harp is now displayed nation-wide via *Science Animation*.
- **Inter-acting with PR2** (2011): An intriguing interactive play featuring a theatre actor and a Willow Garage PR2 robot.

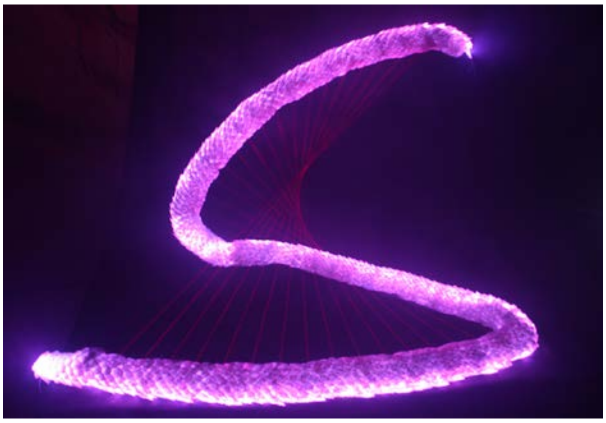


Figure 21: The Laser-based Luminescent Harp

- **Dancing with HRP2** (2011 & 2012): A fascinating synchronized ballet involving a professional dancer and a humanoid robot.

The Lab. is also very much pro-active in promoting science towards young pupils. In addition to the "Open Doors Day", during the period we have hosted 135 middle school and high school pupils and we receive annually the visit of 3 or 4 high-school classes. Other representative contributions in that context are the high-school classroom lectures delivered in the Region:

- "*Nano école*", educational classes on engineering of nanotechnologies delivered annually to ≈200 high-school pupils (2009-14)
- "Analysis and Experimentation: Two Facets of the Scientific Method", lecture delivered at *Lycée Maréchal Soult* in Mazamet as part of the series of meetings set by the *Fondation La Dépêche* for sensibilizing high-school pupils to research and innovation (2011).
- "*Maths en Jeans*", "*Maths à modeler*" Workshops, held in several local high-school classes (2012-14).

9 Concluding Remarks

The self-evaluation of the activities and positioning of the Lab. will be reported after the exposition of the scientific themes and transverse axes that are presented in subsequent sections, as follows:

II. Crucial Computing
III. Networks & Communications
IV. Robotics
V. Decision & Optimization
VI. Microwaves & Optics: from Electromagnetism to Systems
VII. Nano Engineering & Integration
VIII. Micro Nano Bio Technologies
IX. Energy Management
X. The Transverse Axes: ADREAM and ALIVE

On these grounds, Chapter XI presents our "Project for the Future". This section starts with a self-evaluation carried out under the form of a "SWOT" analysis. It then describes, the main orientations for the Lab. and the proposed evolution for the transverse axes.

[46] Unfortunately, the information for 2013 could not be processed yet.
[47] Festival of "Shared Knowledge" launched by *Toulouse Métropole* in 2009.

II - Crucial Computing (*Informatique Critique* — IC)

Leader: K. Kanoun

Research Teams: Dependable Computing and Fault Tolerance, System Engineering and Integration, Verification of Time Critical Systems.

Keywords: Architectures and algorithms for dependability; Formal techniques for system description and verification; Modeling, prototyping and experimentation; Security and Privacy; System and requirement engineering; Verification, validation, testing and assessment.

Personnel Status (as of June 30, 2014):

Team — ISI	**System Engineering and Integration (*Ingénierie Système et Intégration*)**
Leader	H. Demmou (MCF)
Permanent Researchers	V. Albert (MCF) [09/10[, G. Auriol (MCF) [01/10, 03/13], C. Baron (PR) [01/10[, P. Esteban (MCF), C. Foucher (MCF [09/2013[), A. Nketsa (PR), J.-C Pascal (PR), A. Sahraoui (PR) Retired: M. Courvoisier (PR, 02/2010), M. Paludetto (PR, 10/2009)
PhD Students	V. Shukla [10/10-01/14], R. Xue [10/11[, D. Foures [10/11[, S. Ponnusamy [05/13[, A. Jakjoud [10/2010[Alumni: J. Verries [10/07-01/10], J. Konate [10/07-11/09], V. Albert [09/07-10/10], R. Guillerm [10-07-06/11], X. Zhang [06/11-01/12]
Post-docs; Engineers	R. Guillerm [10/11[, V. Albert [10/09-08/10], V. Shukla [01/14-05/14], J. Veries [01/10-04/10], X. Zhang [01/12-10/12]
Team — TSF	**Dependable Computing and Fault Tolerance (*Tolérance aux fautes et Sûreté de Fonctionnement informatique*)**
Leader	M. Kaâniche (DR) [since 04/13], K. Kanoun (DR) [until 03/13]
Permanent Researchers	E. Alata (MCF) [09/09[, J. Arlat (DR, LAAS Director), G. Auriol (MCF) [04/13[, J. Collet (DR, émérite), A. Costes (PR, émérite), Y. Crouzet (CR-HDR), A. de Bonneval (MCF), J.-C. Fabre (PR), J. Guiochet (MCF), K. Kanoun (DR), M.-O. Killijian (CR-HDR), M. Lauer (MCF) [10/13[, G. Motet (PR, Scientific Director Fondation pour une culture de sécurité industrielle) [01/10[, V. Nicomette (PR), D. Powell (DR), N. Rivière (MCF), M. Roy (CR), P. Thévenod-Fosse (DR, LAAS Management and Decision Support Resp.), G. Trédan (CR) [10/10[, H. Waeselynck (CR-HDR) Decease: Y. Deswarte (DR)]01/14], J.-C Laprie (DR),]10/10]
PhD Students	P. André [01/10/11[, Y. Bachy [01/06/12[, O. Baldellon [20/09/10-07/11/14[, J. Barrier [01/10/13[, A. Dessiatnikoff [01/10/10-17/07/14[, J. Duchêne [01/11/13[, Q.-A. Do Hoang [01/10/11[, C. Fayollas [01/10/11[, M. Machin [01/10/12[, H. Martorell [01/12/11[, R. Pasqua [01/09/13[, L. Pintard [01/02/12[, T. Probst [01/10/12[, C. Sauvanaud [01/09/13[, I. Studnia [01/01/12[, M. Traore [01/10/11[, A. Zammali [01/10/12[Alumni: R. Akrout [01/09/09-18/10/12], A. Baina [01/01/06-29/09/09], H.-N. Chu [27/11/07-01/09/11], A. Guduvan [25/12/09-18/04/13], O. Hamouda [01/10/06-19/07/10], Y. Laarouchi [01/11/06-30/11/09], E. Lacombe [01/11/06-15/12/09], M. Lastera [15/09/09-12/12/12], J. Lauret [01/10/09-31/12/12], F. Lone Sang [01/09/09-27/11/12], C. Lu [01/10/2006-14/12/09], A. Mekki Mokhtar [01/10/09-12/12/12], N. Nguyen [15/10/05-30/09/09], M. Nunez del Prado [01/10/10-12/12/2013),M. Sghairi [04/01/07-30/04/10], K. Tiassou [15/10/09-06/02/13], M. Stoicescu (06/10/10-09/12/2013), G. Vache [01/10/06-08/12/09]
Post-docs; Engineers	K. Cabrera Castillos [01/12/2013-30/09/2014], F. Dufossé [01/09/13-31/08/14], J. Friginal [01/04/13-11/07/14], G. Da Silva Silvestre [01/10/13-30/09/15], M. Stoicescu [10/12/13-31/08/14] Alumni: R. Akrout [19/10/12-31/08/13], S. Gambs [01/10/08-31/08/09], O. Hamouda [20/07/10-31/12/10], E. Lacombe [16/12/09-31/08/10], F. Lone Sang [28/11/12-12/11/13], D. Martin-Guillerez [01/08/09-30/09/10], J. Nin [01/06/09-30/09/10]
Visiting Researchers (Affiliation, Country, Period)	Z. Micskei (BUTE, HG) [16-28/03/09], A. Louri (U. Arizona, US) [15/06-15/08/09], S. Poulding (U. York, UK) [23-27/09; 18-22/01/10], R. Moraes (Unicamp, BR) [27/02/11-07/03/12], M. Kato (JAXA, JP) [03/02/13-06/02/14], P. Fraigniaud (LIAFA, FR) [08-21/07/13], E. Gafni (UCLA, US) [08-21/07/13], S. Rajsbaum (UNAM, MX) [28/06/13-31/07/13], S. Schmid (TU Berlin, DE) [01-15/10/13; 17-21/03/14] P. Koopman (Carnegie Mellon University, Pittsburgh, USA) [02-05/06/14]
Team — VERTICS	**Verification of Time Critical Systems (*VERification des Systèmes Temporisés CritiqueS*)**
Leader	B. Berthomieu (CR) [since 01/12], F. Vernadat (PR) [until 12/11]
Permanent Researchers	S. Dal Zilio (CR), P.-E. Hladik (MCF), D. Le Botlan (MCF), B. Chezalviel (PR, delegation), F. Vernadat (PR) Retired: B. Courtiat (DR)]09/13]
PhD Students	M. Cheramy [09/11[, P.-A Bourdil [2/11[Alumni: F. Peres [10/06–01/10], R. Saad [07/08–01/11], N. Abid [09/09–12/12]
Post-docs; Engineers	L. Fronc [11/13[, N. Ge [05/14[Alumni: A. Hamez [02/10–10/11], N. Guermouche [09/10–09/11]
Visiting Researchers	Y. Thierry-Meig (UPMC/Lip6, FR) [21-25/05/12], E. Vicario (U. Florence, IT) [24-28/06/13]

1 Presentation

1.1 Objectives and Scientific Positioning

The research activities of the Crucial Computing theme address the design, analysis and evaluation of complex and critical information and computing systems that need to satisfy the strict requirements of highly constrained applications. These requirements may be expressed by a set of properties, defined in terms of timeliness, quality of service, dependability and security.

The research activities carried out concern the definition, exploitation, tooling of formal and experimental techniques and methods, aimed at the design, verification, evaluation and exploitation of critical systems, in which software is dominating.

The scientific research topics addressed include:

- Engineering of complex and critical systems, with emphasis put on design and validation processes;
- Dependability and resilience of information systems taking into account the most impacting aspects: system architecture, interactions between systems and components and between systems and users, mobility of users, systems and services;
- Formalization of the specification, verification and testing, putting effort on integration of associated tools in the industrial development process;
- Quantitative evaluation of system’s properties, based on i) stochastic processes, ii) measurements in real or simulated environments, under normal or disrupted conditions, and iii) analysis and characterization of the resulting system behavior;
- Definition of policies and models, and development of new technologies, in order to satisfy security requirements and privacy;
- Verification of behavioral properties of systems with stringent time constraints, by defining formal description techniques of system architecture and behavior and verification techniques based on model checking.

A particularity of our research is that it concerns the production process (system engineering approaches that give rise to the critical system) as well as the product itself. We address both the architectural aspects of the product as well as its validation approaches, including qualitative analysis and quantitative evaluation of the properties of the critical system. Also, system validation is ensured by both testing methods and formal verification techniques that cover the temporal aspects as well. Our research is based on conceptual work, but also heavily relies on experimental approaches and tools.

These various topics and aspects are addressed by several other groups (e.g., see IRISA, IRIT, LaBRI, CEA-LIST, TIMA, LRI, LIP6, CRAN, Vérimag, LSV ENS-Cachan, IRCCyN, LGI (Centrale-Paris), ESOE (Mines-Alès), U2IS (ENSTA-Paris)) but not with the same overall coverage. Internationally, we can mention by way of example, the Dependability Group at the University of Newcastle, UK, the Center for Reliable and High-performance Computing at the University of Illinois at Urbana-Champaign, US, the Software Science and Technology Lab at University of Florence and the Uppaal group at Aalborg and Uppsala, Department of Electrical Systems Engineering University of Pennsylvania, Arizona Center for Integrative Modeling & Simulation (ACIMS).

1.2 Organization and Life

To reach the above objectives, the theme is organized in three complementary teams:

- **Fault Tolerance and Dependable Computing**, TSF. The work of the team focuses on the dependability of computing systems, i.e., the ability to deliver a service that can be justifiably trusted. Dependability encompasses the properties of availability, reliability, integrity, confidentiality, maintainability, safety, as well as security. More precisely, the research of the team is best situated in the context of resilience, i.e., the persistence of dependability in the face of change. A strong characteristic of TSF research is the scope of the faults addressed: accidental faults (including physical and software faults) and malicious interaction faults, i.e., intrusions.
- **System Engineering and Integration**, ISI. The team research covers two main areas: systems engineering and system integration. System engineering addresses explicitly process engineering and requirement engineering, which includes the elicitation, analysis, verification and validation of requirements. System Integration focuses on the integration of models, levels of abstraction or heterogeneous components through simulation and prototyping for system validation.
- **VERification of TIme Critical Systems**, VERTICS. Formal description techniques constitute the research object of the team, addressing formal models, the associated model-checking techniques and the tools supporting them. The goal is to increase the expressiveness of formal techniques, in particular those handling temporal constraints, to improve the associated model-checking techniques, and to help integration of these formal techniques within the processes of systems engineering.

The three teams use a set of modeling techniques for system properties analysis and evaluation, such as Petri nets and model checking. These techniques are used either as support techniques for our research or as a research topic to be improved and extended.

1.2.1 Activity Profile

Table 1 hereafter depicts the activity profile for the IC Theme, composed of 22 EC and 12 CNRS researchers. It is worth to mention that the training activities include supervision of doctorate students.

Table 1: Activity Profile

%	Academic research	Interaction with environment	Research Support	Training
IC	45	10	15	30
TSF	50	10	10	30
ISI	45	10	15	30
VERTICS	35	20	20	25

1.2.2 Scientific Coordination

A Scientific Council, composed of representatives from the three teams and two representatives from the IDEA technical service, meets each month or two to discuss coordination matters. However, all meetings are open to all permanent staff. Coordination is also ensured at a more frequent basis by meetings between the Theme and Teams leaders as required. For example, the profiles for recruitment of new researchers are defined in agreement between the three teams.

All members are invited to participate in seminars in which doctorate students (of the three teams) of second year present their research results, as well as permanent staffs on topics interesting the whole theme. The dates are selected in such a way that a maximum number of attendees is ensured. We have also regular seminars given by distinguished invited externals.

In addition, each team has its own specific scientific coordination means such as meetings and seminars.

1.3 Salient Facts

The following examples provide some indicators that reflect the visibility and recognition of our research activities and members by the international community as well as in terms of innovation and dissemination of research results:

- Three patents with Airbus have been delivered, in the US, during the period[1].
- The TINA toolbox (Time Petri Net Analyzer) for analysis of Time Petri nets based models is continuously improved. To integrate our formal techniques into industrial engineering processes, we defined Fiacre as a higher level input language for TINA. Fiacre resulted from a joint effort with the INRIA/Vasy and IRIT/Acadie teams. Fiacre/TINA, matured in several academic and industrial projects, is now considered a reference verification engine by the real time systems verification community.
- We chaired the program committee of 5 major international conferences in our domain and organized 2 international conferences.
- Several awards obtained during the period (e.g., Grand Prize in Informatics of the French Academy of Sciences and IFIP TC-11 Kristian Beckman Award).

Considering the research topics addressed by IC, we can mention the following key facts:

- Reinforcement of our activities related to security and privacy protection and assessment, with a particular focus on low level attacks, of critical embedded systems and geolocated data.
- Implementation of a framework enabling the development of adaptable and resilient software systems, combining component-based software engineering techniques and reflective middleware.
- Particular attention has been focused on research challenges raised by model-based verification, testing and assessment activities, and on the efficient integration of these techniques within industrial system engineering processes.
- Our work on autonomously adapting systems, with the ROB Theme, has been very fruitful (2 European and 2 national projects).

[1] Patent numbers: US8239075 (B2), US8761969 (B2), US8805600 (B2)

2 Scientific Production

The systems of interest to us are embedded critical systems and large, networked, evolving systems, interconnecting servers, mobile computers, and embedded devices to form complex information infrastructures. The major issue at stake in such ubiquitous systems is how to maintain their dependability, i.e., their ability to deliver service that can justifiably be trusted, in spite of continuous changes. The changes to which ubiquitous systems are subjected can be functional, technological, or environmental, and may include or induce new threats.

Taking into account both our expertise and the likely applications of our work to the current and future resilient ubiquitous systems, we focus on four major challenges: *mobility*, *evolvability* and *autonomy*, *openness*, and *reactivity*.

We address these challenges from two complementary, and closely related, viewpoints:

- Architecture: design approaches, policies, algorithms, and mechanisms, for fault prevention and fault tolerance.
- Analysis: test, verification and evaluation techniques for fault removal and fault forecasting.

Erreur ! Source du renvoi introuvable. presents our research topics, structured according to the four identified challenges, and to the architecture and analysis viewpoints. The major achievements related to these topics are detailed in the remaining of this section.

A part of our work is carried out in the framework of the ADREAM strategic axis. In particular, we significantly contribute to the following scientific topics: formal development of mobile, adaptive and dependable systems, environments for system co-simulation and co-validation, security and privacy protection.

2.1 Mobility

Mobility has both negative and positive facets. On the negative side, mobility introduces new threats (e.g., sparse connectivity, wireless communication eavesdropping). On the positive side, the related notion of locality, when handled correctly, can be beneficial to system design. Both facets of mobility need to be studied in the context of resilient ubiquitous systems. In this context, anonymizing personal data is also a major challenge.

From the architecture viewpoint, our work mainly focuses on privacy protection considering geolocated data. It is noteworthy that in the period covered by this report, we have also addressed the more general problem related to the design of innovative technologies that are aimed at giving people control over their personal information, and preventing applications and devices from disclosing personal information without the consent of their users [RVSI09088, RVSI10270].

From the analysis viewpoint, we address: i) the development of geoprivacy assessment techniques considering the particular problem of deanonymization of geolocated data, ii) the modeling of interactions in a mobile context and iii) the development of testing.

Table 2: Research Topics Addressed

	Challenges			
	Mobility	Evolvability and Autonomy	Openness	Reactivity
Architecture	Geoprivacy protocols	Adaptability of fault tolerance software Defenses for autonomously-adapting systems	Virtualization and diversification Protection against I/O attacks	Online error detection HMI for reactive critical systems Fault tolerant architectures for reactive critical systems
Analysis	Geoprivacy assessment Modeling of interactions in a mobile context Testing mobile settings	Risk analysis for autonomously-adapting systems Testing of autonomous system software Testing of aspect-oriented software On-line evaluation of resilience	Assessment of security protection Embedded systems vulnerability analysis	Optimization of process and requirement engineering Simulation for system integration Bridging the gap between formal methods and industrial processes Modeling and verification of time critical systems Scaling up verification methods

2.1.1 Geoprivacy Protocols

The advent of ubiquitous devices and the growing development of location-based services have led to a large scale collection of individuals' mobility data on a daily basis. Among all the Personally Identifiable Information, learning the location of an individual is one of the major threats against privacy. In order to help location-based services developers to provide privacy-preserving applications, we propose the PROPS protocol, a PRivacy-preserving lOcation Proof System that allows a user to generate a proof of his location in a private way using neighboring nodes as witnesses [MAI12255]. The gathered proof can be used to anonymously prove his current or past location (see Figure 1).

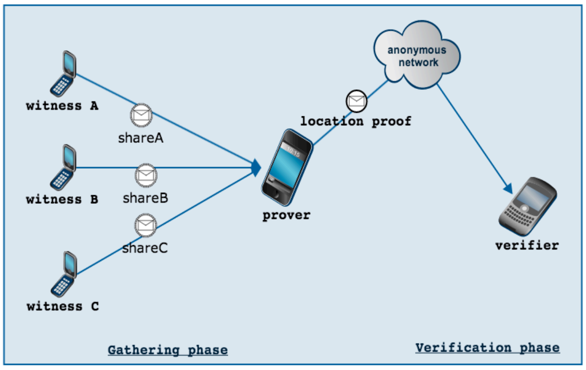


Figure 1: A Privacy-preserving Location Proof System

A secure location-based service requires that a mobile user certifies his position before gaining access to a particular resource. Currently, most of existing solutions assume a trusted third party that can vouch for the position claimed by a user. However, as computation and communication capacities become ubiquitous with the large-scale adoption of smart-phones by individuals, we propose to leverage on these resources to solve this issue in a collaborative and private manner. We have demonstrated that our protocol provides security properties such as the unforgeability and the non-transferability of the proofs, as well as resistance to classical attacks on such systems like mafia and terrorist frauds.

2.1.2 Assessment of Geoprivacy

Appropriate assessment techniques are needed to analyze the efficiency of geoprivacy protection protocols and mechanisms. We focus here on assessment via inference attacks.

From the movements of an individual it is possible to infer his Points Of Interest (POIs) (such as his home and place of work), to predict his past, current and future locations, or even to infer his social network. Furthermore, we advocate that a simple signature of one's mobility is enough to i) identify him and ii) learn most of this private information. We developed the Markov Mobility Chain mobility model (MMC) [RVSI11461], a probabilistic automaton, in which each state corresponds to one or several POIs, and an arc indicates a probabilistic transition between two states.

We proposed a wide range of inference attacks based on MMCs: next-place prediction [MAI12539], learning the semantics of mobility, de-anonymization. Via a de-anonymization attack [RVSI11461], an adversary tries to infer the identity of a particular individual behind a set of mobility traces. Experiments conducted on real datasets demonstrate that the attacks are both accurate and resilient to sanitization mechanisms such as downsampling. Moreover, we have developed GEPETO, for GEoPrivacy-Enhancing TOolkit, a flexible software that can be used to visualize, sanitize, perform various inference attacks and measure the utility of a particular geolocated dataset.

2.1.3 Modeling of Interactions in a Mobile Context

Simulating human-centered pervasive systems requires accurate assumptions on the behavior of human groups. Recent models consider this behavior as a combination of both social and spatial factors. Yet, establishing accurate traces of human groups is difficult: current techniques capture either positions, or contacts, with a limited accuracy. We developed two complementary solutions to capture human traces, enabling both coarse-grained and fine-grained analyses. For coarse-grain and large-scale traces, we developed an application for smartphones to log every spatial and interaction event reported during an experiment [MAI10141]. For fine-grain and small-scale traces, we introduced SOUK (Social Observation of hUman Kinetics) [MAI13262], a new technique to capture crowd behaviors. The interest of SOUK lies in the unprecedented accuracy at which both positions and orientations of humans, even gathered in a crowd, are captured. We also developed an open-source framework to analyze such behavioral traces, offering a layered approach that can be tailored, allowing comparison of and reasoning about models and traces.

2.1.4 Testing Mobile Settings

We have defined a passive testing approach for applications and services in mobile computing systems. The system under test is run in a simulated environment. Its execution traces are collected and automatically checked against key properties. To model the properties, we have developed a graphical scenario language, called TERMOS, representing interactions in mobile settings (Figure 2). TERMOS is a formal language based on UML Sequence Diagrams. Various verification artifacts (positive and negative requirements, test purposes) can be specified and then used for checking the traces. A scenario contains two views: (i) a spatial view, depicting the dynamically changing topology of system nodes as a sequence of graphs, and (ii) an event view representing the communications between nodes. The checking of traces against scenarios then combines graph matching and event order analysis. The graph matching part searches for occurrences of the target sequence of spatial configurations [MAI08714], with some optimization for the average case [MAI13063]. Event order analysis relies on an automaton-based semantics of sequence diagrams [MAI10520], which was defined based on a review of alternative semantics [RVSI09550]. TERMOS has been integrated into UML support technology [MAI13063].

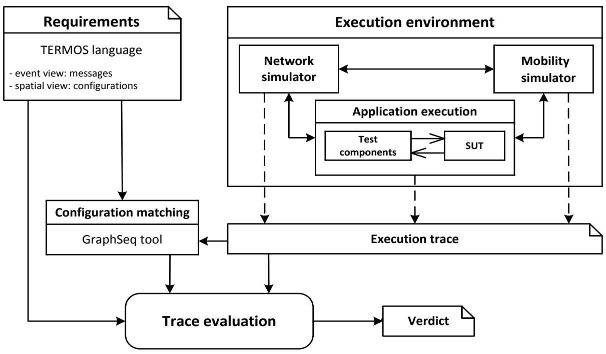


Figure 2: Checking a Trace against a TERMOS Scenario

A profile has been developed for the editing of scenarios, as well as an Eclipse plugin for the automated checking of traces. We have demonstrated the approach on a case study, a group membership protocol in ad hoc networks.

2.2 Evolvability and Autonomy

Evolution during service life is a requirement, particularly for long-lived systems. Dependable systems, which continuously deliver trustworthy services, must exhibit a high degree of evolvability and autonomy to accommodate changes, e.g., new threats or variations in available resources. To this end, we need to develop new theories and methods for describing, designing and analyzing dependable self-organizing and self-adapting systems.

2.2.1 Adaptability of Fault Tolerance Software

The adaptation of software systems is essential to implement resilient computing, in particular when targeting fault tolerance software. We leverage component-based software engineering techniques and reflective middleware to implement resilient computing systems. We proposed a development process and a middleware (MARACAS) for enabling fine-grained runtime transitions between fault tolerance mechanisms (FTMs) that minimize the impact on the overall software architecture [MAI12301]. The process comprises four milestones: i) the identification of change criteria (application assumptions, resources, fault model) with an impact on FTM selection, ii) a design for adaptation approach revealing the variable features of these FTMs and their common parts, iii) the mapping of this fine-grained design on a reflective component-based middleware providing the necessary runtime control features, and iv) the implementation of fine-grained transitions between FTMs on the FraSCAti reflective component-based middleware developed at INRIA.

Adaptation is a real challenge today also in automotive embedded systems, to improve the manufacturing process, the maintenance, the selection of the software options after shipment, etc. Architectural standards in automotive systems (like AUTOSAR) impose a static and frozen architecture, and thus disable by design any further update. Our objective is to tackle the problem of safe incremental software updates in the context of embedded automotive systems. On-line adaptation allows the inclusion of new functionalities in an efficient way, without restarting the full validation and uploading procedure. A deep analysis of AUTOSAR led us to extract relevant features to precisely define the notion of "containers" as a placeholder for dynamic updates [MAI14411]. Then, we have defined a tool-based approach for enabling these updates, and provided an evaluation of our approach on a classical RISC micro controller.

Our current work includes the addition of FTMs to ensure a correct behavior of the system in the presence of faults, and the evaluation of our approach on a case study from Renault Automotive (Figure 3).

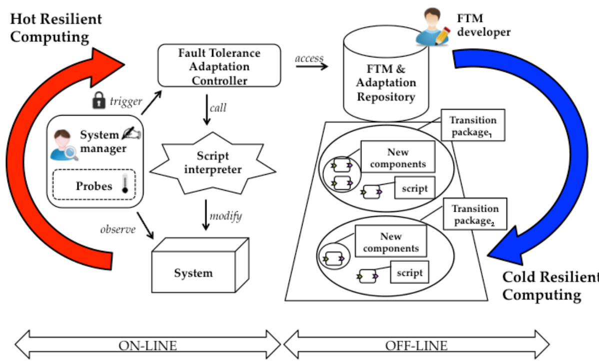


Figure 3: FTM Adaptation Process

2.2.2 Defenses for Autonomously-Adapting Systems

Autonomous systems have to cope with various execution environments while guaranteeing safety, and in particular when they interact with humans, as is the case for robotic systems. Such critical systems are difficult to validate due to their high complexity and the fact that they operate within complex, variable and uncertain environments in which it is difficult to predict all possible system behaviors. As a result, autonomous systems have to be equipped with means for context-dependent safety enforcement. We consider here a device called a safety monitor, which has access to the necessary means for context observation (i.e., sensors) and is able to trigger, when necessary, appropriate safety enforcement.

We have addressed the process for eliciting safety rules that will be checked by a safety monitor during operation, considering the system as a black box [MAI12517] (Figure 4). The proposed process is based on safety constraints identified through a hazard analysis using HAZOP-UML. The constraints are formalized and analyzed to identify safety rules. We distinguish initiative rules and restriction rules [MAI13261]. An initiative rule launches an action to change the state, when it has been detected that the system has entered a warning (or safety margin) state. On the contrary, a restriction rule inhibits certain state changes, e.g., by means of an interlock device or by request filtering. This systematic process is based on graphs and formal logic to determine safety margins and possible rules.

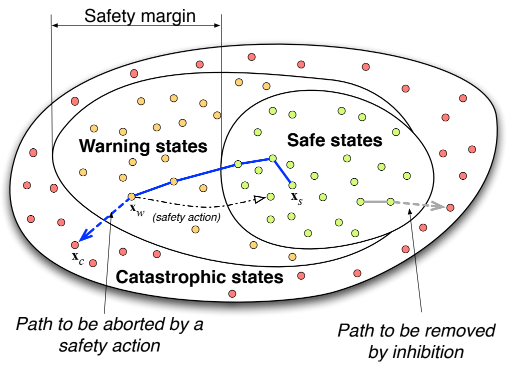


Figure 4: Conceptual Model for Safety Monitoring

We have also investigated the case when the system can be considered as a white box. The safety requirements are defined in a safety monitor that can control the internal behavior of the system. Formally, the symbols of the automaton implementing the monitor (Â) are transitions of the automaton (A) defining the controlled system [XMA134]. An operator composing A and Â allows a safe behavior of the system to be obtained [MAI101006]. This approach facilitates the expression of complex safety rules. It can be used to implement a functional safety approach (IEC 61508) [MAI11896].

2.2.3 Risk Analysis for Autonomously-Adapting Systems

Recent advances in robotics technologies have opened multiple opportunities for the use of autonomous systems in contact with humans to support various activities of our daily life. In such contexts, it is crucial to identify potential threats related to physical interactions between system and human and to assess the associated risks that might affect safety and reliability. Because of the complexity of human-system interactions, rigorous and systematic approaches are needed to assist the developers in: i) the identification of significant threats and the implementation of efficient protection mechanisms to cope with these threats, and ii) the elaboration of a sound argumentation to justify the level of safety that can be achieved by the system. The risk analysis method HAZOP-UML that we have developed is a guided method to identify potential occurrences of harm, their causes and their severity [MAI10785]. The results from risk analysis are then used as input to build an argumentation about system safety, using a modeling language for safety cases (Goal Structuring Notation) [MAI13218]. These approaches have been experimented and successfully applied on real case studies in a European Project (FP7-PHRIENDS) and a national project (ANR-MIRAS).

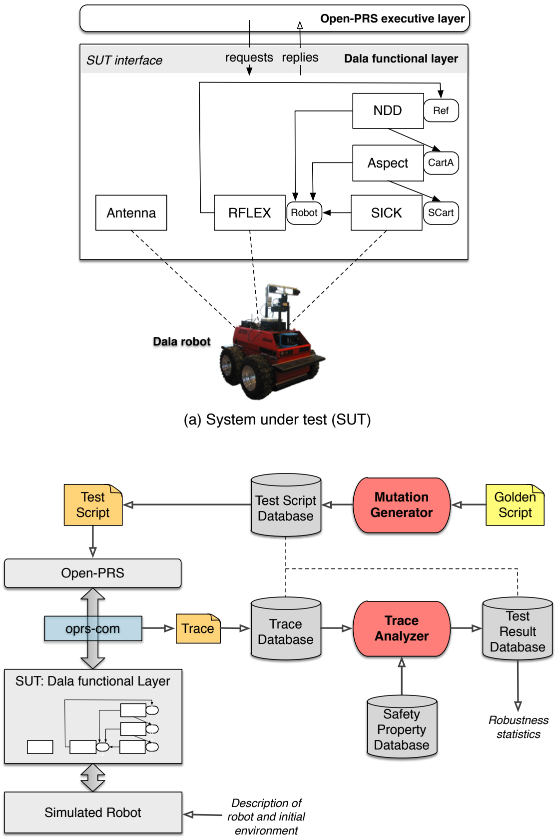
2.2.4 Testing of Autonomous System Software

Software architectures for autonomous systems such as robots are typically structured in layers. Upper layers operate at high levels of abstraction and real-time granularity to carry out, for example, long-term planning of activities to reach user-specified goals. The lowest layer, usually called the functional layer, is typically required to carry out multiple hard real-time control activities in parallel. These activities are launched by asynchronous calls from clients situated at the upper layers, so there is a need for the functional layer to provide built-in protection to ensure that it is robust with respect to requests that are issued at instants that are incompatible with its current state and could therefore cause the system to fail. We have developed a hybrid black-box testing approach to assess the robustness provided by such protection mechanisms [MAI12100]. Test cases are generated by random mutation of a valid sequence of requests. Test verdicts are obtained by a set of property-based robustness oracles applied to a logged trace of requests and responses. The approach has been applied successfully in the context of the DALA experimental planetary explorer robot (Figure 5).

2.2.5 Testing of Aspect-oriented Software

Aspect-oriented programming (AOP) is one of the means for separation of concerns. For example, non-functional concerns such as fault tolerance can be implemented in separate components and then woven into the application code.

Our work uses AOP to develop micro-aspects that can be combined to realize a given fault tolerance mechanism. The toolbox of micro-aspects also makes mechanisms easily reconfigurable at a fine grain. However, the composed micro-aspects may exhibit undesirable interactions and side effects, called interferences. We have developed an approach to detect interferences with executable assertions [MAI12607], based on an existing extension of AspectJ. The AIRIA extension offers a *Resolver* operator to precisely control the composition of conflicting aspects.



(a) System under test (SUT)

(b) Hybrid robustness testing environment

Figure 5: Robustness Testing of Dala Rover Functional Layer

It also adds observation points that are lacking in AspectJ, making it possible to automatically instrument the code to detect various types of interferences during testing (including both control- and data-flow interferences). We have demonstrated the micro-aspects development and instrumentation approach on a case study, involving a Primary-Backup replication protocol [MAI13255]. The micro-aspects facilitate reconfigurations from passive to active replication, as well as the introduction of new mechanisms (e.g., an authentication mechanism). Non-interference properties attached to the micro-aspects allow us to automatically produce the assertion-checking code. Four integration faults have been successfully detected during the development of the case study, two genuine ones and two introduced ones.

2.2.6 On-line Evaluation of Resilience

Evolvability of systems during operation raises some challenges with respect to the assessment of their dependability. Usually, dependability assessment is carried only once out during system design, in order to define an appropriate system architecture satisfying the system dependability requirements. When in operation, the success of a mission is subject to the fulfillment of specific operational requirements that should be satisfied, even in the presence of faults. Indeed, during a mission, the effects of some failures can be very severe if they are not anticipated. Using dependability assessment during system operation could be very helpful to anticipate and avoid system failure (or mission interruption). To this end, we have developed a modeling approach, based on a meta-model used to i) structure the information needed to assess operational reliability, and to ii) build a stochastic model to be tuned dynamically to take into account the system operational state, the mission profile and the maintenance facilities [RVSI12689]. This model allows to i) assess, on-the-fly, the ability to succeed in continuing on the remaining part of the mission, in case of an unscheduled event occurrence, and to ii) support maintenance planning. The main challenge comes from the fact that the model is to be tuned, in operation, by operators who do not have any knowledge of dependability modeling techniques. Hence the model should be built and validated off-line in a way that makes it easily and very quickly configurable in operation. A case study, based on an aircraft subsystem, is considered for illustration, using the Stochastic Activity Networks formalism. It shows how to re-schedule a mission, based on the failed component and its impact on the remaining part of the mission, as well as the maintenance possibilities at the various stops of the aircraft [MAI12474].

2.3 Openness

The need for interoperability with multiple systems and multiple stakeholders is fuelling a trend for increased openness, even for embedded systems. The attendant risks of malicious attack require architectures able to provide adequate protection and analysis techniques for assessing their effectiveness.

Our work at the architecture level focuses on protection against I/O attacks and the use of virtualization and diversification for securing operating system kernels. From the analysis viewpoint, we address the development of experimental methods aimed at the analysis of vulnerabilities and the assessment of security protection mechanisms considering various types of target systems, including web based applications, cloud infrastructures and embedded systems for different application domains (avionics, automotive, etc.). These research topics are complemented by: i) the characterization of Internet malicious activities based on the collection and analysis of real-life attack data using high-interaction honeypots [RVSI09062], and ii) the development of probabilistic modeling approaches aimed at evaluating quantitative security metrics to help the system designers in the assessment of vulnerability exploitation risks [RVSI11020].

2.3.1 Virtualization and Diversification

Virtualization technologies allow multiple virtual machines to be executed on a single physical machine. Virtual machine access to hardware resources is controlled by a virtual machine manager, also called a hypervisor. Today, these technologies are primarily used to reduce the costs of computing systems by mutualizing the use of hardware and software resources. Virtualization can affect computer security both positively or negatively. On the positive side, we have used virtualization to apply diversity in critical computing systems at the level of operating systems [RVSI06333, RVSI09461]. We make the assumption that an attack succeeds if it reaches a particular version of software on a particular version of the operating system. We have designed an architecture that is able to diversify the runtime environment of an application with different virtual machines running different operating systems. This approach has been applied to avionics maintenance laptops [MAI09210]. Virtualization can also have negative effect on computing system security, in particular if the hypervisor is compromised. To detect hypervisor compromise, we are developing an approach based on nested virtualization to observe the state of the hypervisor [MAN14287]. Our new minimalist virtualization layer is below the original hypervisor and it checks periodically whether the invariants of the hypervisor state are still valid. This architecture is studied in the context of cloud computing, in which some virtual machines can be malicious and may try to attack the other virtual machines through the hypervisor.

2.3.2 Protection against I/O Attacks

Nowadays, most malware consists in code executed by the victim's CPU, either with user privilege (e.g., code hidden in maliciously crafted web pages) or with supervisor privilege (e.g., rootkits). Efficient counter-measures can be developed against this kind of malware, since they can be detected either by observing the CPU behavior or the induced modifications in main memory. More recently, a new class of attacks has appeared, which defeat these countermeasures because they do not depend on code run by the CPU. This class of attacks includes the so-called *Input/Output* attacks, in which attackers divert legitimate hardware features, such as I/O mechanisms, to achieve different malicious actions. We have analyzed these attacks to propose countermeasures based mainly on reliable hardware components that cannot be circumvented [MAI10447, RVSI12640].

Our research focused on two cases: hardware components that are deliberately designed to act maliciously, in the same way as a program incorporating a Trojan; and vulnerable hardware components that have been modified by a hacker, either locally or through the network, to include malicious functions (typically a backdoor in the firmware). To identify I/O attacks, we defined an attack model that describes a computer system behavior at different abstraction levels. We studied these attacks with two complementary approaches: classical vulnerability analysis consisting in identifying a vulnerability, developing proof-of-concept and proposing counter-measures; and fuzzing-based vulnerability analysis, using IronHide, a fault injection tool we have developed, which is able to simulate a powerful malicious hardware [RVSI12640] (Figure 6).

2.3.3 Assessment of Security Protection

Our research is aimed at the development of systematic experimental methodologies for the evaluation of the effectiveness of security mechanisms, such as intrusion detection systems (IDS). Our investigation is focused on two main contexts that have become increasingly prone to vulnerabilities: web based applications and Cloud-based infrastructures.

Considering web applications, we have developed a methodology to automatically identify and exploit residual vulnerabilities, based on a black-box approach [RVSI14077]. This methodology is also used to generate attack scenarios, including those exploiting several vulnerabilities that may not be independent.

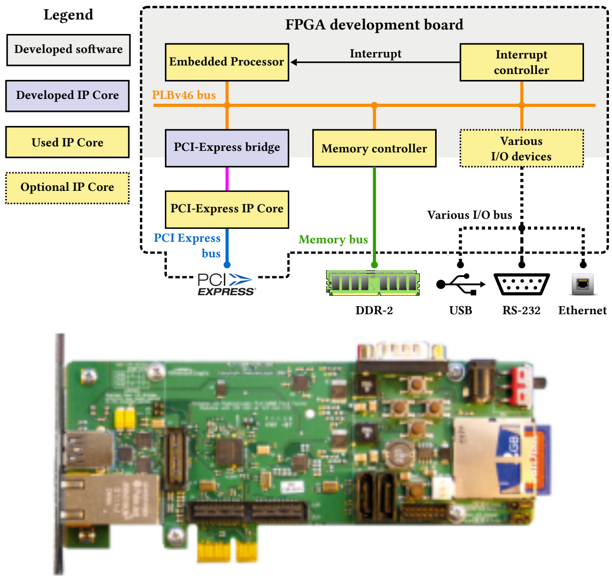


Figure 6: IronHide Architecture and Prototype

These attack scenarios can then be used to assess the effectiveness of IDS that are designed to detect such attacks. A main concern is the exploitation of code injection vulnerabilities, such as SQL injections. To support this methodology, we have developed a web vulnerability scanner called Wasapy (Web Applications Security Assessment in Python), which has been validated experimentally on typical examples of vulnerable applications [MAI11343]. Wasapy has also been used to assess two IDS techniques developed within the ANR project DALI [RVSI14335].

Our current work is to extend these results to the particular context of Infrastructure-as-a-Service (IaaS) Cloud computing environments. The security mechanisms to assess are the access control means and the intrusion detection and prevention systems that are deployed in the Cloud [MAI13622]. Our objective is to conduct automated security evaluations and analyses that are able to give i) the client a detailed picture of the risks he takes by using the Cloud, and ii) the IaaS provider a good insight into the threats that a client may represent for the infrastructure.

2.3.4 Embedded Systems Vulnerability Analysis

Vulnerability analysis in low level software has been applied for a long time to traditional computer systems (such as desktop computers) but only recently to some critical embedded systems such as real-time avionics on-board computers or Electronic Control Units (ECUs) embedded in most modern vehicles. Such vulnerability analysis is justified by the current trend regarding software development and integration in such industrial domains: reduction of costs, increasing use of COTS software, increasing connectivity of the critical embedded systems to other untrusted systems. Our research is aimed at developing a *Security for Safety* approach in order to identify potential vulnerabilities whose exploitation could have serious consequences on the safety of critical embedded systems such as in aircrafts or cars. The proposed approach includes two parts. The first one aims to identify classes of vulnerabilities that affect the targeted system. The second part provides a methodology for the analysis of these vulnerabilities while the development is pending. As an example, we have defined a taxonomy of attacks for aerospace onboard systems distinguishing two main classes targeting either the computing system core functions or the fault tolerance mechanisms [RVSI12527].

A similar approach is investigated to support vulnerability analysis in home-network equipment connected to the Internet. In particular, we are currently analyzing and comparing the security mechanisms implemented in French ADSL boxes [MAN14062].

These studies are carried out jointly with Airbus, Renault and Thales.

2.4 Reactivity

Our research on architecture for dependable reactive systems covers the definition of online monitors to verify real-time system related properties, and the development of innovative fault-tolerant architectures dedicated to Human Machine Interfaces (HMI) and distributed control systems.

With regards to analysis, our research focuses on:

- System engineering and integration: optimization of process and requirement engineering approaches, and simulation approaches for system integration.
- Improving the applicability and acceptance of our research outcomes by the industrial developers of critical systems.
- Extension of formal verification approaches to address time critical systems, and to scale them up.

2.4.1 Online Error Detection

Detection of violations of system specifications at run-time enforces dependability, since it may be used as a trigger for possible recovery actions. We focused on run-time monitoring of system properties that include both causality and timing constraints, in distributed and time-constrained systems. Based on a description of a property that includes events and temporal constraints, expressed as a timed-edge Petri net, we developed an automated transformation that translates it into an executable and distributed monitoring engine.

We introduced a modification of the semantics of Petri nets [AFF12214, MAI13731] to be able to execute it online on partial executions and distributed observation environments. Based on this formal framework we developed Minotor [MAI13731], a model-driven distributed monitoring system, that is able to express advanced specifications that describe several system operation modes, i.e., nominal mode, warning mode and degraded mode.

The synthesis of the monitoring engine from the specification results in a lightweight and fully distributed program that is integrated with the system to be monitored. Hence, our approach is not limited to control-and-command systems, and we are investigating its integration into a wireless sensor network application.

2.4.2 HMI for Reactive Critical Systems

The deployment of higher interactivity in digital cockpits for critical applications (in particular in avionics) is a challenge today both in terms of software engineering and fault tolerance. Although glass cockpit HMIs have been largely developed for non-critical functions in modern aircraft, critical functions are still implemented today with conventional means (e.g., analog switches, buttons, knobs). The challenge is to develop highly dependable HMI for critical command and control functions. The work is based on the ARINC661 standard that specifies the HMI items format and behavior (widgets, layers and other concepts).

Our work focuses on proposing an approach combining fault prevention and fault tolerance techniques to address this challenge [MAI11547, RVSI12606]. Fault prevention is ensured by a model-based development of the interactive software (following the ARINC 661 standard) aiming at providing as much as possible zero-defect software. Regarding remaining software faults in the underlying runtime support and also physical faults, the approach is based on fault tolerance design patterns, like self-checking components and replication techniques. The first objective is to formally define the properties of ARINC661 widgets composition to monitor at runtime. The implementation relies on the space and time partitioning provided by the IMA executive support following the ARINC 653 standard. To validate our approach, we developed an ARINC 653 OS simulator running on a Linux platform, on top of which we will implement our self-checking HMI architecture. Designing resilient interactive cockpits is a necessity in the near future as these command and control systems provide a great opportunity to improve maintenance, evolvability and usability of long living avionic systems. This work is done in close collaboration with IRIT.

2.4.3 Fault Tolerant Architectures for Reactive Critical Systems

Recent advances in digital networks and smart sensors and actuators offer new opportunities for the development of innovative fault tolerant architectures for critical control systems that have to satisfy hard dependability, performance and cost reduction requirements. The main issue is to take advantage of the increasing computing capabilities at the sensors and actuators levels to achieve an optimal distribution of systems functionalities and fault tolerance mechanisms among computers and actuators.

We have investigated this problem in the context of Flight Control Systems (FCS). We proposed distributed and reconfigurable architectures that break with the traditional COM/MON centralized-federated architectures where specific fault-tolerant computers perform all processing. The new alternative FCS architectures [TH10414, MAI09657] are based on: simplex computers, distribution of system functionalities between computers and actuators, less hardware and software resources while meeting the same level of safety and availability requirements (or even better) as in the prior art.

Two architectures have been investigated - the Massive Voting (Figure 7) and the Priority voting architectures - validated through respectively OCAS/AltaRica (for safety requirements) and Matlab/Simulink simulations (for robustness requirements). This work was carried out with Airbus-France.

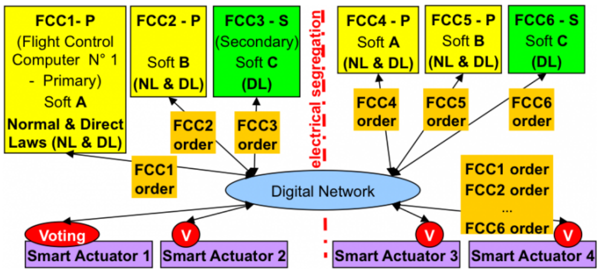


Figure 7: Massive Voting Architecture

2.4.4 Optimization of Process and Requirement Engineering

Work on process engineering is based on System Engineering (SE) standards: EIA-632, ISO/IEC-15288, IEEE-1220, SEBOK (Systems Engineering Body Of Knowledge), SE hand-book, and project management standards: PMBOK (Project Management Body Of Knowledge), ISO-21500. We are motivated by the emerging industrial concern that is basing implementation of collaborative engineering techniques on methods and tools to conduct the development process of a product rather than targeting the sole product technical development.

In this context, part of the work consisted of analyzing standards merging [MAI13393] with the objective of harmonizing definitions and concepts, as well as integrating practices. Our findings lead us to make the choice of the ISO standard for SE and PMBOK (or ISO) for Project Management (PM).

We also developed approaches that take in consideration decision helper components in order to promote joint decisions between product engineering processes (technical design choices, performance, etc.) and project management (resource allocation, budget, time management, partners choice, etc.) all along the project [RVSI10955]. To that extent, we compared two approaches: i) an exact one (decision support using constraint propagation), ii) an heuristic one (search for best compromise using an optimization based on multiple criterion). This work has led to proposals of both methods and computer tools (GESOS, “Genetic Evaluation, Selection & Optimization of Scenarios”, a tool based on an evolutionary algorithm implementation and its variants) and a COFIADE (tool developed by *École des Mines d'Albi*) version extended to constraints and project management. A comparison was used to evaluate these approaches and validate their results.

The above work represented a first step towards the definition of a comprehensive approach and a monitoring and decision support tool aimed at helping the product development process. These tools are in the ongoing move of RNTL ATLAS project, and preluded the development of new collaborations (*Université de Lorraine, Ecole des Mines d'Alès*).

We also focus on **requirements engineering** within a system engineering framework (SE), based on an appropriate combination of methods and tools, made possible through use of a suitable methodological process and system management procedures. We distinguish three levels in SE:

- The third level, SE processes, focuses on high level issues: high-level requirements as business needs and strategic needs, and methods.
- The second level, SE methods, deals with all technical issues as systems requirements design methodologies standards.
- The first level, SE tools or technologies, covers the implementation issues concerning the tools to be used, and the required technologies to respond to the various assets of requirements such as reliability costs, maintainability, enabling technologies [RVSI12021].

Based upon these principles, and in collaboration with Latécoère, we defined a methodology aiming at facilitating the adoption of a system approach that can be common to aero-structures and embedded electronics aspects. It has been implemented using a set of technical processes and methods for:

- Requirement modeling.
- Technical solution modeling.
- Formalization of intermediate elements of integration, validation, evaluation and design analyses, using an engineering model approach [TH10177].
- In another context, we developed a method for automatic consideration of safety operating requirements, consistent with SE standards. This method is based on decomposing a complex system into various subsystems. It requires the description of the system, its function, its architecture, its subsystems and their functions. From these, the method combines FMECA (Failure Mode and Effect Analysis) and fault trees to define operating safety requirements of the system and their local requirements variations [RVSI11297]. The different steps of the method are presented in Figure 8.

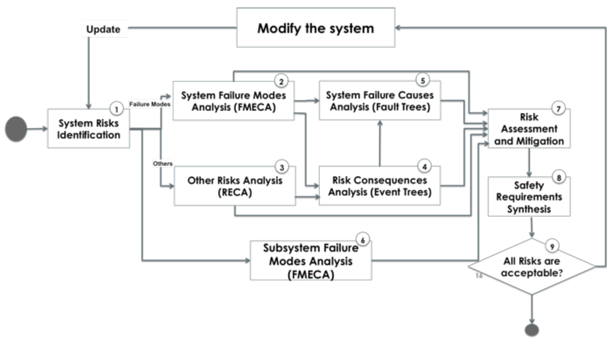


Figure 8: A Method for Safety Requirements Management

We also developed a system design methodology consisting in modeling the system using SysML, which model is then entered in HiLeS tool (High Level System designer, a module integrated within SysEngLab). This module allows formal verification using TINA, as well as generation of a VHDL-AMS prototype that led to a behavioral simulation verification of the system. This design methodology ensures that the initial requirements are met in the final solution, before its actual implementation. An example was developed using that methodology for ATLAS ANR project.

2.4.5 Simulation for System Integration

Our methods and approaches aim at reducing simulation duration as well as giving some confidence in the simulation results. We strongly recommend, when possible, to include a formal verification phase (e.g. based on model checking) and a unit test before the actual simulation. In addition, we combine formal verification with simulation on the following items.

Method: parallel product of environment model and system model. We globally handle two models: one from experimental framework, and one from simulation. We perform a parallel product in order to obtain a model taking into consideration the restrictions indicated by the simulation aims [MAI13230].

Component and model-based approach. This approach is based on a composition algebra matching Petri nets. Indeed, from a structural point of view, components are seen as Petri net's places. This enables composition of various kinds: sequential, parallel, synchronized, rendezvous, etc. Using Petri nets formalism enables us to grant conservation for some properties. As an example, we focused on well-formed Petri nets. Otherwise, this component-based approach allows us for treating one or various models using interfaces, and we used the existing theoretical knowledge in this field.

Meta-model-based approach, for simulation concepts formalization, and structuring. The environmental modeling is used to set up a meta-model-based approach implemented by the definition of a simulation profile. This profile includes simulation specification, i.e., simulation context and objectives. In other terms, this meta-model based approach enables structuring and formalizing the above simulation concepts when attempting to evaluate the identified metrics. Simulation specification is an important step that is frequently ignored by simulation users, yet it is a mandatory step when defining models abstraction level.

Metrics extraction and coverage analysis of induced model using traces inclusion. Our work on metrics is divided in two phases: i) identifying the metrics that match the simulation evaluation, and ii) developing these approaches in order to bring out these metrics.

Co-simulation. Sometimes, two models composing a design are developed based on different formalisms. Simulating a system using heterogeneous formalisms can be done in two ways: either transform them into a single formalism, or connect the various simulators between them. We chose this second way. Using the component approach, we set up a multilevel co-simulation tool for virtual prototyping [MAI12532]. We thus allow connection of models using different languages by connecting the simulator tools themselves. In Figure 9, we show the interaction between the different levels and type of models and the associated simulators, with the objective of simulation validation. It also shows an example of co-simulation.

2.4.6 Bridging the Gap between Formal Methods and Industrial Processes

A key goal underlying our work on verification is to improve practical applicability and acceptance of our research outcomes by the industrial developers of critical systems. To this end, we always take care of associating our theoretical research results with tool developments making their use possible by non-experts. One of our major contributions is the tool line articulated around the TINA toolbox, allowing the analysis of Time Petri nets based models and their verification by model-checking.

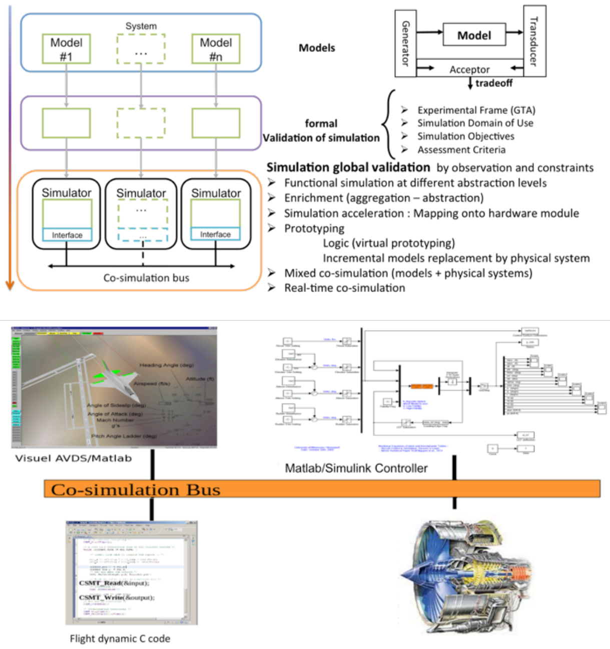


Figure 9: Co-simulation - Validation & Prototyping

The integration of formal methods in industrial processes is often hampered by the expressiveness gap between formal methods and the notations used in industry, and by the poor scalability of some formal methods. The improvement of scalability is addressed in Section 2.4.8. The expressiveness gap calls for domain-specific languages that can be used as front-end, user-level notations, and for common intermediate formalisms that establish gateways between tool platforms. These issues are addressed through the following research actions, for the most part carried out in collaborative projects.

Fiacre: A formal language designed as an intermediate formal description between low-level verification formalisms and user-level notations. The Fiacre language is expressive enough for being used as the target language of model transformation engines from various user models such as SDL, UML, AADL, yet formal enough to be faithfully translated into the source formalisms of verification toolboxes like CADP and TINA in the first step. Fiacre also provides a property layer for expressing real-time properties of Fiacre descriptions. This language relies on patterns that are most commonly used in practice in industry and academia. It has the benefit of being quickly understandable by non-experts, so that no prior knowledge of temporal logics is required. Furthermore, this property language is timed, allowing designers to easily express time constraints on their Fiacre models [TH12749, RSVI11687]. Fiacre, and its compiler to TINA models, is our main vehicle for providing verification capabilities to the description languages used in industry; it was designed jointly with the teams IRIT/Acadie and INRIA/Vasy in the framework of the TOPCASED project dealing with model-driven engineering, that gathered numerous partners, from both industry and academia.

Pola: A Domain Specific Language (DSL) designed to describe scheduling policies and resource constraints for real-time systems. A compiler translates these descriptions into Time Petri net and associated logical formulas [MAI09388, TH10134, RSVI11688] for the TINA model checkers. Pola allows users to check real-time systems validity without any prerequisite knowledge on how it is actually accomplished.

STELAE: A model-driven test development environment that addresses the issue of multiplicity of in-house test languages to develop test code for embedded systems, with no standard emerging. Using STELAE, test models are developed and maintained in place of code, with model-to-code transformations towards target test implementation languages. Our work started by the analysis of proprietary test languages currently deployed in the avionic domain. It allowed us to identify the domain-specific concepts, best practices, as well as pitfalls to avoid. We then defined a meta-model in EMF Ecore that formalizes and integrates all identified concepts and their relations [MAI12369]. The meta-model was the basis for demonstrating the use of model-driven technologies in the development of tests. The STELAE demonstrator includes customizable graphical and textual editors for test models, checkers, and finally template-based transformations towards code executable on top of a real industrial test platform [MAI13060].

Verification support for AADL: AADL is an architecture description language that describes both the hardware and software components of a system. A key extension to this standard is the Behavioral Annex that has been added for describing precisely thread activities. With the collaboration of IRIT/Acadie, we investigated a verification path for AADL enriched with its behavioral annex, making use of Fiacre as an intermediate language, and relying on TINA for verification. This work [MAI101010] has been matured in projects SPICES (ITEA-2) and Quarteft (FNRAE) and was ultimately integrated in an AADL toolchain around ADELE, Ellidis' semantic editor for the elaboration of AADL models.

Support for debugging Scade and Simulink models: The main challenge addressed in this context is to locate faults that caused property violation, when a lengthy counterexample is returned by a model checker. We addressed this issue in the framework of Scade or Simulink data-flow models [MAI10257]. The approach is based on a structural analysis that identifies paths of the model that are activated by a counterexample over time. This analysis allows the extraction of relevant information to explain the observed violation. It may also serve to guide the model checker toward the search for different counterexamples, exhibiting new path activation patterns and thus new ways to violate the property. The aim is to give engineers as much usable feedback as possible before a fix is attempted. The approach has been implemented in a tool called STANCE (Structural ANalysis of CounterExamples).

ProDEVS: We have defined and developed, ProDEVS, a modeling and simulation environment for safety critical system that is integrated within SysEngLab. ProDEVS is based on discrete-event simulation theory and DEVS (Discrete-EVent Specification) formalism. DEVS is component-based and can easily include continuous dynamics for hybrid modeling and simulation. ProDEVS defines a DSL that specializes the UML State Machine for building, animating and simulating graphical DEVS formal specification. It allows creation of trajectory visualization, with just a few clicks. It provides an easy navigation within the decomposition levels of the model, and allows simulating the model at different abstraction levels. The advantage of ProDEVS with respect to DEVS is to be graphical, which does not require specific knowledge of the underlying programming language. Two simulation algorithms are available: classic or parallel. In classic simulation only one event at a time can occur. In parallel simulation, more than one event can be received by a component at the same time. In that case the receiver component chooses randomly an event to execute. A parallel simulation is useful for simulation of distributed architectures. ProDEVS uses Fiacre and TINA to explore all the trajectories of a model and to check simulation properties e.g., the precision of a numerical integration. ProDEVS supports co-simulation so that it is easy to simulate a discrete controller using ProDEVS and to simulate the physical environment using for instance, Modelica or Matlab.

2.4.7 Modeling and Verification of Time Critical Systems

Compositionality of timed Petri Nets models: It is well known that Petri nets allow component based modeling, that is, smaller subsystems can be combined together to form a larger system. On the contrary, Time Petri Nets (TPNs) are not trivially compositional, because fusion of the temporal information of transitions must be taken into account. We propose an extension of TPNs that allows one to easily move time information out of the synchronized transitions. Hence, composition remains traditional, while the new relations introduced between transitions (the forbid and allow relations) allow one to fine tune time constraints. The compiler for the Pola domain-specific language [RSVI11687] takes advantage of the technique. The state space exploration tools of the TINA toolbox have been extended to handle such relations.

Timed model checking: Verification of timed temporal logics formulae is notoriously difficult. Instead, we verify timed patterns on real-time models by grafting observers to these models, reducing the verification of timed properties to the verification of simple, untimed, LTL formula on an enriched model. We have considered different classes of observers for each pattern and used a pragmatic approach in order to select the most efficient candidate in practice, in terms of verification time and system size growth [RSVI14038]. Additionally, we have defined a formal framework to verify that our observers are sound and non-intrusive, meaning that they compute the correct answer and have no impact on the system under observation. This framework is not only useful for proving the validity of formal results but also for checking the soundness of optimizations in the implementation. We use this theoretical proof method for checking the correctness of our best “candidates”.

Critical embedded systems: Verification and validation of timing properties is extremely important during the design of critical embedded systems. One major difficulty is to consider dynamic scheduling. We propose some new tools to help during the design phase such as to guarantee the timing behavior. We based our approach on Pola and Fiacre to check schedulability properties from a high level model (AADL, MCSE, UML, etc.) of the systems and developed new algorithms to generate correct systems' configuration [RSVI11688].

Multicore scheduling: New perspectives have arisen with the availability of multicore hardware architectures for critical embedded systems: a considerable increase of the processor performance, and an obvious economic interest because of the decreasing number of the embedded hardware components. However, it also brings many scientific problems. For instance, validate and verify the schedulability, i.e., the satisfaction of the time constraints, of embedded applications on multicore architectures is a difficult problem.

Our studies on multicore scheduling are focused on the evaluation of performance of scheduler algorithms and their impact on schedulability. A simulation tool, called SimSo [MAI12495], was designed to account for the specificities of the system, starting with LRU caches, context-save/load overheads and scheduling overhead. For that, we extend classical task model to add enough information to characterize how the tasks access memory. This allows us to use statistical models to calculate the cache miss rates and to deduce job execution times.

2.4.8 Scaling up Verification Methods

This research topic aims at improving scalability of verification techniques, including both model-checking and testing techniques. From the model checking side, scalability is improved by proposing verification methods taking advantage of modern multi-core architectures, improving the space and time performances of verification tools, and studying verification techniques that take advantage of structural properties of models, like symmetries or reductions. From the testing side, we explore automated test generation techniques combining optimization metaheuristics and probabilistic sampling.

Improving speed - Parallel model checking: New algorithms and data structures for exhaustive parallel model checking that are as efficient as possible have been considered. This includes both the construction of the state space as the detection of cycles in parallel, which is one of the key points of performance for the evaluation of complex formulas [TH11835, MAI12400].

Alongside the definition of enumerative, model checking algorithms for many-cores architectures, we have studied probabilistic verification algorithms. Probabilistic verification trades savings at the level of memory usage for the probability of missing some states. Consequently, it becomes possible to analyze part of the system state space when there is not enough memory available to represent the entire state space.

Decreasing memory usage - Space efficient verification techniques: More than by computing time, verification techniques are limited by their storage requirements. Several space saving techniques have been investigated and evaluated for integration in future versions of the TINA toolbox.

The so-called *Symbolic exploration methods* are known adequate to master the complexity of very large (untimed) systems. We investigated such an approach, based on a proprietary implementation of Set Decision Diagrams (SDD's). The TINA toolbox now supports symbolic exploration methods for untimed models, based on that library. Experiments and theoretical studies are going on concerning the application of SDD's to the analysis of Time Petri nets, in discrete or dense time, and high level descriptions like those obtained from fiacre descriptions.

The other investigated space saving techniques include various *state compression* schemes, *on-disk* storage of state spaces, *on-the-fly* verification methods, and *simplification of models* prior to exploration. Some of these techniques have been integrated in the TINA toolbox, others are still in the process of development.

Finally, as part of a thesis work, a study in going on aimed at exploiting structural *symmetries* in models. When applicable, symmetry reduction requires exploration of only a fraction of the original state space while preserving all state reachability properties. Symmetry reduction applied to untimed systems is a well-known technique. The novelty is that we apply it to timed formalisms, precisely to the state space abstractions available for Time Petri nets, including the so-called and well known *state classes* construction that we proposed long ago, continuously improved, and promote in our tools.

These experiments lead to a major release of the TINA toolbox allowing to verify systems with state spaces larger by an order of magnitude, and with better computing times.

Metaheuristic search applied to the automated synthesis of probabilistic test profiles: software statistical testing is a probabilistic approach for test generation developed at LAAS in the 1990s. Its corner stone is the use of coverage criteria to design sampling profiles over the input domain. The optimization of a sampling profile may however be a complex task. Recent work at the University of York has revisited this approach, demonstrating an automated search-based technique for synthesizing profiles suitable for statistical testing. The input profile is represented by a stochastic grammar, which is incrementally modified using a metaheuristic search algorithm until the adequacy criterion is met. Joint work has investigated the tuning of the search [MAI11119, MAI13438].

Based on exemplary profiles derived from our previous work, we have shown that the grammar-based representation is unable to properly express some key relationships between input arguments. When the search attempts to approximate these relationships, it is only able to do so over small regions of the input domain, yielding 'degenerate' profiles with poor fault-revealing power. We have proposed an augmentation of the grammar with operators that allow the user to incorporate knowledge guiding the search algorithm. Empirical results for two case studies are promising: knowledge gained by a very straightforward review of the software-under-test is sufficient to dramatically increase the efficacy of the profiles synthesized by search (Figure 10). Hence, the potential time and cost advantages of having an automated synthesis of profiles may now be better realized in practice.

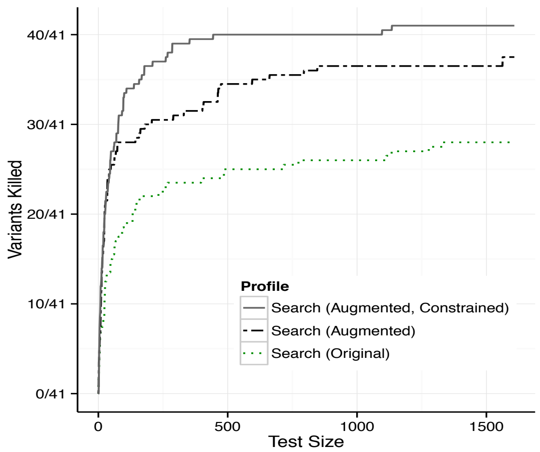


Figure 10: Fault Revealing Power of Search-synthesized Profiles (Original vs. Augmented Grammars)

2.5 Tools and Demonstrators

In order to validate our research results, we have developed a number of software tools and demonstrators (listed in Table 3). Even though most of them are intended for internal purpose, to be used for proof of concepts, a few of them have matured enough to be available for external purposes, such as our flagship TINA toolbox that served in many projects.

3 Academic Reputation and Appeal

National and international collaborations, developed over the years, are the basis of our scientific policies. Exchanges with academia and industrial companies are very important to discuss, compare and validate research results and paradigms on real-life concerns.

Table 3: Overview of our Tools

Acronym	Description
MARACAS	CBSE middleware for adaptive fault tolerance
GEPETO	GEoPrivacy-Enhancing TOolkit
HAZOP-UML	Risk analysis for the identification and validation of safety requirements
IronHIDE	A tool for analyzing I/O attacks
SOUK	Social Observation of hUman Kinetics
STELAE	Systems TEst LAnguage Environment
STANCE	Structural ANalysis of Counter Examples
TERMOS	TEst Requirement language for Mobile Setting
WASAPY	Web Applications Security Assessment in Python
MINOTOR	Monitoring tool for timing and behavioral analysis
SysEngLab	SE platform upon which different modules are integrated (requirement engineering, decision process & safety)
TINA	TIme Petri Net Analyzer
Fiacre/Frac	Fiacre to TINA Compiler
POLA	POLicies Analyzer
MERCURY	Parallel exploratory and model-checker for Petri nets
SimSO	SImulation of Multiprocessor Scheduling with Overheads

3.1 Main International and National Collaborations

A large part of our research activities are exemplified and exploited within cooperative projects. In total 44 projects run either partially or totally during the period covered by this report. They include 6 European projects, 10 ANR projects and 8 direct collaborations with industry. We have been involved in the management of 2 European projects, 2 ANR projects and 1 FNRAE Project.

In addition to the contractual context, we have strong cooperation with colleagues in the Toulouse area, and at the national and international levels. To name a few of them: IRIT, ONERA, IRISA, INRIA Bordeaux and Rhône Alpes, U. Nice Sophia Antipolis, BUTE (HU), U. York and U. of Newcastle (UK), T. U. Berlin (DE), UNICAMP and UFSC (BR), JAXA and JST (JP), U. of Illinois at Urbana Champaign and Carnegie Mellon U. (US). These collaborations are made possible thanks to exchanges of permanent staff or doctorate students, as well as co-advised theses, and joined publications.

3.2 Journal Editorial Boards

Over the period, 9 IC members have been involved in the editorial boards of 8 international journals and 2 national journals, in addition to a co-editor and guest editor of a special issue, listed in Table 4.

Table 4: Involvement in Journal Editorial Boards

IEEE Transactions on Dependable and Secure Computing
Journal in Computer Virology
International Journal of Performability Engineering
International Journal of Critical Computer-Based Systems
International Journal of Discrete Event Control Systems
IET Journal on Information Security
International Journal on Advances in Security
Software: Practice and Experience - Wiley Eds
Technique et Science informatique
International Journal of computer aided engineering and technology
EUROSIS Journal
Revue de l'électricité et de l'électronique
EEE Security and Privacy - It All Depends Department, co-editor
IEEE Transactions on Software Engineering, special issue: Evaluation and Improvement of Software Dependability, guest co-editor

3.3 Organization of Major Conferences and Workshops

We are involved in the Steering Committees of the major conferences in our domain, and we are chairing the steering Committee of the European Dependable Computing Conference as summarized in Table 5.

Table 5: Membership of Steering Committees

DSN: IEEE/IFIP Int. Conf. on Dependable Systems and Networks
ISSRE: IEEE Int. Symp. on Software Reliability Engineering
EDCC: European Dependable Computing Conference (chairship and membership)
ESORICS: European Symp. on Research in Computer Security
LADC: Latin American Symp. on Dependable Computing;
SSIRI: IEEE Int. Conf. on Software Security and Reliability
SERE: IEEE Int. Conference on Secure Software Integration and Reliability improvement
CARDIS: Smart Card Research and Advanced Application Conference
VeCos: Int. Workshop on Verification and Evaluation of Computer and Communication System
WOSD, Workshop on Open Systems Dependability
APVP: Atelier pour la Protection de la Vie Privée

Over the period, we have been involved as chairs or co-chairs of International Program Committees of five major international conferences: DSN 2010, EDCC-2014, ISSRE-2012, LADC-2011, Safecomp-2013. We have also organized (chaired) two International conferences in Toulouse: OPODIS (15th Conference on Principles of Distributed Systems), and SAFECOMP: (32rd

International Conference on Computer Safety, Reliability and Security). It is worth to mention that we will organize DSN 2016 in Toulouse.

In addition to the above international conferences, we have organized more than 20 national conferences, and national and international workshops.

3.4 Major and Long Term Visits

Several research members from IC have been invited by colleagues to visit and spend sometime in their institutions for collaboration. 12 such visits took place during the covered period, among which 5 visits by doctorate students for durations from two weeks to 3 months (UIUC, CMU, U. Arizona, US; UNAM, MX; U. Wtaerloo, CA). Meanwhile, 11 colleagues from foreign institutions spent sometime at LAAS.

3.5 Scientific Evaluation Committees

At the international level, we have contributed to the evaluation of project proposals for various institutions, such as DFG, Deutsche Forschungsgemeinschaft, MIUR, Italian Ministry for Education, University and Research, NOW, the Netherlands Organization for Scientific Research, Sepere Aude (DFF Starting Grant Application), or the evaluation of ongoing scientific projects.

At the national level, we have contributed to several i) ANR evaluation committees (Arpège, Blanc, Emergence JST-STIC,Ingénierie Numérique et Systèmes, Techlog), ii) AERES evaluation committees (ENSTA-U2IS, INRETS, INRIA Lille Nord Europe, LIFL-LAGIS, LIP6, LSV ENS-Cachan, CRC Ecole des Mines de Paris), iii) Digiteo/DIMLS, iv) ANRT proposals, and participated to a number of scientific councils (Commission informatique Sup-Elec, Institut pour une Culture de la sécurité Industrielle, Fondation pour une Culture de la sécurité Industrielle, GIS surveillance, sûreté et sécurité des grands systèmes, CPER 2007-2013).

One IC researcher was member of the *Comité National du CNRS, Section 7* (2008-2012).

3.6 Scientific Societies

Table 6 lists the scientific societies in which we are involved in various positions.

Table 6: Involvement in Scientific Societies

EAPLS (European Association for Programming Languages)
IFIP TC 10, Computer Systems technology
IFIP Working Group 10.4, on Dependable Computing and Fault Tolerance
IFIP TC11, Security & Privacy Protection in Information Processing Systems
IEEE Computer Society TC on Dependable Computing and Fault Tolerance
CEPIS (Council of European Professional Informatics Societies)
European Privacy Institute - Scientific Advisory Committee
Fondation pour une culture de sécurité industrielle
ISO/TC 262 (Risk Management)
CREIS (Centre de Coordination pour la Recherche et l'Enseignement en Informatique et Société)
SEE, Conseil scientifique et technique
SEE, TC Systèmes informatiques de confiance
IARP/IEEE-RAS working group on Technical Challenges for Dependable Robots in Human Environments

3.7 Awards and Distinctions

In addition to papers that were awarded as "best paper" of specific conferences, some members from IC received individual awards that are listed in Table 7.

Table 7: Awards

French Academy of Sciences Grand Prize in Informatics, 2009, J.C. Laprie
IEEE Meritorious Service Award, 2009, K. Kanoun
Cercle d'OC Prize, 2009, A. Costes
IEEE Computer Society Golden Core Member, 2010, K. Kanoun
IEEE Distinguished Service Award, 2010, J.C. Laprie
IFIP TC-11 Kristian Beckman Award, 2012, Y. Deswarte
ESORICS Outstanding Service award, 2012, Y. Deswarte
Médaille Ampère de la SEE, 2013, K. Kanoun

4 Interaction with Social, Economic and Cultural Environment

4.1 Projects with Industrial Partners

Our research has a large impact in many industrial domains. We participated and are participating to several ANR projects including industrial partners (large companies e.g., AIRBUS, THALES, RENAULT, VALEO, BULL, etc. as well as SMEs). We co-advise 8 PhD students funded by industry in the framework of a CIFRE grant and we have 10 bilateral industrial projects.

4.2 Activities Related to Carnot Label

Three members of IC are representative of LAAS in three thematic groups (*filières*) dedicated to the development of SMEs competitiveness and innovation, namely ICT-digital technology, Aeronautics, Automotive.

4.3 Other Major Innovation Activities

Three patents with Airbus were delivered during the period in the US.

Also, we can mention an ongoing initiative with Quarkslab SME for the set up of a LabCom about the vulnerability analysis and security protection with respect to low level attacks.

We contribute to the activities of the Aerospace Valley Cluster as coordinators of DAS-SE, DAS-SEEL, DAS-SSTA.

We are involved in the Innovation Council of Digital Place Cluster, and System@tic Cluster, Working group "Automobile & Transport ".

Some IC researchers have consultancy activities for EADS-Astrium, DIT/DSN/Air Navigation Technical Services, Technicolor, Rockwell-Collins, to cite a few of them.

Finally, we are actively involved in the IRT Saint Exupery and in the RTRA STAE (Sciences et Technologies de l'Aéronautique et de l'Espace).

4.4 Scientific Popularization

Table 8 gives examples of scientific popularization events.

Table 8: Examples of Scientific Popularization Events

Demonstration of SOUK, Novela, Fête de la science, Metabody
Video Interview- Demonstration of HIDENETS results, CNRS Video
Analyse et expérimentation : deux faces de la méthode scientifique, Fondation La Dépêche, Séminaire classes de terminale,Lycée de Mazamet
Données personnelles : que va faire l'Europe ?, Journal du CNRS
Interview: De l'automobile au médical, les systèmes embarqués créent de l'emploi, Le Monde Eco&Entreprise
Interview: Quand le numérique ne fait pas rêver les jeunes, Le Monde Eco&Entreprise

5 Involvement in Training through Research

IC Members are strongly involved in education programs and training support, and management activities.

5.1 Leading Roles in Doctoral Schools

Several members of the IC theme have administrative and training responsibilities in the EDSyS and MITT doctoral schools, at the Paul Sabatier University or at the INPT and INSA engineering schools:

- EDSyS: several IC members belong to the doctoral school Executive Committee. We also contribute to the school council and PhD theses commission. Two IC members are responsible of the "computer science" area and the "industrial systems" area.
- MITT: Several researchers are members of the scientific council in computer science.
- UT3PS: Head of EEA department, creation and direction of the UPS Master of Engineering cursus, UPS representative in the steering committee of the national network FIGURE (CMI), Responsibility of two Masters M2 (*Systèmes intelligents*, and *Systèmes et Micro-systèmes Embarqués*, membership Pole MST2I council and *Commission Stratégie Recherche*; several responsibilities in departments EEA and GEE–IUT A.
- INPT: membership of the scientific council, Research operational council, and GEA department council.
- INSA: Administration Council membership, Reponsibility of Master M2 *Ingénierie des Systèmes*; M1 *Informatique et réseaux*; *Option 5ème Année Sécurité du Logiciel et des réseaux*; coordination of the DGEI council on Computer science and Networks, *conseil scientifique*, DGEI department, *Commission Informatique Telecom*.

5.2 Research Seminars in Training Programs

5.2.1 Seasonal Schools

Some members of IC have been invited to give tutorials at the following seasonal schools:

- IEEE TTC Test Spring School (2012).
- Summer school "Safety and Risk Management", Keio U., JP (2011)
- Summer school "Software Dependability and System Safety", CAPE, Beijing, CN (2013)
- Ecole d'été Temps Réel (2011 and 2013).
- GDR I3 Ecole d'été Informatique Ambiante (2009).
- École de Printemps, La sécurité des réseaux et des systèmes, École Nationale des Sciences Appliquées, Marrakech (2014).

We are also member of the organizing committee of the 2nd Summer School on Critical Embedded Systems held in Toulouse in September. This school is supported by AIRBUS Group Foundation through the Critical Embedded System Education Chair, CESEC.

5.2.2 Advanced University Courses

Almost all IC permanent members contribute to the training and education programs in computer science and engineering at local universities and engineering schools. In this context, we can mention two original initiatives:

- The set up of a Joint Master project on critical embedded systems in cooperation with ENSEEIHT and ASTRIUM Satellite with Aerospace foundation support.
- The organization of a one day tutorials on "Recent advances in information security" in the context of the training program "*Sécurité du Logiciel et des réseaux*" at INSA with invited talks from EADS-IW, Quarkslab, Univ. Catholique de Louvain, Supelec Rennes, Symantec and ANSII.

In addition, we can mention two participations to Master programs abroad: the Ph.D. Program in Information Engineering at Pisa University, and the Master on Sustainability Safety and Security in Transportation Systems and Infrastructures at Genoa University, jointly with ANSALDO.

5.3 PhD and Internship/Master Programs

5.3.1 Thesis Supervised

50 PhD students have been supervised during the period. The average duration of a PhD thesis is 3.5 years.

5.3.2 Co-Supervised Thesis

We can mention 14 co-supervised PhD theses with researchers external to LAAS: 4 with ONERA; 3 with IRIT; and one with Budapest Univ. of Technology and Economics, HU; Technological Institute of Toluca, Mexico, University of Southampton, UK, IRISA / Université de Rennes, Université de Bordeaux 1, Ecole des Mines d'Albi, Université de Strasbourg. In addition, two theses have been co-advised with researchers from other themes at LAAS: one with RC and one with ROB.

5.4 Teaching and Education Materials

- ReSIST courseware, prepared in the framework of the ReSIST European Network of Excellence, managed by LAAS (http://resist.isti.cnr.it/home.php)
- Book: T.MONTEIL, V.NICOMETTE, F.POMPIGNAC, S. HERNANDO, *Du langage C au C++*, Presses universitaires du Mirail (2009), N 978-2-8107-0054-7.
- The TINA toolbox for analysis of Time Petri nets based models is made available to the community. It is used for teaching purposes at many institutions, in France and in several foreign universities.

5.5 PhD/HDR Committees

At least, 50 IC members were part of PhD and HDR committees (excluding those prepared at LAAS), among which 7 abroad and 19 as committee chairs.

5.6 Faculty Selection Committees

IC members regularly participate to PR/MCF recruitment committees at different local and national universities.

At the international level, we have participated to two professor recruitment committees: one on Dependable real-time and embedded software systems, at Luxembourg University, the other one is on System dependability, at Technical University of Vienna.

III - Networks and Communications (*Réseaux et Communications* — RC)

Leader: K. Drira

Research Teams: Distributed Computing and Asynchronism, Services and Architectures for Advanced Networks

Keywords: Communication Networks, Protocols and Communication Services, Internet of Things and Machine-to-Machine, Software Services and Architectures, Performance Evaluation, Quality of Service, Autonomic Computing and Networking, Ontologies, Network Computing, Traffic Engineering (Models and Tools)

Personnel Status (as of June 30, 2014):

Team — CDA	Distributed Computing and Asynchronism (*Calcul Distribué et Asynchronisme*)
Leader	D. Elbaz (CR HdR)
Permanent Researchers	V. Boyer (MCF, affiliated), M. Elkihel (MCF), J-M. Enjalbert.
PhD Students	B. Plazolles [01/09/13]. <u>Alumni</u>: M. E. Lalami [01/10/08-05/10/12], T. T. Nguyen [01/09/08-16/11/11]
Post-docs; Engineers	<u>Alumni</u>: V. Boyer (post-doc) [01/09/2009-01/09/2010], S. R. Tembo (Ing.) [01/10/2012-21/07/2013]
Visiting Researchers (Affiliation, Country, Period)	
Team — SARA	Services and Architectures for Advanced Networks (Services et Architectures pour les Réseaux Avancés)
Leader	K. Drira (DR)
Permanent Researchers	S. Abdellatif (MC), C. Albea Sanchez (MC), U; Ayesta (CR), P. Berthou (MC), O. Brun (CR HdR), C. Chassot (PR), M. Diaz (DR Emérite), E. Exposito (MC, HDR), JM. Garcia (DR), T. Gayraud (PR), N. Guermouche (MC)[10/11[, G. Juanole (P Emérite), Y. Labit (MC), S. Medjiah (MC) [10/13[, Th. Monteil (MC HdR), P. Owezarski (DR), B. Prabhu (CR), S. Tazi (MC HdR), T. Villemur (PR) <u>Retirement</u>: A. Lozes]07/13], G. Mouney]02/12]
PhD Students	I. Abdennadher [01/09/2011], D. Allison [01/01/2012], H. Arous [15/09/2009], Y. Banouar [01/11/2013], S. Baraketi [19/12/2011], M. Ben Alaya [01/03/2011], H. Ben Cheikh [15/02/2012], M. Bruyere [01/10/2012], D. Carvin [01/10/2010], C. Diop [01/10/2011], J. Doncel [15/03/12], G. Dugue [01/10/2009], C. Eichler [01/11/2011], E. Fki [01/02/2013], G. Gharbi [01/10/2012], S. Gil Casals [01/03/2011], A. Guedhrib [01/09/2011], T. Guerout [01/09/2011], I. Guidara [01/09/2011], M.A Hannachi [01/11/2010], A. Izagirre [01/10/2012], A. Jemal [01/09/2011], A. Kamoun [01/05/2011], G. Kremer [01/11/2010], M. Larranaga [01/10/2012], E. Mezghani [15/04/2013], O. Mokrenko [27/03/2013], A. Omezzine [01/02/2013], C.C Ruiz Sanabria [20/03/2012], T. Seregina [01/10/2011], J. Vallet [01/02/2012], W. Zouaoui [01/10/2012] <u>Alumni:</u> F. Nivor [01/10/2004-31/08/2009], B. Jacquemin [01/10/2006-30/06/2010], F. Armando [01/09/2005-17/02/2010], G. Sancho [01/10/2007-23/12/2010], I. Alberdi [01/10/2006-30/04/2010], I. Bouassida Rodriguez [12/02/2007-19/02/2011], U. Ashraf [13/11/2006-18/04/2010], R. Albu [01/11/2007-31/7/2011], A. Akl [01/02/2008-23/12/2011], J. R. Gomez Montalvo [12/11/2007-16/02/2012], N. Van Wambeke [01/09/2006-09/09/2009], L. Bertaux [01/09/2009-30/09/2013], M. Alexandru [14/12/2012], I. Tou [01/10/2007-13/12/2012], M. Oprescu [27/10/2008-12/10/2012], A. Hakiri [01/092008-31/08/2012], P.U. Tournoux [15/11/2008-31/12/2010], A. Bouabdallah [27/02/2006-03/12/2010], J. Mazel [01/10/2008-19/12/2011], S. Rahme [01/10/2008-16/11/2011], Y. Ariba [23/11/2009], A. Al Sheikh [15/11/2008-15/10/2011], M. Ben Hamouda [23/04/2007-30/05/2010], M. El Masri [01/10/2005-10/07/2009], R. Sharrock [01/10/2007-8/12/2010], K. Fakhfakh [21/05/2011], S. Khemakhem [19/04/2006-08/07/2011], M.Mahdi [24/11/2008-23/11/2011], L.Zhang [01/10/2006-15/11/2009], A.D.Nguyen [01/10/2009-18/07/2013], G. Kang [19/11/2010].
Post-docs; Engineers	Lionel Berthaux [10/02/2014-09/08/2014] <u>Alumni:</u> Ahmed Al Sheikh [15/12/2011-14/06/2012], Riadh Ben Halima [18/06/2009-31/08/2009], Pedro Casas [15/03/2010-31/08/2011], Mohamed El Masri [10/07/2009-31/08/2010], Dawood Khan [01/12/2011-31/11/2012], Jérôme Lacouture [15/04/2009-15/01/2010], Johan Mazel [20/10/2011- 31/08/2012], Sakkaravarthi Ramanathan [01/03/2012-30/04/2012], Nicolas Van Wambeke [10/09/2009-31/10/2009]
Visiting Researchers (Affiliation, Country, Period)	Riadh Ben Halima (Sfax, Tunisia) [17/01/2013-15/07/2013], Ismail Bouassida (Sfax, Tunisia) [01/02/2013-31/07/2013, Saul Eduardo Pomares Hernandez (Cholula, Puebla, Mexico) [15/08/2012-14/07/2013], Alfredo Grieco (Bari, Italy) [01/10/2013-30/11/2013], Dimiter Avresky (Germany/ USA) [02/12/2013-31/12/2013]

1 Presentation

1.1 Objectives and Scientific Positioning

RC research work addresses next generation networks and advanced communication systems, including smart objects, services and applications. The research is aimed to build a new global approach able to master and manage such complex systems including **design**, **planning**, **deployment**, **monitoring** and **control**.

Our research objectives include the development of methods, models and tools, as well as the design and implementation of architectures, protocols and services. In particular, our work focuses on the **analysis, performance evaluation, control and prototyping of software platforms** for communication services and applications.

We develop a model-based approach supported by simulation-based techniques for the development of new architectures, using *model-driven design* as well as *validation* and *performance evaluation.* We elaborate new approaches addressing the behavioral, structural and semantic properties of communication networks and services at different layers, using the methods of Game Theory, Queuing Theory, Graph Theory, Graph Grammars, Machine Learning, and Ontologies.

Stochastic modeling and analysis has been a popular method for analyzing the behavior of **algorithms in complex networks**, because **randomness** is inherent in network. As fine grain analysis of such networks is computationally intensive and gives almost no insight into the relationship between the parameters and the performance measures, we develop various new **asymptotic and approximation methods,** such as **fluid limits**, light and heavy **traffic approximations**. These methods have the advantage of being analytically tractable, insightful and of giving easy-to-implement rules of thumb that are efficient in practice. These methods have been applied to resource allocation, scheduling, and network provisioning.

The choice of **game-theoretic techniques** is complementary to stochastic methods and appropriate as well. Game theory is the study of optimal **decentralized decision-making** process when several independent agents interact in order to minimize their own cost. In the environment of the Internet, the end-users and routers can be thought of as agents who need to make independent decisions. Decentralized decision-making can be highly inefficient compared to centralized ones. Our approach consists of performing worst-case analysis (Price of Anarchy) to determine the efficiency of decentralized algorithms, design efficient ones, and investigate their convergence.

The theme RC has a long experience in **optimization theory** for **network design and planning problems and applications**. Relying on precise knowledge of the traffic matrix enables nice provably optimal solutions, but is unrealistic in practice due to the high volatility of traffic patterns. A very recent and dynamic research area aims at taking into account traffic uncertainty and searching for robust solutions to network planning problems. Robust optimization methods have been applied to IGP weight optimization in IP networks, and optimal VPN design.

The theme RC also introduced methods based on **machine learning** techniques in order to develop autonomic capabilities for network and **QoS optimization** in general and especially for **anomaly detection**. RC more specifically addresses the problem of **unsupervised** machine learning that helps the network and its components to make decision without previous knowledge on the traffic, and without requiring labeled data, or learning stages which are hard to produce and costly. Our unsupervised machine learning technique relies on the **clustering technique** for data mining.

Graph grammars are applied for modeling **structural properties** for a wide range of **dynamic** systems and applications in multiple fields, including software and communication systems architectures. As a generic model, graphs can be used to represent different architectural views, including component-based, service-oriented, event-driven, and group-wide architectures. Our approach aims at avoiding configuration enumeration to handle scalability. We proceed by characterization of the set of the different configurations via a set of rewriting rules applied to the initial configuration.

Models based on **ontologies** are used for **semantic reasoning**. Ontologies have proven beneficial for intelligent information integration, information retrieval, and knowledge management. Ontologies constitute a way of cleverly structuring a domain making use of semantic hierarchical and property/value relationships, utilizing a vocabulary of concepts/instances in order to describe reasoning rules. Our approach consists in using ontologies to represent the relationships between distributed components of communication architectures and protocols, including both behavioral and structural semantics, in order to build inference-based and consistency-preserved knowledge base decision models to guarantee self-adaptation properties of autonomic communication services.

1.2 Organization and Life

The RC research theme has been created in 2012 and is composed of two research teams: Distributed Computing and Asynchronism (CDA) addressing algorithms and protocols for parallel and distributed computing and Services and Architectures for Advanced Networks (SARA) addressing, communication systems, their functional and non functional properties including performance, QoS, architectures, and services.

1.2.1 Activity Profile

The RC theme members participate in four main missions: **academic research** by: scientific production including papers in journals and conferences and books; **interactions with environment** by: expertise, transfers, contracts, open source software; **research support** by: scientific animation at the national and international levels, and **training** by: organization and training at Master's level and supervision of PhD thesis.

Table 1 depicts the activity profile for the Theme and gives also the profiles for the Teams involved.

Table 1: Activity Profile

%	Academic research	Interaction with environment	Research Support	Training
RC	50	10	10	30

1.2.2 Scientific Coordination

Aside frequent informal scientific discussions on the topics of RC theme between members of the teams SARA and CDA, external and internal seminars are organized periodically with an average of monthly internal speaker seminars and quarterly external speaker seminars including researchers from France, Europe, Brazil, Mexico, USA and CANADA. Additionally, biannual one-day workshops are organized outside LAAS and focused events are organized such as PhD progress work plenary presentations and technical presentations (cookbooks). Specific meetings are organized periodically for each research topic (M2M, Performance Analysis, Architectures, Virtualization,…) or project including presentations of PhD students and trainees. Regularly, 2-day meetings are organized at LAAS for Collaborative Projects where RC researchers are involved. Monthly internal meetings are organized between the RC theme council members or alternatively between the members of the scientific councils of each team. For a better collaborative teams-wide seamless knowledge management, a semantic wiki has been implemented. A global ontology of scientific directions, contributions and challenges of RC has been elaborated and implemented using semantic mediawiki[1] extensions. Moreover, an ontology of RC organization has been elaborated and implemented for easing information sharing among RC members.

1.3 Salient Facts

- We have developed the first ETSI-compliant open source M2M platform, and extended it with autonomic management capabilities; APP CNRS, Approval of Eclipse foundation for OM2M as an eclipse M2M project. Available on http://eclipse.org/om2m. Our platform is being used by industrial and academic partners from France, Europe and USA. Users with planned partnership include: Orange France, Bull, Italtel, SAP Labs Palo Alto , CA, USA. Many other academic and industrial partners are using OM2M since its official publication on Eclipse website in May 2014. More than 23.000 reads of answers to users questions on OM2M wiki website were recorded. Since July 2012, our implementation and the associated application scenarios have been showed in the LAAS ADREAM building in more than 80 times for external visitors (mainly industrials, but also academic and general public) and (using ADREAM Mokup) outside of LAAS, in Toulouse (Digital Place'2013, FUTURAPOLIS'2013), France (rencontres des IC at Lyon'2013) and in Europe (ITEA/ARTHEMIS symposiums'2013-14, ETSI workshops'2013-14, A2NETS projects reviews in Helsinki'2013 and in Oulou'2014).
- RC members are actively participating to the European (ETSI) and international (OneM2M) standardization activities on M2M service architectures since 2013. We are now getting involved in responsibilities for ETSI interoperability test activity supervision. We are elaborating a change request to improve the future international M2M services architecture within the OneM2M alliance.
- RC has coordinated the ANR CIP project on peer-to-peer high performance computing (2008-2011) and the ANR SOP project on Home remote personal service (2011-2014). RC coordinates the two European projects: FP7 PANACEA on cloud and overlay networks (2013-2015) and H2020 CYWORK on cloud and IoT/M2M services submitted in 2014 (15 partners from France, Italy, Finland, UK and Germany including academic and industrial partners and the European standardization institute ETSI and ECLIPSE foundation). We have been also actively involved in the preparation of a new project on IoT and connected vehicles for smart transportation systems (in the context of the PIA "Objets connectés of June 2013). The project has been submitted in January 2014 and accepted in June 2014.
- A researcher from RC has been invited by the French President François Hollande, and the Minister of Foreign Trade Nicole Brick, to be part of the French delegation including several French companies in Tunis in 2013 for the establishment of the Franco-Tunisian Digital alliance (*Alliance Numérique Franco-Tunisenne*).
- RC has been recipient of the IdEx Grant "*chaire d'attractivité Univ. de Toulouse*" 2013 for hosting Pr. Gene Cooperman Northeastern University, Boston, MA, USA on a research activity entitled "Adaptation, Negotiation and Checkpointing for Cloud Computing" — 530.000 euros for a 5 years period, starting from May 2014.
- A researcher from RC has obtained a 140.000 euros Grant for a 3-year period in recognition of research work on Optimal and decentralized control of communication networks.
- A researcher from RC has obtained a NVIDIA Academic Partnership and CDA team has been endowed with two NVIDIA Tesla C2050 computing processors with 448 CUDA cores each. The support of NVIDIA corporation was renewed mid 2014 with a gift to LAAS of the brand new Tesla K40 GPU accelerator with 2880 cuda cores.
- The project ITEA2 USENET, in which we were actively involved, obtained in 2010 the silver award from ITEA2.
- Our past and on-going collaboration activities with Tunis and Sfax Universities of Tunisia (co-tutelles, CNRS-PICS projects, PHP-CMCU projects) are being extended to industrial collaboration supported by CNRS (a collaboration agreement including LAAS-CNRS, the spinoff “QoS Design”, and “Tunisie Telecom” will be signed in last quarter 2014). A LIA (*Laboratoire International Associé*) project is under preparation in the context of the new CNRS/Tunisian Ministry[2] framework agreement signed in July 2014[3].
- In addition to organizing annual international workshops, RC members will chair and organize in 2015 two international conferences supported by IEEE: the 8th Wireless Days in Toulouse and the 13th International Conference on Software Engineering Research, Management and Applications (SERA 2015) in Hammamet, Tunisia[4].

2 Scientific Production

The scientific research topics addressed are organized along five research directions supported by experimental platforms:

1. Traffic Monitoring, Modeling and Analysis
2. Network Planning and Optimization
3. Protocols for Adaptiveness and Guarantee
4. Architectures for Communication and Services
5. Distributed Algorithms and Applications
6. Development of experimental platforms

[1] https://semantic-mediawiki.org/

[2] Ministry of Higher Education, Scientific Research and Technologies of Information and Communication

[3] http://www.cnrs.fr/derci/spip.php?article807

[4] http://sera2015.redcad.org/

2.1 Traffic Monitoring, Modeling and Analysis

The objective is the design and the analysis of mathematical models to predict, optimize and monitor the performance of next generation networks. Our contributions are both theoretical in nature, with the design of new approaches for stochastic modeling and distributed control, and applied with the development of metrology tools and software for network analysis.

2.1.1 Performance Characterization

We have developed asymptotic and approximation methods in order to understand the performance of systems for which classical models cannot be applied. Our main contributions are:

- Light and Heavy-Traffic: This method analyzes the performance when the offered load is such that the system is almost always idle (light) or in saturation (heavy). We have developed a novel technique to characterize the light and heavy-traffic regimes, and applied it to investigate the performance of complex resource sharing algorithms [RVSI09601].
- Fluid Limit: The fluid model, a stochastic allocation problem, is a deterministic approximation. It is thus easier to study and to derive an optimal control for the fluid model, yet it can provide valuable insights into the solution of the original problem. We have studied two main areas: In a wireless downlink channel we used it to characterize the set of stable policies, and to derive scheduling policies that provide near-optimal performance [RVSI13354]. In a data network we have investigated the impact of traffic surges or flash crowd on the performance of concurrent flows.
- Abandonment (a.k.a. reneging) is a ubiquitous phenomenon that happens in a multitude of systems, for instance, when customers abandon after being waiting for too long in a queue, or users in the Internet that give up a transfer if the connection is too slow. It has a dramatic impact on the performance of systems and it has attracted a lot of effort from the research community in recent years. In our two main contributions, we have characterized the performance in the presence of impatient customers [MAI11603], and we have derived nearly-optimal resource allocation algorithms, see [RVSI13287]

2.1.2 Network Metrology

The Metrology activity deals with analysis, characterization and modeling of network traffic. It consists of several research directions driven by projects:

- The design of new measurement based architectures that take advantage of machine learning techniques in order to develop autonomous and cognitive management and security capabilities for future communication networks. This research objective has significantly been addressed in the context of the ECODE project (Figure 1), and will continue in the ONTIC project [RVSI11450], [MAI11028], [RVSI12638].

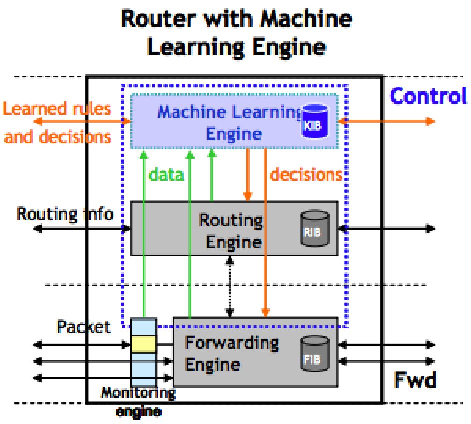


Figure 1: The ECODE system architecture overview

- The monitoring of wireless networks from physical to high level layers, in order to predict performance decrease and failure of such networks, and to anticipate the deployment of substitution networks. This work requires skills in networking as well as in electronics; it aims at bridging the gap between physical spectrum and signal to the digital world. We then use electronic facilities as oscilloscopes and an anechoic chamber. The analysis and estimations are mainly made using supervised machine learning techniques. Another contribution in this project deals with the monitoring of highly dynamic wireless networks (*ad hoc*, sensor nets, Internet of Things,…) for optimizing the traffic engineering according to the fast evolution of the network dynamic topology. This work mainly took place in the framework of the RESCUE project [CII14227].
- Jointly with the use of honeypots, network metrology permits the analysis of traffic and attacks, and aims at proposing new solutions for network security. The goal is to avoid QoS to be degraded when denial of service (DoS) attacks or flash crowds arise. This work then mainly deals with detecting unwanted traffic (anomalous traffic detection or anomaly detection). The proposed techniques do not need any preliminary knowledge on the traffic or the attacks. They rely on the use of unsupervised machine learning techniques and clustering (for data mining in big data), jointly with some information theory scores for classifying traffic classes into legitimate and illegitimate, and also giving a dangerousness score for the security system so that it can autonomously make the appropriate decision.

We also worked on studying malicious traffic. For this purpose, a specific platform consisting of honeypots for collecting malware (viruses, worms, etc.), sand boxes for executing malware in a protected environment, DNS servers for routing outgoing malicious traffic towards our protected environment, and a new multi-levels firewall for detecting dangerous outgoing traffic and blocking it in order not to corrupt distant hosts. This last work is conducted in collaboration with the theme IC (TSF team).

Active techniques provide the easiest and the most flexible approach to estimate network parameters as available bandwidth but require a control of the level of traffic intrusion probing. Many active techniques and tools have recently appeared, but little attention has been given to the accuracy of estimated values and to application in security in the Internet and Energy-aware in networks; most studies have been conducted on local platforms. This work mainly took place in the framework of the FLOWER project, see [RVSI12502].

2.2 Network Planning and Optimization

The main contributions are the development of mathematical methods and software tools for the design, optimization and control of communication networks and distributed systems, with particular emphasis on the Internet and wireless systems. These contributions are organized in the following three sub-sections.

2.2.1 Non-cooperative Load-Balancing based on Algorithmic Game Theory

Algorithmic Game Theory is one of the most dynamic and vibrant research areas in the last decade in computer science. We summarize below our most important contributions in this area:

- We have investigated the performance of distributed and non-cooperative load-balancing strategies in server farms and data centers. For a fixed amount of total incoming traffic, we have shown that, under mild assumptions on latency functions, the worst-case social cost occurs when each dispatcher routes the same amount of traffic, that is, the game is symmetric [RVSI10051, MAI10052, RVS08295]. Using this result, we have shown that the Price of Anarchy (PoA), a standard measure of the performance degradation induced by distributed decision-making, can be arbitrarily large under this worst-case scenario. More recently, we have shown in [MAI13022] that the PoA is an overly pessimistic measure, which is rarely achieved in practice.
- We addressed the following question: do uncoordinated routing agents converge to a Nash equilibrium in load-balancing games, assuming best-response dynamics? We have proven that a sufficient condition for the convergence is that the joint spectral radius of Jacobian matrices of best-response operators be strictly less than unity, and we have shown that this condition is met in several important special cases [MAI13365].

2.2.2 Network Optimization

Optimal resource allocation under time-varying demand can be handled by online monitoring and adapting resource allocation when changes are observed. We have proposed such dynamic mechanisms for two network-related applications:

- Dynamic speed scaling, which varies the server speed with the number of tasks, has been proposed to balance energy and delay costs in data-centers. For a single processor, we first proposed an alternative method to compute the asymptotically optimal speed-scaling policy. We then proposed approximations, related to the diffusion approximations by Halfin and Whitt, for the mean energy consumed per task and the mean delay under this optimal policy. These approximations were used for the computation of optimal routing policies in data centers [MAI12616].
- The high volatility of traffic patterns in IP networks calls for dynamic routing schemes allowing to adapt resource utilization to prevailing traffic. In the context of the FUI-NEC project, we have proposed an online approach to optimize OSPF weights, and thus the routing paths, adaptively when some changes are observed in the traffic. The approach relies on the estimation of traffic demands using SNMP link counts and uses robust optimization techniques [MAI11585] (Figure 2).

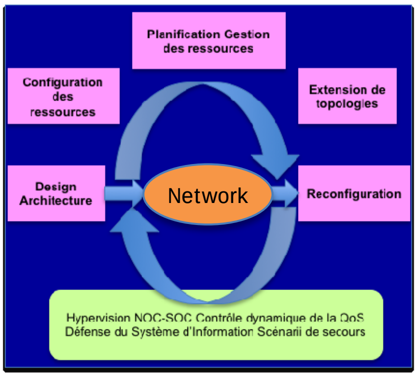


Figure 2: An Overview of NEC System Functionalities

2.2.3 Resource Allocation in Real-Time Avionic Systems

Modern avionic architectures allow the execution of avionic functions on a shared computing platform while avoiding any interference between them. Although resource sharing reduces the weight, the complexity and the power consumption of the physical architecture, it gives rise to complex resource allocation problems that have been addressed in the context of the ANR-SATRIMMAP project (in collaboration with VERTICS – theme IC):

- The first problem concerns scheduling strictly periodic tasks, i.e., tasks that have to be executed at constant time intervals. An exact formulation based on Integer Linear Programming [MAI10364] and a heuristic inspired from Game Theory [MAI11055] were proposed. It was observed numerically that the heuristic generates periodic schedules with modest relative errors in a few seconds, whereas the exact method usually requires several hours [RVSI12152].
- The second problem is related to the configuration of the Avionics Full Duplex Switched Ethernet (AFDX) backbone. We have proposed different methods to configure Virtual Links and to route them in the network while minimizing the maximum utilization rate of the links [RVSI12053].

2.3 Protocols for Adaptiveness and Guarantee

Our goal is to design for a given level of communication, protocols and mechanisms able to provide basic adaptive or guaranteed communication services to a higher level of communication, the application level or the end user level.

2.3.1 Transport Protocol Mechanism

Our work on the transport layer has been oriented to cope with the large diversity of transport services as well as the complexity resulting from the deployment of a particular transport protocol or transport mechanism over the different services provided by heterogeneous networks.

2.3.1.1 Autonomic Transport Protocol (ATP)

This solution is based on an autonomic communication architecture driven by a QoS ontology model that integrates the required semantic of standard and specialized transport services, protocols, functions and mechanisms in order to facilitate service discovery, selection and composition based on application requirements and network constraints [RVSI12744, RVS10056, RVS12494, RVS08351, MAI12069, MAI10456, HDR10940] (Figure 3). This solution integrates an extensible and dynamic context-aware decision model intended to guide transport self-managing strategies in dynamic and heterogeneous network environments [OAI13009]. Various collaborations have been established in order to develop several research topics in the area of autonomic transport protocols [MAI13049, MAI13421] in the framework of local, (ADREAM), regional (BQR Energy) and international collaborative projects (PCP France-Venezuela).

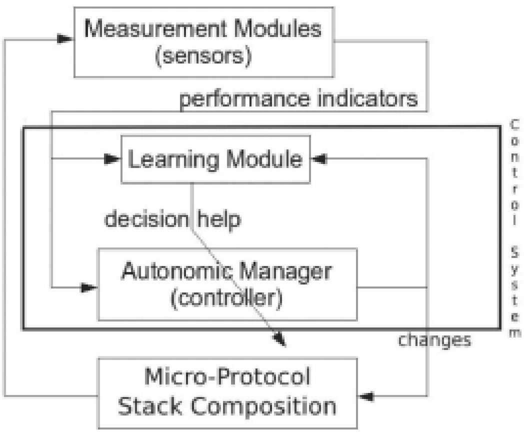


Figure 3: An Overview of ATP Architecture

2.3.1.2 Satellite Communication Networking

Since more than 10 years, RC contributes to the definition of new communication architectures for satellite communication networks. This work is mainly the result of multiple collaborations between LAAS and leading industries (THALES, ASTRIUM, CNES). This period has seen the end of the OURSES project where LAAS/ASTRIUM have made the first evaluations of DVB-S2 in the Ka band. Two contracts with the CNES have studied "Next Generation Networks and Quality of Service" (2008-2010) and "Transport protocols performances" (2010-2012) in terrestrial / satellite hybrid networks. 4 PhD were defended during this period. The first two have proposed service oriented QoS architecture for satellite networking and an extension to manage mobility and Quality of Service. The latter have studied the Transport layer performances over hybrid terrestrial and satellite networks and proposed PEPless transport solutions. Long-term transport solutions have also been studied with the Stream Control Transmission Protocol. Our work on satellite communications has contributed to the development of OPENSAND, an open source simulation platform of satellite: http://opensand.org.

2.3.2 Energy-aware Communication Protocols

We addressed the modeling and control of networks and the observation of traffic evolution in realizing new mechanisms for congestion/admission controls and observers (linear or nonlinear observers) for anomaly detection. The development of new mechanisms plays a key role in the implementation of current applications in the Internet. In recent years, a fluid dynamic model of TCP behavior was developed. It connects the mean value of the main network variables (number of TCP sessions, load, link capacity, RTT, ...) and is described by a nonlinear dynamical model. New Active Queue Mechanisms (with state feedback law) taking into account delays and parameter-varying over time have been developed [RVSI09057], [RVSI09055]. A second work in this direction was carried out on decentralized control and observation of self-organized systems combining quality of service and anomaly detection (taking into account delays), [RVSI12502], [RVSI09655]. A third work is underway on improving Quality of Service and energy consumption in networks with Automatic Control. This work is supported by the FLOWER project. A control flow mechanism is proposed from control theory. The control problem is focused on a node, whose input traffic can be stochastic. Here, a sub-optimum as well as an unsaturated traffic (below a determined capacity) must be guaranteed, ensuring acceptable resource reservation and a suited end-to-end delay. This is translated into finding a sub-optimum traffic, as a trade-off between traffic and fast convergence to the queue length reference. As a side effect congestion is avoided. Furthermore, the proposed control should be robust with respect to any traffic disturbance. A fourth work (in collaboration with CEA) about control application in wireless network aims to finding an optimal balance for the user comfort and energy efficiency in Smart Buildings. The controller is designed by using predictive control and it has been applied in a benchmark.

2.3.3 QoC in Networked Control Systems

Networked Control Systems (NCS) are systems where the applications are Control-Command applications i.e., applications, with a feedback loop, where the guarantee of a Quality of Control (QoC), more particularly the stability, is essential. Works have been done in this context with the objective that the QoS provided by the network is dependent on the QoC required by the applications. After the initialization of such works by considering the CAN network and more precisely the MAC protocol, wireless local area networks have been considered and CSMA MAC protocols without collisions (based on the concept of dynamic priorities, which depend on the control signal of the applications, for the priorities of the application messages) have been specified (providing, in such a way, a link QoC/QoS) [OPI10045, MAI10455, MAI12006, MAI13104].

2.3.4 Controlled QoS in Wireless Networks

We addressed the problem of providing predictive (controlled QoS) services for wireless networks with high resource utilization. The targeted services must provide fairly reliable QoS assurances/guarantees, based on measured values from wireless links and from on-going traffic/flows. Our research work focuses on the definition of algorithms and mechanisms for the MAC and routing layers' network functions, namely network resource estimation, network resource allocation, admission control, channel switching, routing metric, route maintenance, etc. The performance of the proposed mechanisms is assessed via analytical modeling (stochastic modeling, Petri Nets, network calculus), numerical analysis as well as experimental analysis. Major results are the proposal of novel algorithms and mechanisms for the following network functions:

- Resource allocation framework (routing, QoS signaling, network resource estimation, load-balancing) for multi-channel multi-interface wireless multi-hop networks [RVSI12568].
- Routing metrics [RVSI10230] and route maintenance algorithms [RVSI10232] for wireless multi-hop networks.
- Channel switching algorithms for multi-channel wireless networks [MAI10511].
- Admission control and resource allocation algorithms for single-hop wireless networks [RVSI09689].

2.3.5 The P2PSAP Communication Protocol

We have designed and developed the P2PSAP self-adaptive communication protocol dedicated to High Performance Peer-to-Peer Computing applications. The P2PSAP protocol of communication is an extension of CTP that is based on the concept of micro-protocols [MAI09513]. The idea is to apply the peer-to-peer concept to HPC for applications that are not necessarily data parallel. For example, we have concentrated on applications in optimization and numerical simulation that are solved via iterative or recursive methods. One challenge is to design a communication protocol that permits to have fast data exchanges between peers, e.g., in order to communicate updates. Another challenge is reconfiguration according to application requirements, i.e., schemes of computation, network topology, i.e., intra or inter cluster contexts and also multi network contexts. Several types of networks (e.g., Ethernet, Infiniband, Myrinet) have been considered [MAI13030]. This research study was conducted within the ANR project CIP.

2.4 Architectures for Communication and Service

This research considers both highly constrained environments of embedded systems as in the avionics and transportation domains and heterogeneous dynamic large-scale contexts, as ambient intelligence and smart services for energy management. The dynamic nature of such systems is addressed consistently at the different levels of communication. We handle this dynamicity considering both the evolving requirements of the network applications and the changing constraints of the environments in which they must operate.

In order to satisfy functional and non-functional requirements of distributed applications, we have designed and developed generic component-based and service-oriented dynamic communication architectures by using as a foundation for their autonomic management, formal (graph grammars) and semi-formal (ontologies) models to guide the required self-configuring and self-adapting capabilities at the different levels of the communication system.

Our activity has been initiated in the domain of networked collaborative enterprises and virtual organizations and has evolved towards enabling the support of Future Internet for Enterprises associating the Internet of Things and the Internet of Services domains.

The contributions cover web applications and IoT domains. They address the application domain of dynamic advanced distributed design and manufacturing and the related collaborative activities in cloud environments and Internet of Things and Services.

2.4.1 Future Internet for Enterprise systems and Advanced Manufacturing

2.4.1.1 *Autonomic Service Bus (ASB) for IT infrastructures*

At the middleware communication layer, the autonomic services provided by ASB is intended to deploy, configure and reconfigure adequate intra and extra bus mediation communication services able to guarantee the expected QoS performances of extended and dynamic enterprise networks [RVSI12317, MAI13541, MAI13565, MAI13109, MAI12073] while ensuring the secure access to resources and services at intra and inter-organizations levels [RVSI12184, MAI12156, MAI12188]. This solution has been developed in the framework of the IMAGINE IP-FP7 project, and deployed in the extended and virtual factories of a future living lab in collaboration with EADS as a Platform as a Service (PaaS) of an autonomic cloud-computing environment.

2.4.1.2 *QoS-aware Business Process and Service-based Systems Management*

Our aim is to define an end-to-end management framework based on models, methods and tools to enable the development of dynamic inter-organizational business processes (IOBP) [MAI13061, AP13593] and service-oriented systems. As first results, we have defined rich specifications and formal models [MAI13736], process view generation [MAI13594], service-based system selection [MAI14040] and composition [OPI14012, RVS14190], where functional and non-functional properties are considered. In the framework of this research work, the BPEL2FCR tool intended to formally validate choreographies of orchestrated BPEL processes has been developed [MAI12495].

2.4.2 Internet of Things and Amart Applications

2.4.2.1 *Hybrid Cloud Platforms Simulator*

In the context of the ANR project SOP, we elaborated solutions to optimize the use of hybrid platform (Peer-to-peer + cloud + personal computer) with SLA (Service Level Agreement) and energy constraints. Autonomic policy integrates a base of knowledge that contains graph rewriting rules for model transformation, DSL (Domain Specific Language) for representation and mathematical programming of optimal policies using the autonomic FRAMESELF framework developed in the theme [RVSI12702]. This work is connected to a long-term cooperation with IRIT-SEPIA on autonomic computing and energy management (co-supervision of 2

PhDs), and an international cooperation with "the Cloud Computing and Distributed Systems (CLOUDS) Laboratory, University of Melbourne" for a extension of the cloudsim simulator with DVFS (dynamic voltage and frequency scaling) capabilities [RVSI12703].

2.4.2.2 Management of Machine to Machine (M2M) Systems

The theme has a long experience in M2M systems with an international partnership in the USENETand A2NETS projects and recently, we are involved in the ETSI standardization activity and we are supported by the international Eclipse foundation for our M2M service platform, OM2M (Figure 4). Researches are focused on providing intelligent management for QoS and QoE in M2M systems and their cyber-physical applications based on semantic, graph modeling and autonomic computing. Ontology-based semantic models for M2M systems have been developed for managing self-deployment, self-configuration of sensors [MAI12670]. New lectures have been introduced at INSA-Toulouse based on our platforms OM2M and FRAMESELF.

2.4.2.3 Multi-layer Architectures Adaptation

Model-driven and rule-oriented dynamic architectural reconfiguration allows correct by design solutions to be built [RVSI09759, MAI09675]. This approach has been experimented for collaborative activities such as crisis management addressed in the project ROSACE. This approach has been applied for mastering the scalability and complexity of the management model in the heterogeneous network and devices context of M2M Networks in the A2NETS. For this purpose Graph Grammars models have been elaborated for managing context-aware reconfiguration. These contributions are related to the scenarios definition and components and services specification, to use M2M technology to enable cooperation and group communication [MAI08467]. We have implemented an algorithmic framework [MAI09029, RVS09509] using model-driven techniques to develop correct by construction reconfiguration policies [TH11156]. We have enriched SWRL rules to describe the context and reasoning related to the adaptation of configurations for different situations in the Framework FACUS [MAI09211, MAI10355]. We are now extending our work to address the design and dynamic reconfiguration of cyber-physical systems from physical layers to service and application layers in cooperation with the theme HOPES (MINC team) and IRIT (SEPIA team) in the context of the collaboration action CoDeM2M and in the context of two newly submitted H2020 projects (AAA4CPS and CYWORK).

2.5 Distributed Algorithms and Applications

Important advances in multicore architectures and great improvements in network technologies have characterized recent years. New concepts like computing accelerators, heterogeneous computing, peer-to-peer (P2P) computing and cloud computing have emerged. Conjointly, parallel and distributed computing have started to converge and new solutions for High Performance Computing (HPC), most of which concern data parallelism applications, like P2P HPC, have been proposed.

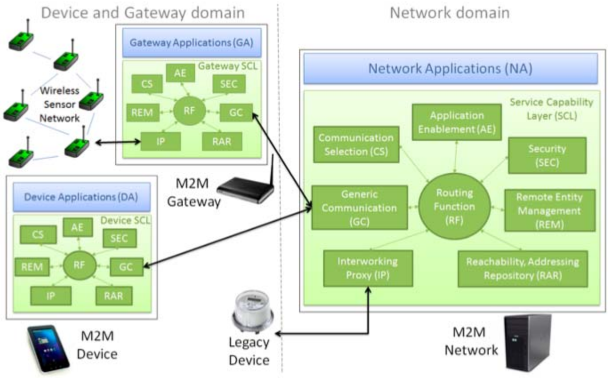


Figure 4: Architecture of the OM2M Platform

Our research in this context aims mainly at designing and analyzing efficient distributed or parallel algorithms that scale well, and at facilitating the use of massively distributed or parallel architectures for computing purpose.

2.5.1 Peer-to-peer HPC

In the context of the ANR project CIP originated and leaded by a researcher of theme RC, we have deeply investigated P2P HPC and contributed to the challenge of facilitating the use of massively distributed or parallel architectures for computing purpose. Our contributions has focused on HPC applications in optimization and numerical simulation that use iterative or recursive methods.

The challenge was to design P2PDC (Figure 5), an efficient decentralized environment that facilitates the implementation of distributed algorithms [MAI09748]. P2PDC uses the P2PSAP communication protocol that we have designed in order to facilitate data exchanges (§ 2.3.5). It relies on a limited set of operations of communication in order to facilitate programming. One of the originality of P2PDC is that the communication mode between any peers, e.g., synchronous or asynchronous, can rely on a combination of the scheme of computation that is selected at the application level, e.g., synchronous iterations or asynchronous iterations and elements of context like network topology at transport level. Combinatorial optimization applications like cutting stocks problems have been considered [MAI12183] Numerical simulation problems like the obstacle problem [MAI12157, MAI09748] or option-pricing problems have also been considered [MAI11037]. Computational experiments on several testbeds like PlanetLab or Grid5000 with hundreds of peers distributed on several sites have shown that the combination of asynchronous schemes of computation with the decentralized environment P2PDC is very efficient (almost linear speedups with Grid5000 and 256 machines in 5 cities).

Among the many results of the project, a cooperation with the Networked Systems Group at NICTA, Sidney Australia (that was not partner of the project) has started that has led to several common papers [MAI09748] [MAI14042] and student exchange (Figure 5 illustrates an application example).

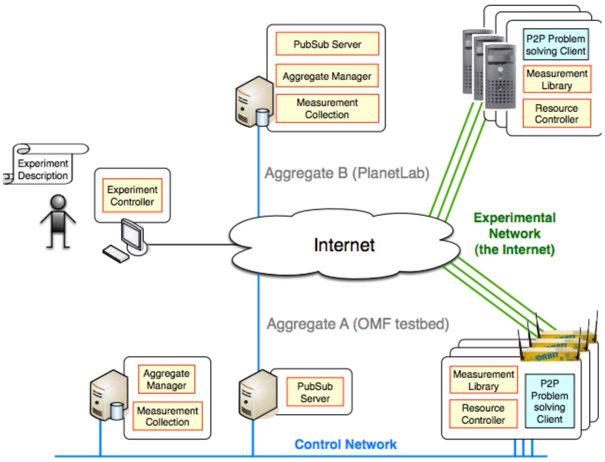


Figure 5: Example of Peer-to-peer Problem Resolution Using the P2PDC Framework

2.5.1.1 Heterogeneous Distributed Computing with Application to Optimization

We have been working on combinatorial optimization problems that occur in telecommunication and logistics. We have studied several techniques, like constraint rotation, for the solution of problems of the knapsack family [RVSII06834]). We have studied a heuristics [RVSII06539] dedicated to multidimensional knapsack problems which is based on dynamic programming and that has been quoted 40 times, (see Google Scholar). We have also studied exact methods for several problems of the knapsack family [RVSII10967], [RVSII09744], [RVSII10035]. Aside from sequential efficient approaches, we have considered the benefit obtained via distributed and parallel computing for the solution of difficult combinatorial optimization problems. We have concentrated in particular on new techniques related to heterogeneous computing that use Graphics Processing Units (GPUs) accelerators. The interdisciplinary research studies conducted at the cross section of Applied Mathematics and Computer Science have permitted us to obtain new results. Thanks to the NVIDIA Academic Partnership, we have designed, implemented and analyzed several GPU or multi GPU-based exact methods, like dynamic programming parallel algorithms [RVSII10009], branch & bound parallel algorithms [MAI12143], and Simplex algorithms [MAI11341]. We have obtained reductions in computing time by factors of 20 to 50 according to the method and problems considered. The papers on GPU computing have been quoted more than 85 times (see Google Scholar). The series of GPU computing methods can be combined in order to propose efficient hybrid parallel or distributed methods to solve several types of difficult combinatorial optimization problems.

2.5.1.2 Distributed Algorithms with Application to Micro Robotics Conveyor Systems

We have worked on several aspects related to distributed systems in two ANR projects with application to micro-robotics. Differentiation of micro-parts lying on a MEMS-based distributed system has been studied in the ANR project “Smart Surface”. The reconfiguration of a modular conveying system and optimal routing of parts and blocks has been studied in the ANR project “Smart-Blocks”. These two projects have permitted us to reinforce collaboration with FEMTO-ST and to design several distributed iterative algorithms to micro robotics applications, resulting in common publications [RVSII10640] and [MAI14295].

2.5.1.3 Grid computing and numerical simulation

Since 2009, we cooperate with the MINC team (theme HOPES) and the MESCAL team at INRIA on parallelization and optimal execution of electromagnetic simulation algorithms to compute the propagation of waves in oversized structure like airplanes. Models to predict execution time based on hybrid approach (past execution and code analysis), new parallel algorithms and dynamic management of experiments on grid and supercomputer allows a breakthrough of scale of simulation from one million to one billion of cells.

2.5.2 Algorithms for Distributed Checkpointing for Recovery and Causality Management in Asynchronous Group Communication

One open challenge in such systems is their efficient monitoring at runtime that needs the collection of information from which the system itself is able to detect, diagnose, and repair problems that result from failures in software and/or hardware components. For this purpose, communication-induced checkpointing (CIC) can be very useful. CIC aims at producing global consistent snapshots from which the system can recover. To achieve this, CIC solutions monitor the exchanged information among the processes to identify dangerous checkpointing patterns. When a dangerous pattern is identified, it is broken by locally triggering a forced checkpoint. In general, the main drawbacks of CIC algorithms are the amount of overhead per message and the induced storage overhead. To attack the overhead per message we developed the S-FI (Scalable Fully Information) algorithm that dynamically adapts the control information piggybacked. To attack the storage overhead we designed a delayed CIC approach [RVSI12600]. The S-FI algorithm is based on the immediate dependency relation and the delayed CIC approach on a set of safe checkpoint conditions that we defined. The results show that both works efficiently reduces the overhead.

2.6 Development of Experimental Platforms

2.6.1 LaasNetExp

Research in networking requires strong experimental assessment and validation. This requirement led to the continuous design, building, and management of an experimental platform allowing simulation, emulation and experimentation in real environments. This platform, named LaasNetExp (LAAS NETwork EXPerimentation) consists of around 50 versatile machines, monitoring equipment, switches, routers, 7 terminals, and a screen wall for visualizing running experiments and realistic traffic generators (http://hal.archives-ouvertes.fr/hal-00250238).

2.6.2 DMN/FoF Training Platform

We have developed an active, Collaborative, Semantic Driven and Experimental Learning Platform for the

Imagine Project, designed as an open-door platform for the European Factory of Future consortium (http://training.imagine-futurefactory.eu/moodle/). This platform integrates also learning material developed in the framework of regional (BQF/BQR Toulouse COMU) and international (PCP France-Venezuela) collaborations.

2.6.3 OM2M (APP CNRS 2014, ECLIPSE Project)

We have developed OM2M, the first Open ETSI-compliant M2M Platform (CNRS APP). OM2M is approved and diffused by the eclipse foundation. New collaborations with industrials and labs in several countries (France, Italy, Poland, India, Canada, Tunisia, Finland, Croatia) have started (http://eclipse.org/om2m/**).** The OM2M platform is used by the connected objects in ADREAM (Figure 6).

Figure 6: M2M Platform and the ADREAM Building

2.6.4 High Performance Computing Platform

RC contributes also to national or international platforms like GRID 5000 and PlanetLab for experimentations on both High Performance computing and networking.

2.6.5 ADREAM

RC has a strong participation in the ADREAM project, as the goal of its research is the design, the implementation and the validation of advanced communication networks and systems. In this area, it is in particular developing the basic machine-to-machine communication systems that will serve as a basis for the ADREAM and it is participating to the development of the multi-disciplinary modeling and software supports.

2.7 Tools and Demonstrators

RC members research work includes an important activity of software development. An excerpt of the main tools and demonstrators developed by RC members is listed in Table 1.

3 Academic Reputation and Appeal

3.1 Main International and National Collaborations

3.1.1 International Collaborations

We collaborate with Argentina (Univ. Buenos Aires), Australia (NICTA Sydney, UNSW Sydney), Brazil (UniCamp, CTI, Univ. Tecn. Federal do Parana, Campinas), USA (Northeastern, Univ. of Berkeley, Univ of Delaware), Canada (UWO Univ. of W. Ontario and Queen's Univ., Univ. of Dalhousie), Chile (Univ. of Chile), China (University of Science and Technology, Beijing), Mexico (CINVESTAV Mexico, INAOE Puebla, University of Nuevo Leon, Monterey), Morocco (INPT, ENSIAS Rabat, Unversity Hassan II), Tunisia (ENIS/FSGES/ISIMS. RedCAd Lab of Univ. Sfax, ENSI/Hana Lab and SUPCOM Univ of Tunis), Venezuela (Univ. de Los Andes ULA), Uruguay (Univ. de la Rep. de Uruguay), Iceland (Univ. of Reykjavik). These collaborations are conducted through joint publications, exchange of graduate students or PhD students or through funded collaborative actions or official collaboration conventions (STIC-AmSud, PHC Tournesol, Utique, Volubilis, CNRS/PICS, UPS/APC, MAE, IDEX).

Table 2: Main Tools and Demonstrators

Acronym	Description
GMTE	The Graph Matching and Transformation Engine (http://projects.laas.fr/GMTE/) CNRS License DL-N° 03998-02
NEST	(Network Engineering and Simulation Tool) is a consistent software suite for telecommunication network modeling, simulation, planning and supervision. It emanates from our research work and is being now developed in cooperation with QoS Design, a spin-off of LAAS-CNRS.
FRAMESELF	Frameself is an autonomic manager based on models and rules for supervision, analysis, planning and execution of reconfiguration actions in complex systems. (Approval of TTT support has been obtained for industrial exploitation). It is used by two labs (IRIT, INRIA-MESCAL)
OM2M	(Eclipse license, APP CNRS): supported and diffused by the eclipse foundation, used by industrials and labs in several countries (Italy, Poland, India, Canada, Tunisia, Finland, Korea, USA) http://eclipse.org/proposals/technology.om2m/
FACUS	FACUS is an extensible framework for the design and development of dynamically reconfigurable distributed collaborative applications. It manages the dynamic deployment of software components according to the evolving requirements of applications with awareness of the constraints of resources (energy, communication, processing)
DMN Living Lab	DMN Living Lab in Aerospace and Defense industry, EADS/LAAS - IMAGINE IP FP7 Project**:** In the framework of the IMAGINE project, EADS and LAAS-CNRS have developed the Aerospace and Defense Living Lab, intended to provide an experimental platform to support a Dynamic Manufacturing Network environment in the context of Virtual Factories of Future. (http://bit.ly/eads_laas_imagineLL). As members of the FInES European cluster (Future INternet Enterprise Systems) [FInES] part of this work has been presented during collaboration and standardization workshops
P2PDC	Decentralized environment for P2P HPC, used by NICTA (Sydney)
SSS	Smart Surface Simulator, used by Smart Surface project partners

3.1.2 Europe

For the past 5 years, our academic European collaboration included: Belgium (Univ. of Ghent, Alcatel-Lucent, Université de Liège, Université Catholique de Louvain), Italy (Poli Bari: collaboration since 2012 on ICN, University of Naples, Università della Calabria, Rende, University of Genova), Germany (Deutsch Telekom Labs, Fraunhofer: Institute for Manufacturing Engineering and Automation, IPA, Stuttgart, University of Passau), Spain (Advanced Network Architectures Lab, Technical University of Catalonia, UPC, Univ of Malaga, BSC: Barcelona Supercomputing Center, Telefonica I&D), University Carlos III of Madrid, University of Seville), Finland (VTT Oulu: Collaboration since 2007 on M2M technology), UK (University of Warwick, Coventry, Lancaster university, King's College London, University of Manchester, Royal Holloway University, London), Portugal (INESC, Lisboa), Danemark (IT University Copenhagen), Hungary (Budapest University of Technology and Economics).

3.1.3 National Collaborations

The theme RC has a collaboration activity with the regional labs IRIT (SIERA, SEPIA, ACADIE), ISAE, ONERA (CERT) and many national labs including: ONERA (MOIS), IRISA (Archware and REOP), UPMC (LIP6), SAMOVAR TSP (METHODES, ACME, R3S), France Telecom R&D, LORIA (SCORE), Télécom Bretagne, INRIA/ENS Lyon (Lyon), INRIA (TRISKELL), CEA-Leti, Telecom-Paris-Tech, EPROAD (ROAD) Amiens, FEMTO-ST Besançon (AS2M) and Montbéliard (OMNI), LIPN (AOC) Université de Paris 13.

Local collaborations at LAAS are with GE (ESE and ISGE) HOPES (MINC), IC (TSF and VERTICS), DO (DISCO, ROC and MAC) and ROB (RIS and RAP).

3.2 Journal Editorial Boards

3.2.1 National

Researchers of the theme RC serve in national journal as guest editors and reviewers (e.g., RNTI).

3.2.2 International

Researchers of the theme RC serve in international journal as associate editors, guest editors and reviewers. They also serve as members or directors of periodic series (LNCS, ISTE).

Editorial membership includes: IEEE Transaction on Network and System Management, IEEE Transactions on Networking, Performance Evaluation (Elsevier), The Journal of Scientific Programming, published (IOS PRESS), International Journal on "Interactive Technology and Smart Education (Emerald Gp., UK), The serie of Lecture Notes in Computer Science (LNCS) "Transactions on Petri Nets and Other Models of Concurrency" (ToPNoC), IET Wireless Sensor Systems, Open Journal of Information Systems.

Guest Editor activity includes: Wiley Journal on Concurrency and Computation: Practice and Experience, International Journal of Network Management, Journal of Software and Systems, Future Generation of Computing Systems, IEEE Transaction on Network and System Management, IET Wireless Sensor Systems, Revue des Nouvelles Technologies de l'Information.

Series Editorial membership: Direction of the Series of books on Networking Architecture for the *Hermes Science Publishing* for the books published in French, and for the *two publishers, ISTE* for Europe and *John Wiley and Sons Inc.* for the rest of the world, for all books published in English; co-direction of the serie of book "pour l'ingénieur" for Presses Universitaires du Midi.

3.3 Organization of Major Conferences and Workshops

Members of the theme RC participate in the organization of international and national conferences and workshops addressing their different research areas. These activities includes Program Committee membership with up to 150 conferences, symposiums and workshops over the past period in the field of distributed computing applications and services, communication networks including network and software design and management, traffic and software engineering, performance modeling and analysis.

Members of RC chaired the Steering Committees of the 23rd and 22nd IEEE International Conference on Enabling Technologies: Infrastructures for Collaborative Enterprises (IEEE-WETICE'2014, IEEE-WETICE'2013) and the IEEE 4th, 2nd and 1st Symposium on Network Cloud Computing and Applications (NCCA'2104, NCCA'21012, NCCA'2011 -in Toulouse-).

Members of RC are in the Steering Committee of La Conférence internationale sur les NOuvelles TEchnologies de la REpartition (NOTERE) since 2011), et le Colloque francophone sur l'ingénierie des protocoles (CFIP) since its beginning, La Conférence sur la Sécurité des Architectures Réseaux et des Systèmes d'Information (SARSSI) since 2013, Conference on Parallel, Distributed and Network-based Processing (PDP) since 2009, the IEEE International Conference on Internet of Things (IEEE iThings) since 2014.

Members of RC chaired the Program Committee of the national (bilingual) conferences on Communication Networks, Software, Distributed Computing and Applications: 10ème conférence internationale sur les NOuvelles TEchnologies de la REpartition (NOTERE'2010), 4ème et 6ème Conférence francophone sur les Architectures Logicielles (CAL'2010, CAL'2013 in Toulouse)

Members of RC chaired the Program Committee of: 17th conference on Parallel, Distributed and Network-based Processing (PDP'2009), IEEE 1st International Symposium on Network and Cloud Computing and Applications (NCCA'2011 in Toulouse), 7th European Conference on Software Architecture (ECSA'2013), 8th International Conference on Network and Service Management (CNSM'2012), International Conference on Communication and Signal Processing (CSP'2013), 12th Conference on Applied Chryptography and Network Security (ACNS'2014), 21st IEEE International Conference on Enabling Technologies: Infrastructures for Collaborative Enterprises (IEEE-WETICE'2012 in Toulouse), 2nd and 1st International Conference on Models and Ontology-based Design of Protocols, Architectures and Services (MOPAS'2011, MOPAS'2010).

Members of RC served as General Co-Chair of: IEEE International conference on Internet of Things (IEEE iThings'2013), 21st IEEE International Conference on Enabling Technologies: Infrastructures for Collaborative Enterprises (IEEE-WETICE'2012 in Toulouse), and Honorary Chair of the 16th IEEE International conference on Emerging Technologies and Factory Automation (IEEE ETFA'2011 in Toulouse).

Members of RC chaired the committees for selection of Workshops satellite of the internal conferences: IEEE iThings 2012, IEEE-GreenCom'2012, IEEE-CPSCom'2012, IEEE-HPCC'2014, ECOOP'2013, ECSA'2013, ECMFA'2013.

Members of RC chaired several international workshops, including: TMA'2009; PCO'2011, PCO'2012, PCO'2013, PCO'2014; GPU Computing'2012, GPU Computing'2013, GPU Computing'2014; SESoS'2013, SESoS'2014; RAMCOM'2014; AROSA'2011, AROSA'2013, AROSA'2014; CAGing'2012, CAGing'2013 CAGing'2014; Madyne'2012, Madyne'2013, Madyne'2014,

3.4 Major and Long Term Visits

3.4.1 Sojourns of Researchers Abroad

Different visits were made to international Labs and Universities. The list includes:

- Scientific visit to Prof. M. Ott in the Networked Systems group of NICTA, Sydney during 5 months.
- Scientific visit to Prof. D. Pisinger in University of Copenhagen, Denmark during 2 months.
- Scientific visit to Prof. A. Makowski at Univ. of Maryland at College Park, during 2 months.
- Scientific visit to Prof. R. Nunez-Queija at Univ of Amsterdam during one month.
- Scientific visit to Prof. A. Seneviratne at the Network Research Group at NICTA (National ICT Limited) and to Prof. R. Malaney at the School of Electrical Engineering and Telecommunications of UNSW (University of New South Wales) at Sydney, Australia during 2 months.
- Scientific visit to Prof. R. Willrich at the University of Santa Catarina, Florianópolis, Brésil during one month.
- Scientific visit to Prof. R. Buyya at University of Melbourne, Australia during one month.
- Scientific visit to Pr. M. Capretz University of Western Ontario, Canada during twice one month.

3.4.2 Researchers Hosted

We have hosted about 50 researchers and PhD students from France, Italy, Spain, USA, Canada, Mexico, Brazil and Tunisia in the context of on-going collaboration funded by projects or of informal collaboration funded by LAAS or the lab of origin or by third parties. We can highlight the followings long period visits:

Researchers: Alfredo Grieco (Poli Bari, Itlay), **Rhonda Righter** (Univ. of California at Berkley, USA), Bruno Gaujal (INRIA Grenoble), **H. Tambine** (Supelec), **M. Jonckheere** (CONICET, Argentina), **J. Walrand** (UC Berkeley), **Miriam Capretz** (Univ. of Western Ontario, London, Canada), **Mohamed Ibn Kahla** (Queen's University, Kingston, Ontario, Canada), **Saul Pomares Hernandez** (INAOE, Puebla, Mexico), **Ismail Bouassida Rodriguez** (ISIMS, Univ. of Sfax, Tunisa), **Riadh Ben Halima** (ENIS, Univ. of Sfax, Tunisia). **Gene Cooperman** (Northeastern University, Boston), **Fabio Gomez Estern** (Univ. of Seville, Spain), **Rene Pegoraro** (UNESP, Brazil).

PhD students: **David Allison** (Univ. of Western Ontario, London, Canada), **Sergi Rene** (Departament d'Enginyeria Telemàtica, Univ. Politècnica de Catalunya, UPC), **Elvis Vogli** (Poli Bari, Itlay), **Ilhem Ammar**, **Saoussan Cheikhrouhou**, **Nessrine Khebou**, **Houda Khlif**, **Imen Tounsi** (REDCAD Lab, Univ of Sfax, Tunisia), **Marwa Meddeb**, (HANA Lab, ENSI, Univ of Mannouba, Tunis, Tunisia).

3.5 Scientific Evaluation Committees

3.5.1 International

RC members have served as expert for Research Agencies: Belgium, The Netherlands, Switzerland, Israel and Canada during the last period.

3.5.2 National

Several RC members have served as expert or review board member for ANR project and ANRT (several projects from several calls). One RC member has also served as expert for the Programme "Future et Ruptures" of Institut Télécom, 2012. Two RC members were expert for evaluating a UNIT (Université Numérique Ingénierie et Technologie) project, France, in 2009 and 2010. Members of RC have been experts in AERES evaluation committees.

3.6 Major Roles in National Animation and Evaluation Structures

3.6.1 CNRS and University

Roles in Animation by Members of RC include:

- Director of UPSSITECH Engineering School of Univ. Toulouse 3 (P. Sabatier)
- Head of Department of Electrical and Computer Engineering (DGEI), INSA Toulouse
- Head of Networks and Telecommunications Department (RT), IUT Blagnac, Univ. Toulouse 2
- Responsible of CISCO Academy and Apple developer University, INSA Toulouse
- Coordinator of International Exchange Latin American Programs, INSA Toulouse
- Chargé de Mission Innovative Pedagogy, INSA Toulouse

Members of RC are also involved in the different councils and committees, including the following excerpt:

- Member of the committee devoted to the IdEx project contracting, Univ. Toulouse (COMUE)
- Member of the committee devoted to the elaboration of the UT status, Univ. Toulouse (COMUE)
- Member of the Council of Faculty of Science and Engineering (FSI), Univ. Toulouse 3 (P. Sabatier)
- Member of the Collège Scientifique EEA, Univ. Toulouse 3 (P. Sabatier)

3.6.2 GDRs

Members of RC are actively participating in different working groups of the GDR ASR (*Architecture, Systèmes, Réseaux*) and GDR GPL (*Génie de la Programmation et du Logiciel*). An ex-member of RC is the head of the GDR ASR.

3.7 Scientific Societies

3.7.1 International

Most of RC researchers are members of international scientific associations including: IFIP, IEEE and ACM. In 2013, one RC researcher has been elected member of IFIP W.G. 7.3 Computer Performance Modeling and Analysis Working Group. One RC researcher is IEEE senior member.

3.8 Awards and Distinctions

The members of RC have received different awards and distinctions including best papers in international conferences, nomination in standardization organizations, awards for European projects and industrial grants:

Best Paper awards: CNSM'2011 (MAI11362), ECEC'2012 (MAI12156), ICC'2012 (MAI12069), MoMM'2012 (MAI11548), ECEC'2014, WETICE'2014

Standardization organization expertise: One RC member is selected as an international M2M expert to develop the interoperability tests based on the ETSI M2M architecture, and to provide technical support for the ETSI M2M Plugtest event 2014.

ITEA2-2010 SILVER AWARD for the USENET project in which we were actively involved

NVIDIA Academic Partnership (October 2010): NVIDIA endowed CDA team with two Tesla C2050 GPU computing processors (each one with 448 cores).

Airbus Group (EADS) Foundation Grant (oct 2012): Optimal and decentralized control of communication networks

Thalès Alenia Space Grant (Mar. 2014): Energy-aware transport protocols design.

4 Interaction with Social, Economic and Cultural Environment

4.1 Projects with Industrial Partners

RC researchers have close long term and recent collaborations with industry.

We can highlight for example the recent collaboration with OVH (leader of Cloud Computing infrastructures in Europe) that was initiated since their involvement in a collaborative project we elaborated and which now continues with educational benefits for INSA Toulouse. Recent collaboration with OVH results in an extension to educational activities aiming to building a Pedagogical Virtual Learning Environment. The project aims to allow students to design and develop virtual enterprise infrastructures and to be aware about the non-functional properties in terms of scalability, dependability, privacy and security. This partnership with OVH also includes the active participation of OVH engineers and researchers in the definition and the supervision of undergraduate and master research and innovative projects and internships.

We can also highlight a long-term collaboration with Airbus Group in the context of direct partnership, in the context of AIRSYS Lab (involvement in Roadmap definition, IMAP project) and in the context of collaborative projects (e.g., FP7 IP-IMAGINE project).

The most recent collaboration with LAAS-Airbus group results in elaborating the Dynamic Manufacturing Networks Living Lab: Based on the platform and methodology developed in the framework of the FP7 IMAGINE European Project, a very productive collaboration has been established between LAAS-CNRS and Airbus group (EADS) in order to design, develop and exploit a Living Lab experimental platform. This Living Lab is intended to provide a real ecosystem where diverse actors including industrial, engineers, researchers and students collaborate on common projects including not only learning and research activities but also industrial standards implementation and evaluation. The Living Lab will be funded and supported by the LAAS and Airbus group until 2017.

Additional long term collaboration involves Orange and France Telecom, BULL, ACTIA, Thales. A recent collaboration is established around our M2M activity with BULL and Orange who are using om2m, our open source M2M service platform implementation. A collaboration is established with R.Tech in the aerospace domain on the topic: parallel platform using GPUs with application to design for demise

Our activity also includes participation in standardization groups, and open source foundations namely:

- Participation to the Future Internet Enterprise Systems (FInES) European cluster which aims at enabling enterprises, including SMEs, by means of ICT, to exploit the full potential of the Future Internet. http://www.fines-cluster.eu/
- Participation to the European Telecommunications Standards Institute (ETSI) working group on M2M. A member of RC is working on the test elaboration activity for M2M platforms interoperability.
- Representation of CNRS at the European Telecommunications Standards Institute since 2013 with close collaboration with Alcatel-Lucent, the leader of M2M working group.
- Representation of CNRS at Eclipse Foundation since 2013 with close interaction with industrials working on M2M such as Sierrawireless.
- Collaboration with the openESB community for semantic and autonomic extensions since 2013.

The projects established by the RC theme aim at investigating new research directions and exploitation of the confirmed research results by the industrial partners in different application domains. The projects are of different natures, including collaborative projects at the national and European levels, networks of excellence, industrial partnerships, and PhD Thesis funding. We highlight the following projects of the period:

- **National Projects (ANR, OSEO, FUI)**

On-going: [SOP] [NEC] [Smart Blocks]

Recent: [Smart Surface] [CIP] [SATRIMMAP] [RESCUE] [OSEO/AMIC-TCP] [ECOSCELLS] [PLATSIM] [SatNGGN]

- **European Projects (FP6 & FP7: IP, STREP, COST, NoE, ITEA2)**

On-going: **[ONTIC] [PANACEA] [IMAGINE]**,

Recent: **[A2NETS] [NEWCOM++] [ECODE] [USENET] [TMA-**COST action IC 0703]

- **Industrial Partnership**

On-going: [CIFRE R.TECH] [CIFRE DELL] [EADS-OPTNET] [CIFRE THALES] [CIFRE QoS Design]

Recent: [R&T CNES- 08-09, 08-10, 10-11] [Feel@Home] [CIFRE Orange]

- **Regional Projects**

On-going: [SYCYPH]

Recent: [HEMERA] [IMAP] [ROSACE]

4.2 Activities related to Carnot label

One member of RC ensures the liaison of the "Filière Numérique" for Carnot Institutes.

4.3 Other Major Innovation Activities

- RC members have been involved in different wokshops of "*Club des Affiliés*" as speakers. We can also highlight strong involvement in the organization of "*Enjeux et défis de l'intégration d'objets intelligents dans le secteur pétrolier Jeudi 12 septembre 2013, au LAAS-CNRS*"
- One RC member was seconded to the LAAS Start-Up QoS Design' for two year during the last period.

4.4 Scientific Popularization

RC researchers actively, regularly and frequently participate in different events for science popularization and technology demonstrations including:

- LAAS open doors and fête de la science and ADREAM visits for journalists and other visitors (about 10 to 15 by year), mainly for platform-based demonstrations (LAASNetexp for Network Security and OM2M/FRAMESELF platforms for connected objects IoT and Ambient Intelligence applications), see Le Monde journal report of January 2012 (URL) where RC members have participated to introduce the ADREAM activities and demonstrations made by the RC theme.
- Documentary "Ambient Intelligence" of the documentary series "The World of Tomorrow" broadcasted by TV "AB Encyclo" on May 13 2014 (URL).
- Reports in newspapers or letters: a) "Gestion intelligente de l'énergie via la communication directe entre machines", p. 21, in Energie, regards croisés de chercheurs, la dépêche du midi, CNRS, collection petit illustré N°14, 02/2014 (URL) [RVV12701] b) Communications et applications Machine-to-Machine La lettre du LAAS, num. 40 July 2012 (URL).

5 Involvement in Training through Research

5.1 Leading Roles in Doctoral Schools

All RC members are affiliated either to EDSYS (ECOLE DOCTORALE SYSTEMES) or EDMITT (Ecole Doctorale Mathématiques, Informatique, Télécommunications de Toulouse) doctoral schools. One member of RC is in the steering committee of EDSYS. Another member of RC is in the steering committee of EDMITT. One RC member is the representative of the doctoral school EDSYS in charge of HDR applications at Univ. Toulouse 3. Two members of RC are Member of the Board of EDSYS, and three members of RC are Member of the Board of MITT.

5.2 Research Seminars in Training Programs

5.2.1 "Seasonal" Schools

RC researchers are involved in regular seasonal schools organization such as RESCOM (yearly), and ponctually in focused seasonal schools such as IoT/M2M spring school'2014, Ecole d'été temps réel (ETR'2009), "Internet of Things" 15 May 2014 at INSA Toulouse. RC researchers also involved in shadow committees of conferences for training students to the reading and evaluation of scientific research papers.

5.2.2 Advanced University Courses

Most of RC researchers are involved in training and education activities. Our activity includes the involvement of Professors and CNRS researchers in France (mainly in Toulouse) and abroad. We can highlight the CNRS researcher involvement at INSA, ISAE, Univ. Toulouse 3 for advanced lectures in Master level. New pedagogical methods have been introduced by RC members at INSA mainly using computer-based learning [5] and problem-based learning [MAI10055] for the last 3 years of this period. Specific lectures also have been delivered to Master students at Univ. Toulouse 3 for initiation to research activities.

5.3 PhD and Internship/Master Programs

5.3.1 Thesis Supervised

- Number of PhDs (ratios wrt Permanent members): 33 current PhD and 33 alumni for 21 researchers. This gives almost 1,5 PhD/Permanent for current and alumni.
- Future positions of PhDs students: All alumni PhD students are now working in industry or in University in France or abroad

5.3.2 Co-Supervised Thesis

Different PhD theses have been/are co-supervised with international or national universities. At the International level, most of them have been associated with an agreement of joint supervision ("convention de cotutelle") between Toulouse University (INSA, Toulouse 1 and Toulouse 3) and abroad universities (Tunisia, Canada). The list includes:

- D. Allison between INSA Toulouse and Univ. Western Ontario, Canada.
- S. Khemakhem between Univ Toulouse 3 and Univ. Sfax, Tunisia
- I. Bouassida-Rodriguez, K. Fakhfakh, I. Lahiani Abdennadher, A. Chaabane Guedhrib, I. Guidara, between INSA Toulouse and Univ. Sfax, Tunisia.

[5] For an excerpt, see moodle.ypbl.net (login: guest_sara, passwd: sara2014) or https://moodle.insa-toulouse.fr/course/index.php?categoryid=90

Four new joint supervision actions are being planned for 2014 by collaboration between Univ. Toulouse, Univ. of Mexico (INAOE La at Puebla), Northern University at Boston, MA, USA, and Univ. de Sfax, Tunisia, Univ. of Science and technology Beijing, China.

At the National level, we have participated to local joint supervision with other teams at LAAS or IRIT and Grenoble:

- M.Alexandru (defended on: 14 December 2012) co-supervised with HOPES (MINC) at LAAS-CNRS
- O. Mokrenko (started in 2013) co-supervised with CEA-Leti, Grenoble
- C. Ruiz (started in 2011) co-supervised with MESCAL-INRIA, Grenoble
- C. Eichler (started in 2011) co-supervised with SEPIA-IRIT, Toulouse

5.4 Teaching and Education Materials

RC researchers contribute to producing teaching and education materials including handouts for students, technology cookbooks and 3 books published by:

- Presses Universitaires du Mirail on “programming languages”
- Wiley-ISTE on “Transport Protocols” and on “SOA Platforms in Cloud Computing Architectures”.

A Learning Platform has been developed in the framework of the FP7 European IMAGINE Project (2011-2014), to host and teach courses in the area of Dynamic Manufacturing Network (DMN). Current learning platform users include engineering students from various European and non-European universities, industrials, standardization actors and researchers.

The Platform has been enhanced to host the courses of other European Projects in the area of Factories of Future (FoF), resource have been provisioned until 2017.

A member of RC is the Creator and co-editor of the series of books "for the engineer" published by the Presse Universitaire du Mirail (PUM of Univ. Toulouse 2)

5.5 PhD/HdR Committees

RC researchers have participated to 57 PhD and 3 HDR Jurys: 49 in France (Paris, Lyon, Rennes, Brest, Nancy, Nantes, Montbéliard, Pau, Toulouse, etc.) and 11 abroad (Austria, Canada, Italy, Luxembourg, Netherland, Mexico, Tunisia) as a reviewer (35), president (7) or member (18) of the Jury.

5.6 Faculty Selection Committees

Members of RC have participated to different selection committees in Toulouse, in France and abroad.

5.6.1 National and International

In France different RC members have served for the selection committees in France. The list includes the following committees: FSC Univ Lyon 1 -MCF-2506 (2014), FSC INSA Lyon -MCF-0548 (2014), FSC Univ Nantes MCF-4076 (2012) , FSC Univ Nantes PR-0936 (2011).

One RC member has served as an expert for Univ Purdue USA- Professor Promotion.

5.6.2 Local

Locally, RC members have served for the following selection committees: CS UPS-MCF-1170, CS MCF 61-27 Univ. Toulouse 2, CS MCF 27-61 Univ. Toulouse 2, CS MCF 61 Univ. Toulouse 2.

IV - Robotics (*Robotique* — ROB)

Leader: R. Alami

Research Teams: Movement of Anthropomorphic Systems (GEPETTO) – Robotics, Action, and Perception (RAP) – Robotics and Interactions (RIS)

Keywords: Motion Planning, Deliberation and Task Planning, Visio-auditive Perception, Human-robot Interaction and collaboration, Multi-robot Cooperation, Humanoid Motion Generation and Control, Human Motion, Control Architectures, Sensor Integration, Learning, Sensor-based Robot Control, Autonomous Mobile Manipulation

Personnel Status (as of June 30, 2014):

Team — Gepetto	Movement of Anthropomorphic Systems (Mouvement des Systèmes Anthropomorphes)
Leader	P. Souères (DR)
Permanent Researchers	F. Lamiraux (DR), J.P. Laumond (DR), N. Mansard (CR-HDR), O. Stasse (DR), M. Taïx (MCF-HDR), B. Tondu (PR)
PhD Students	G. K. Hari Shankar Lal Das (15/10/2013), K. H. Koch (1/10/2010), J. Mirabel (1/04/2014), M. Naveau (1/10/2013), A. Orthey (1/10/2012), O.E. Ramos Ponce (1/10/2011), O. Roussel (1/09/2012), A. Simaite (1/10/2013), C. Vassallo (15/10/2013), Alumni: O. Kanoun [01/09/06-26/10/09], M. Poirier [01/10/06-15/10/09], A. Nakhei [01/10/06-25/09/09], A. Herdt [01/01/09-30/06/10], M. Tran [01/10/06-01/01/10], A. Truong [15/09/07-31/08/10], F. Montecillo [01/10/07-30/09/10], M. Sreenivasa [21/01/08-30/04/11], D. Flavigné [01/10/07-30/09/10], S. Dalibard [01/11/07-16/10/11], C. Halgand [01/10/07-29/09/11], N. Perrin [01/09/08-24/10/11], L. Saab [01/10/08-31/10/11], S. Hak [15/11/08-15/11/11], T. Moulard [01/10/09-31/10/12], D. Dang [15/10/09-4/11/12],
Post-docs; Engineers	M. Benallegue [05/2013], B. Coudrin [01/2014], A. Del Prete [01/2014], P. Salaris [02/2014], N. Abe [04/2014] Alumni: 0. Kanoun[10/2009-09/2010], A. Nakhei[09/2009-04/2010], L. Saab[11/2011-08/2012],
Visiting Researchers (Affiliation, Country, Period)	K. Mombaur (Heidelberg Univ. DE)[07/2010-04/2012], T. Tsuji (Kyushu Univ. JP)[05/2012-06/2012], K. Harada (AIST Tsukuba, JP) [09/2008-10/2008], T. Bretl (Univ. Illinois, US)[06/2013-12/2013], Y. Huang (Beijing Univ. CN)[06/2013-06/2014], F. Kanehiro [11/2009-01/2010], M. Morisawa (AIST Tsukuba, JP)[03/2009-03/2010], E. Yoshida (AIST Tsukuba, JP)[09/2005-07/2009]
Team — RAP	**Robotics, Action, et Perception (*Robotique, Action, and Perception*)**
Leader	P. Danès (PR)
Permanent Researchers	V. Cadenat (MCF-HDR), M. Devy (DR), A. Herbulot (MCF), F. Lerasle (PR), A. Monin (CR-HDR, from LAAS/MRS team) [01/06/2012, E. Montseny (MCF, from LAAS/MRS team) [01/06/2012], G. Montseny (CR-HDR, from LAAS/MRS team) [01/06/2012], J. Piat (MCF) [01/09/2011], M. Renaud (PR Emeritus), B. Vandeportaele (MCF, from LAAS/RIS team) [01/10/2013] Retired: M. Courdesses (PR), [04/2012]
PhD Students	A. Alhamwi [01/10/2012], A. Aouina [29/09/2010], F. Brenot (with LGP, Tarbes) [01/12/2012], G. Bustamante [01/10/2013], F.X. Decroix (with IRIT, Toulouse) [01/10/2013], P. DuboscIard (CIFRE with Alpha MOS, Toulouse) [01/06/2012], S. Durola [01/10/2007], W. Filali [10/2009], L. Fitte-Duval [01/11/2013], R. Fleurmond (with LAAS/RIS) [01/10/2012], L.Fagot-Bouquet (with CEA-LIST, Saclay) [13/06/2014], M. Futterlieb [15/01/2013], A. Izaute (CIFRE with AKKA Technologies) [15/07/2013], M. Lakrouf (with USTHB, DZ) [15/05/2013], G. Manfredi [01/01/2011], L. Marti (CIFRE with ORME, Toulouse) [06/02/2012], J.-T. Masse (CIFRE with MAGELLIUM, Toulouse) [10/10/2011], C. Mollaret (with IRIT, Toulouse) [01/09/2013], P. Paillet (with CEA-LIST, Saclay) [12/2011], S. Petrocelli (with Mines-Albi & ICA, Albi) [01/11/2012], A. Rusu (with ONERA/CNES, Toulouse) [03/10/2011], N.K. Sallem [15/12/2007], L. Thomas (CIFRE with AIRBUS, Toulouse) [07/12/2009], D. Tortei (with U. Novi Saad, RS) [13/03/2013] Alumni: W. Ait-Fares (with Rabat Univ, MA), [09/2013], D.L. Almanza-Ojeda [01/2011], D.A. Botero Galeano (PhD with LAAS/N2IS team) [12/2012], B. Burger (with IRIT, Toulouse) [01/2010], J.M. Codol (CIFRE with NAV ON TIME, Toulouse) [02/2013], B. Coudrin (CIFRE with NOOMEO, Toulouse, and Mines-Albi & ICA, Albi) [03/2011], B. Ducarouge (with Mines-Albi & ICA, Albi) [09/2011], A. Durand Petiteville [01/2012], T. Germa [06/2012], A. Gonzalez [07/2013], J. Harvent (with Mines-Albi & ICA, Albi) [11/2010], M. Ibarra Manzano (with LAAS/N2IS team) [01/2011], R. Lopez (CIFRE with Collecte Localisation Satellites, Ramonville Saint-Agne) [07/2013], D.A. Marquez Gamez [10/2012], B. Meden (with CEA-LIST, Saclay) [01/2013], A.A. Mekonnen [03/2014], A. Portello (with ISIR, Paris) [12/2013], Y. Raoui (with Rabat Univ, MA) [04/2011], B. Van Pham (with LAAS/RIS) [11/2010]
Post-docs; Engineers	A.A. Mekonnen [03/2014], S. Larnier [09.2013], A. Portello (Assist. Prof. INSAT) [12.2013] Alumni: J. Douet (Transfer Engineer with TTT) [09/2012-12/2013], A. Durand Petiteville (Assist. Prof. UPS) [01/2012-08/2012], M. Fontmarty (Assist. Prof. INSAT) [12/2008-08/2010], D. Geronimo [02/2011-07/2011], V. Ila [10/2010-12/2011], D.A. Marquez Gamez (Assist. Prof. INSAT) [09/2012-08/2013], A. Skaf [05/2010-11/2011], J. Sola Ortega (with LAAS/GEPETTO) [04/2008-06/2010]
Visiting Researchers (Affiliation, Country, Period)	Affiliates: P. Chalimbaud (MCF IUT Tarbes) [2009-2014], T. Sentenac (Assoc. Prof. Mines Albi & ICA) [2009] Visiting Researchers: D.F. Coutinho (UFSC, BR), A. Marin Hernandez (Univ, Veracruzana, MX) [09.2011-02.2013], N. Ouadah (CDTA, DZ), D.Oualid (CDTA, DZ) [05.2012-06.2012], L.A. Pereira (UFRGS, BR), A. Salton (PUCRS, BR), M. Torres Torriti (PUC Chile, CL) Visiting Doctoral Students: A.Berguia (Rabat Univ., MA) [09/2013-10/2013], H.Carrillo (Javeriana, Bogota, COL) [04/2010-07/2010], J.O. Esparza Jimenez (ITESM Monterrey, MX) [09/2013-08/2014], Z.Irki (EMP, Algiers, DZ) [11.2009-02.2010], M.Lakrouf (CDTA, DZ) [05.2012-06.2012], F. Madrigal Diaz (Univ. Guanajato, MX), T. Mizumoto (Kyoto Univ, JP) [11/2010-12/2010], T. Yoshida (Tokyo Tech, JP) [11/2010-12/2010], I. Zuriarrain (Mondragón Univ, ES)

Team — RIS	Robotics and InteractionS
Leader	Rachid Alami (DR)
Permanent Researchers	Juan Cortès (CR), Antonio Franchi (CR), Malik Ghallab (DR), Felix Ingrand (CR), Simon Lacroix (DR), Thierry Simeon (DR), Daniel Sidobre (MCF-HDR) Alumni: Raja Chatila (DR; now ISIR, Paris) Christopher Mei (CR; now Microsoft, Seattle, USA), B. Vandeportaele (MCF, joined RAPon 01/10/2013); Passed away: G. Giralt (02/2013)
PhD Students	Arthur Bit-Monnot, Alexandre Boeuf, Laurent Denarie, Didier Devaurs, Michelangelo Fiore, Renliw Fleurmond, Mamoun Gharbi, Romain Iehl, Harmish Khambhaita, Pierrick Koch, Raphaël Lallement, Artur Maligo, Ellon Mendes, Grégoire Milliez, Alexandre Ravet, Cyril Robin, Elena Stumm, Benjamin Vadant, Ran Zhao Alumni: P.Theodorakopoulos (05/2009), L. Marin (11/2009), C. Berger (12/2009), D. Le (09/2010), M. Gharbi (11/2010), B. Pham (12/2010), A. Belbachir (02/2011), S. Alili (04/2011), B. Bounab (06/2011), X. Broquère (07/2011), N. Muhammad (02/2012), A.K. Pandey (06/2012), M. ALi (07/2012), S. Lemaignan (07/2012), Al Bluwi (09/2012), A. Degroote (10/2012), M. Warnier (10/2012), J. Mainprice (12/2012), R. Boumghar (06/2013), C. Roussillon (10/2013), W. He (10/2013)
Post-docs; Engineers	Nemanja Rakicevic, Renaud Viry, Wuwei He, Scot McGregor Alumni: Z. Bo, R. Ros Espinozza, E.A. Sisbot, A. Mosteo, Yi Li, J.P. Saut, R. Tadakuma, S. Lemaignan, M. Warnier, Lavindra De Silva, A. Clodic, A. K. Pandey (07/2012 - 03/2014), M. Gallien, Luis Manso, A. Degroote, Wuwei He (11/2013)
Visiting Researchers (Affiliation, Country, Period]	W. Ruml (New Hampshire Univ, USA. 07/2013 – 07/2014), A.Mouaddib (Pr, GREYC, 01/2012 – 01/2013), M. Manubens (UPC, SP. 06/2012 – 06/2013), Luis Manso (University of Extremadura, SP, 09/2013 – 01/2014)

1 Presentation

1.1 Objectives and Scientific Positioning

The Robotics (ROB) theme area conducts research along several axes involving perception, motion, manipulation, decision-making, communication and interaction between the robot and its environment: the other robots, humans and ambient intelligence systems.

ROB investigates four strategic streams: interactive and cognitive robotics, human and anthropomorphic motion, aerial and terrestrial field robotics, algorithms for molecular motion.

These research activities also involve collaborative investigations with research on living systems such as neurosciences, cognitive sciences and biochemistry.

One main feature of the robotics research at LAAS concerns the robot itself as an object of study i.e., an artificial entity endowed with integrated sensori-motor and cognitive abilities and acting in an open environment.

The main research topics are:

- Environment perception and modeling,
- Navigation, localization, motion planning and control,
- Natural, artificial and virtual motion
- Manipulation planning and control
- Autonomous decision making, temporal planning, learning
- Control architectures, embedded systems, robustness and fault tolerance
- Human-robot multi-modal and decisional interaction
- Multi-robot cooperation.

1.2 Organization and Life

ROB is composed by three research teams: GEPETTO (Understanding and Modeling Anthropomorphic Systems Motions), RAP (Robotics, Action and Perception) and RIS (Robotics & InteractionS).

ROB benefits from an experimental platform including several indoor and outdoor terrestrial and aerial robots. This platform has been extended thanks to CPER-ADREAM and ROBOTEX.

Several highly qualified engineers and technicians are commissioned by the laboratory to support experimental development, deployment and maintenance of this equipment and of the associated software. Activities include also introductory courses to the robot programming and control environment developed at LAAS, as well as maintenance of the software tools, and particularly of the software libraries developed by ROB.

Figure 1: The Robots Operated by the LAAS Robotics Platform

1.2.1 Activity Profile

Table 1 depicts the activity profile for ROB and also gives the profiles for the involved teams.

Table 1: Activity Profile

%	Academic research	Interaction with environment	Research Support	Training
ROB	55	15	10	20
Gepetto	60	10	10	20
RAP	50	15	10	25
RIS	60	10	10	20

1.2.2 Scientific Coordination

Each team has developed its specificities and its own projects. However, the three teams have maintained and developed a strong synergy and contribute in a complementary basis to internal, national or international collaborative projects.

ROB teams contribute jointly to several projects: Locanthrope, AMORCES, ASSIST, I-CARO (ANR projects) ROSACE (RTRA), Romeo-2 (FUI), ADREAM, collaborative projects with University Mohamed V (Morocco) and CDTA (Algeria). ROB teams jointly contribute to the development of open-source software tools (see https://www.openrobots.org/wiki).

ROB teams also conduct a number of collaboration with other teams in LAAS: NBS (Gepetto, RAP) on the development of electroactive polymer muscles and on segmentation and tracking of biological cells by vision; N2IS (RIS, RAP) on molecular motion and on ambient systems, PHOTO (RIS) on sensor design, ROC (RAP) on binary integer programming techniques for visual detection; MAC (RIS) on the control of multi-robot systems; SARA (RIS) on cyber-physical systems; TSF (RIS) on safety and fault-tolerance for robots.

1.3 Salient Facts

1.3.1 Very Important Success in FP7 Calls

ROB was very successful in this reporting period with respect to European competitive calls making. Jean-Paul Laumond obtained an ERC Advanced Grant/ Actanthrope (2014-2019). A very substantial number of projects have been obtained: IP DEXMART (2009-2013), STREP CHRIS (2009-2013), IP SAPHARI (2011-2015), IP ARCAS (2011-2015), STREP SPENCER (2013-2016), STREP KOROIBOT (2013- 2016), PPP Factory in a day (2013-2016), PPP EUROC (2014-2018), FET-Open STREP TWO!EARS (2013-2016).

1.3.2 Distinctions and Awards:

- Jean-Paul Laumond was the 2011-2012 recipient of the Chaire Innovation technologique Liliane Bettencourt at Collège de France.
- Amit Kumar Pandey [TH12806] was awarded the second prize at the Twelfth Georges Giralt Best thesis in Europe PhD Award (March 2013).
- S. Lemaignan [TH12463] was awarded the 2012 GDR Robotique Best Thesis Award.
- M. Sreenivasa et al was awarded the best paper of the IEEE/RAS-EMBS Int. Conference on Biomedical Robotics and Biomechatronics (BioRob 2010) at Tokyo (Japan).
- Raquel Ros et al [MAI10718] was awarded the best paper award of IEEE Ro-Man 2010 Conference at Viareggio (Italy).

1.3.3 Robot Demonstrations for General Audiences

ROB has been very active in designing and deploying robotics systems for general audience. Very successful was the Novela where HRP2 featured with a hip-hop dancer, and PR2 was a main character in a theatre play [MAI12054]. LAAS indoor and outdoor robots were deployed at the Cité de l'Espace in 2013, during the 2012 European Robotics Week and at several ELROB challenges. ROB senior researchers have also given more than 25 conferences targeting general public.

1.3.4 ROB, a Node in ROBOTEX

ROB has substantially contributed to the successful ROBOTEX initiative. Within this framework ROB has been involved as a node in Mobile Robotics and in RHIN (Robotique Humanoïde et Interaction Naturelle) and has obtained a budget to develop substantially its equipment: a PR2 from Willow Garage, 2 fully-equipped UGVs, a set of quadropters and a ROMEO humanoid robot from Aldebaran.

1.3.5 Georges Giralt Building

ROB has contributed substantially to the design and implementation of a new experimental platform for Collaborative Robotics and Ambient Intelligence in strong interaction with the ADREAM LAAS project. This platform has already been used in the framework of several European and ANR projects and also to conduct user studies in coordination with psychologists and ergonomists.

2 Scientific Production

2.1 The Movement of Anthropomorphic Systems

The Gepetto team aims at analyzing and generating the motion of anthropomorphic systems. Created in 2006, it became rapidly one of the world leader teams in humanoid robotics, unanimously recognized for its expertise in motion generation. The key difficulty of motion generation and control of anthropomorphic systems comes from the redundancy of their tree-like structure with respect to most positioning tasks, the natural instability of their bipedal posture, and the under-actuation of their spatial displacement. We aim at studying this problem by following an interdisciplinary approach focused on three research objects: the humanoid robot, the numerical mannequin and the human body.

2.1.1 Methods and Scientific Approaches

Gepetto research activity is structured in three levels: fundamental research, integration and application.

The fundamental research level concerns theoretical developments related to system modeling and motion generation. Modeling is to be understood at large. It includes the mechanics of robotics systems, the mathematics of new representations and operators, and the recording and analysis of the human motion. Motion generation ranges from global trajectory planning to local movement control, both problems being considered under different kinds of constraints. These developments rely on complementary engineering techniques in mechanics, automatic control, applied mathematics and computer sciences, but also in psychophysics, biomechanics, and movement neurosciences in collaboration with specialists of life sciences.

The integration level constitutes our core competence. It consists in integrating our theoretical developments in advanced open source software packages that we strive to maintain and make accessible to the robotics community by using standard formats and tools.

The application level concerns the contribution to specific achievements related to humanoid robotics and human motion such as service robotics, factory of the future, PLM and ergonomics, actuator design, graphic animation, etc.

2.1.2 Highlights and Major Achievements

Scientific production of Gepetto over the period: 3 HDR, 16 PhD thesis, 5 contributions to books, 49 articles in international journals, 86 articles in international conferences. The publications appear in the area of Robotics, Automatic Control, Neurosciences and Biomechanics.

Selected highlights and major achievements covering the core research topic of Gepetto are summarized in the sequel.

Advanced methods in motion planning

Motion planning is a very active research axis in Gepetto. A first contribution concerns motion planning for documented objects. The idea is to reduce the complexity of planning by adding information about how objects should be manipulated. The different steps of the manipulation are described in terms of constraints that define a graph of adjacency and the algorithm explores this graph to find a suitable sequence of movements (collaboration with Toyota Motor Europe)[MAI10844].

Motion planning is also of great interest in PLM to validate industrial plans from numerical mockup. We proposed an interactive approach for sharing the guidance of movement between an operator and a RRT path-planner to improve the concerns of whole-body walking motion planning [RVSI12146].

In order to intensify locally the RRT propagation along the less constrained direction, we developed a new diffusion algorithm based on PCA. As a result, the dimension of the research space is reduced and the diffusion process is accelerated ['TH11458].

Planning for grasping also raises difficult questions. As walking is a dynamic process, whereas the reaching movement is usually executed in a statically stable configuration, the two motion phases classically rely on different methods and the transition is somehow arbitrarily planned. To unify the process, we developed a two-steps method based on a local controllability property. The whole body motion is initially planned while the robot feet are allowed to slide on the floor. Then, the sliding trajectory is approximated by a sequence of dynamic walking [RVSI11697] (see Figure 2).

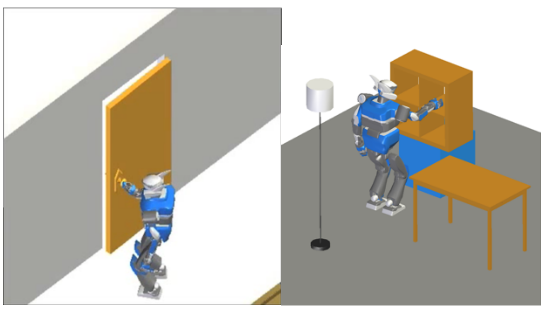


Figure 2: Planned Motions for HRP-2: Using Documented Objects and Combining Locomotion and Manipulation

Following the AMSI ANR Project, we developed with the LGP-ENIT an interactive motion planning scheme including fast motion planning and real time guiding force for 3D CAD part assembly or disassembly tasks [MAI09016]. Mid 2012, we started to work on motion planning for flexible rods within the ANR project Flecto. A first result was to show that the high dimension of space prevents from using RRT algorithms directly. To cope with this problem we developed a motion planning algorithm for quasi-static Kirchhoff elastic rods in complex environments. Our algorithm takes advantage of the configuration space structure to rapidly approximate the deformation space and increase performance over classical motion planning approaches [MAI14089].

Whole-body inverse dynamics

Inverse kinematics is widely used in robotics but not sufficient to cope with important constraints in humanoid robots such as balance, actuation limits and contacts, as soon as the dynamic effects due to the acceleration of bodies cannot be neglected. We developed a complete framework to express the motion generation problem at the dynamic level and represent tasks and unilateral constraints (such as rigid contacts) by a set of linear equalities and inequalities in the operational space. This produces a very efficient solution to design whole-body motions on humanoid robots, and behind, can be applied to a large class of problems [RVSI12014] (collaboration with J-Y. Fourquet ENI de Tarbes). In this approach, the motion generation problems are described as optimization problems and solved with advanced dedicated solvers. In particular, in control, it is very useful to be able to describe multiple objectives in strict hierarchical levels, in order to protect the most important ones when the secondary objectives become impossible to achieve. We proposed an efficient generic hierarchical solver to cope with this class of problems and applied it to HRP-2 and the dynamic model of Romeo (collaboration with INRIA Grenoble and JRL-Japan) [RVSI12794] (see Figure 3)

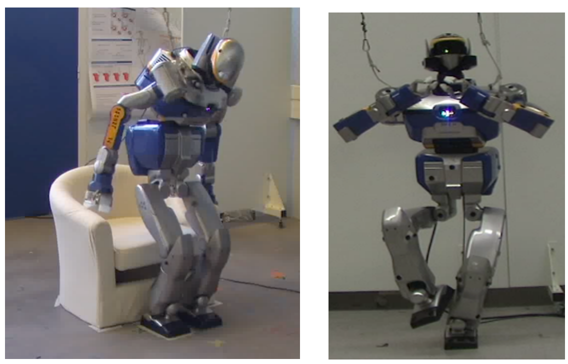


Figure 3: Two dynamic tasks executed by the robot HRP-2

Sensor-based Planning Control and Localization

The task-function formalism provides a framework for controlling the robot motion with respect to external information. However, at higher level, one needs to determine the stack of tasks to be executed by considering the robot limitations. To this end, we extended to humanoid robotics a method for planning vision-based tasks, while taking into account the visibility constraints of on-board cameras. This method was successfully implemented on HRP-2 (collaboration with CIMA, Mexico). Then, to strengthen the link between planning and control, we used the potential field deduced from this method to drive the walking generator in real-time.

We also addressed the problem of localizing the robot despite visual occlusion and environmental changes. We developed a localization process that constructs a model of visibility of points of interest. With this method it is possible to detect and remove the masked points of interest [RVSI1362]. Finally, in collaboration with the RIS and RAP teams of LAAS, we designed an efficient and real-time SLAM software [OPI11722].

Human Motion Analysis, Modeling and Imitation

An important part of our activity aims at analyzing human movement and generating similar behaviors on humanoids. A first result was to identify the shape of human locomotion trajectories by using an original inverse optimal control approach. Starting from a set of observed human trajectories and a hypothetic model of control, the problem was to identify the cost function that is minimized. The proposed approach unifies the holonomic and nonholonomic walking behavior into the same model and emphasizes the key role of the bearing angle in bipedal locomotion ['TH10463], [RVSI09425]. Optimal control was also used to obtain smooth and robust movements in humanoid robots [RVSI10932].

The task-function formalism offers another efficient approach for motion analysis and imitation. A task is both a local controller and a motion descriptor. We used this duality as a basis for motion recognition and imitation. Considering that the set of controller used by the demonstrator is known, we proposed a method to recognize the executed tasks and identify their parameters. The observed movement is projected into the set of candidate tasks and compared with models. The most pertinent task is selected and removed from the movement to avoid false detection in the sequel. This method has proven to be robust and efficient *(*PhD Hak 2011) [RVSI12257]. Once the stack of tasks used by the demonstrator is reconstructed, a similar motion can be easily generated. This method was used to generate HRP-2's movements for the show "Dance with HRP-2" during the Novela Festival [MAI11430] (Figure 4)

Figure 4: A snapshot of show "Dance with HRP-2" a nice example of dynamic movements close the limit of stability.

The task-function framework also provides an efficient approach for human movement analysis in biomechanics. Considering the human body as a system of articulated rigid bodies, the joint torques can be reconstructed from motion capture and additional measurements. In collaboration with the Nakamura's Lab. of Tokyo University we analyzed complex human movements by using the sDIMS software. The task-function formalism was then used to represent and simulate these movements on dynamic anthropomorphic models [MAI12110]. We showed that going back and forth between observation and simulation provides an efficient approach for inferring the organization of complex human movements [RVSI13708].

The transfer from human to humanoid can also be done through the extraction of motion invariant. We recorded and statistically analyzed whole-body walking-to-grasp human movements. Invariants were extracted and expressed as a set of rules synthesizing the stereotypy in human motion. We developed an algorithm that reproduces these key motion parameters by taking into account the limitations of the target humanoid. The output of this algorithm was applied in a prioritized inverse kinematics solver to generate anthropomorphic motion with HRP-2. ['TH10597], [RVSI12111] (see Figure 5)

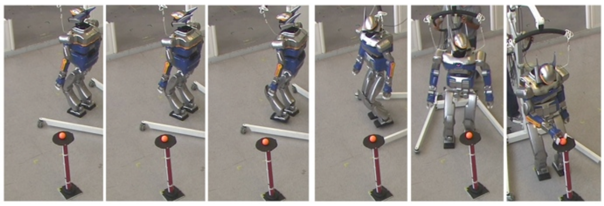


Figure 5: HRP-2 Executing a Walking-to-reach Motion Constructed from Invariants of Human Movements

The research on human locomotion has been extended to account for the mechanical role of the head in walking stabilization. In [MAI13150] it is shown that the upper-body stabilization regulates naturally the limit cycle of passive walkers on shallow slopes and improves the balance and perturbation recovery for steeper slopes. The result is based on a new dynamic simulation algorithm. The novelty of the method is to rely on the property that limit-cycle walkers may return to the limit-cycle several times before to fall. This method was even extended to the cases of bifurcations or chaos [MAI13339].

Movement Optimization

Optimization techniques are used at many levels for motion analysis and generation. In motion planning for instance, the use of numerical optimization is necessary for smoothing the trajectories provided by probabilistic method that are known to be rather erratic with discontinuous velocities. To this end, we integrated the multiple shoot algorithm developed at Heidelberg University in our software platform HPP (collaboration with K. Mombaur, Project Echord-GOP).

For task planning, optimization is also essential. Tasks can be seen as simple motion lexems, whose composition produces complex behaviors. This can be used to bridge the gap between symbolic planner and low-level controller. We proposed a generic solution based on optimization to compute automatically the missing numeric data (timings, controller gains, intermediate points) in order to apply a symbolic sequence of tasks on HRP-2 [RVSI12779], (PhD of

F. Keith, collaboration with JRL-Japan, INRIA Grenoble and Seoul National University).

We also used optimization to tune up walking patterns. In order to increase the quality of walking motions we relaxed several characteristics of the gait, such as foot placement, ZMP position or step time, that are usually fixed in advance, and we used numerical optimization to adjust these parameters, while ensuring stability. Various objective functions were tested showing the occurrence of different walking behavior [MAI12423] (Collaboration with Heidelberg University).

Real-time Walking

For complexity reasons, real-time step planning methods usually consider a reduced number of candidate step positions. To extend this limit, we proposed to learn the step feasibility by considering the foothold position as a continuous variable. Coupled with a probabilistic method, this feasibility function was used to determine paths that better exploit the robot capabilities. In order to guarantee non-collision during the step we generated a dense discrete set of possible actions and we used a probabilistic method locally optimized by a homotopy operator [RVSI12166]. Thanks to this result it was possible to do safe real-time planning in dynamic and highly constrained 3D environment [MAI11369] (see Fig. 6). This method was later extended to integrate a priori knowledge of the environment [MAI13535].

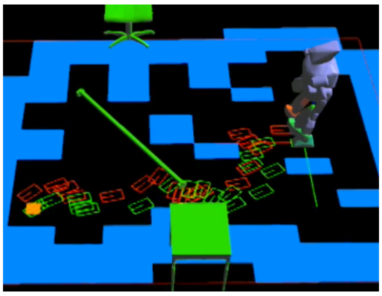


Figure 6: Real-time Reactive Walking with Guarantee of Collision Avoidance in a Variable 3D Environment

We also developed different strategies for generating reactive walking motion by using vision feedback. In [MAI14193] this exteroceptive information was used for generating CoM and CoP balanced trajectories, and for choosing footsteps automatically. Whereas, in [RL 14194] vision was used for generating appropriate foot landing motion for walking on uneven ground.

From Manipulation to Whole-body Motion

The geometric approach to object manipulation, which was previously developed for robotic arms and wheeled robots, was extended to humanoid robots. An original approach was introduced to manipulate bulky objects. We proved that the system is small-space locally controllable and then deduced that any sliding path can be approximated by a feasible trajectory provided by a classical planner. The robot hand trajectories are deduced from the object movement and the coordination of the arm and legs displacement is deduced from inverse kinematics [TH09648], [RVSI08732].

Though the body of anthropomorphic systems is both redundant for reaching and under-actuated in its displacement, an original modeling of locomotion was introduced. It consists in representing the chain of footholds as a virtual manipulator. Adding this virtual chain to the robot model allows to transform the under-actuated system into a redundant one, to which classical inverse kinematics techniques can be applied [TH09767], [RVSI10616] (see Figure 7). Based on this result we developed an optimization-based reactive control approach that allows online adaptation of the whole-body trajectory, including walking, and depending of the perceived environment [TH12585].

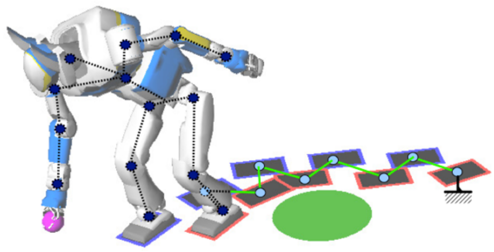


Figure 7: A whole-body Walking Task Planned by Considering the Footholds as Links of the Robot Kinematic Chain

From Biological Models to Robot Motion

The most promising approach for transferring movement from human to humanoids is to apply functional principles of biological motor control. In this vein, we used a biological model based on the principle of separation of static and dynamic movements and the minimization of the energy of motoneurons to generate human-like reaching movements with HRP-2. Then, to reduce the computation time of optimal solutions, we proved that the optimal reaching trajectories can be generated from a small number of motion primitives [RVSI11707] (collaboration with ISIR, Paris).

In collaboration with the neuroscientists of the CerCo in Toulouse, we contributed to the modeling of the primate cortical activity related to sensorimotor integration. This work was based on a study in electrophysiology in monkey. A first result was to propose a computational model to explain the gaze-related modulation of premotor neurons during a reaching movement. We used the visual servoing formalism in robotics to prove that the eye and head positions are natural parameters of the motor control as soon as we agree that the hand-target difference vector is encoded in a visual reference frame [MAI10285]. Then, we proved that afferent proprioceptive signals related to eye/head and head/trunk position modulate the activity of neurons of the primary visual area V1, and we proposed a model of integration to explain this phenomenon [TH11504].

Artificial Muscles

With the integration of B. Tondu in Gepetto in 2011, we started a new research axis on the development of new actuators in robotics. This research was led in two directions. The first one, that can be called the "mechanical" direction, benefits from a long-time experience in pneumatic muscles for developing new variable impedance actuators. In parallel to analyzing and testing advanced nonlinear or biomimetic controllers, we synthesized simpler control schemes that use the physics of system more optimally

[RVSI13806]. The second direction, related to "materials sciences", concerns the development of a new electro-active polymeric actuator (collaboration with NBS-LAAS, co-supervision of the thesis of A. Simaite). A first accomplishment was the development of a ionic polymer prototype with soft electrodes able to perform cyclic bending in response to a low tension. This technology will be integrated in a legged micro robot and compared with other existing technologies, such as memory-shape Nitinol filaments that we recently integrated on a six-legs insect robot [MAI13732] (See Figure 8).

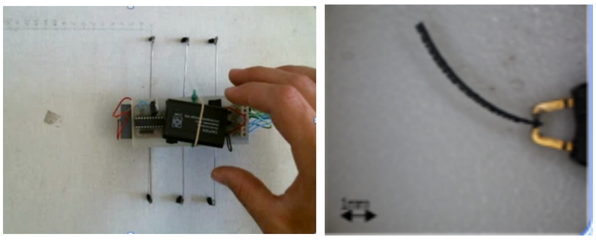


Figure 8: The Stiquito Robot (left) and a Arototype of Soft Ionic Electroactive Polymer Actuator (right)

Anthropomorphism in Robotics

The question of anthropomorphism in robotics was addressed in some publications. Starting from a systemic analysis of the organization of human musculoskeletal system we emphasized the difficulty of any anthropomorphism of realization, inevitably partial, and explain how it competes with the projective anthropomorphism generated by everybody when facing a machine having a more or less human form [RVSI12867]. The originality of this approach comes from the acknowledgement of the psychological processes that could be present, consciously or not, in our relation with human-like robots. We also emphasized the interest of mathematical tools (theory of zonotopes), so far seldom considered by roboticists, for renewing the study of the kinematics of redundant robotics arms, and in particular to justify the dimension and design of humanoid robots limbs [RVSI13751].

Motion Programming (Open Source)

An effort is deployed in Gepetto for implementing our algorithms in usable open-source software packages. This is notably the case for the Human-Path-Planner environment (HPP) and the Stack-Of-Tasks framework (SoT: http://stack-of-tasks.github.io) which are regularly updated and maintained in order to integrate new result via the middleware ROS. These software packages are implemented on different platforms in different labs such as INRIA-Rennes, INRIA-Grenoble, LIRMM Montpellier, Aldebaran Robotics (France), JRL-Japan, Univ. Sapienza (Roma, Italy), PAL-Robotics (industry, Spain), IHMC (FL, USA).

2.2 Robotics, Action, and Perception

The research conducted by the Robotics, Action, and Perception team (RAP) mostly takes place within the fields of *perception*, *sensor-based motion* and *sensor integration* in robotics. Contributions range from functions design and prototyping to implementation on robots and real-world evaluation. Most of them are steered to *robotics in interaction with humans* (human populated scenes analysis; coordinated human-robot navigation; cobotics), or *ubiquitous robotics and ambient intelligence* in the vein of the ADREAM axis (data fusion from embedded and deported sensors; design of integrated communicating sensors). *Signal processing* underlies many works, and is addressed *per se* as a separate upstream research.

2.2.1 Methods and Scientific Approaches

Perception spans acquisition, filtering, detection, segmentation, tracking, identification and interpretation. Robust real-time functions are aimed for, from optical (monocular, 3D, polydioptric, active PTZ, RGB-D, IR, multispectral), auditory (microphone array, binaural head) and RFID modalities. The sensors can be static or moving, onboard a robot, deported in the environment, or worn by humans. Several results rely upon probabilistic data fusion: vision and RFID based tracking and identification of multiple people; multimodal pedestrian localization in urban environments; audio-motor sound localization; simultaneous localization, mapping and moving object tracking. Other contributions include: vision based detection, segmentation, tracking and recognition of multiple objects; 3D vision modeling; sound detection and azimuth estimation.

Research in sensor-based motion mostly concerns vision and laser based reactive navigation. The underlying techniques for occlusions and dynamic obstacles handling are complementary to vision based functions on humans in that their conjunction enables a mobile robot to guide a tutor among crowds. In addition, strategies to vision based dual arm manipulation are investigated. To a lesser extent, advanced control techniques were applied to visual servo analysis.

The integration of perception algorithms on smart-sensors considers multiple targets (processors, FPGAs, GPUs…) in order to cope with latency, cadence, size, energy and memory footprint. This implies algorithms evaluation and selection, model-driven engineering, optimization (at the algorithmic, operating and hardware levels), and hardware-software co-design.

Separate contributions relate to stochastic filtering and operational transforms of dynamic problems for analysis, simulation, identification, estimation or control.

The above topics are intertwined thanks to internal collaborations. RAP has been involved in international or national projects, as well as in national or local collaborations, which often led to joint PhD supervisions. Many studies are in connection with applications outside robotics, e.g., videosurveillance, quality control, and geolocation. These have given rise to collaborations with industry (local VSMEs, SMEs, large groups), including many CIFRE theses.

2.2.2 Highlights and Major Achievements

Visual Perception of Humans and Videosurveillance

The privileged applications are passive human-robot interaction (e.g., navigation with passer-by avoidance, coordinated motions) [TH10710], active human-robot interaction (e.g., proximal interaction through postures and gestures) [TH10303], and human environment surveillance (Figure 9). Privative spaces as well as large-scale human-populated environments are considered.

Functions span human detection, multiple people and posture tracking, human identification, and interpretation of human motion. Importantly, they entail data fusion at the sensor level (of low-level cues extracted from the raw signals) or at higher levels (by combining the outputs from lower-level perceptual modalities.

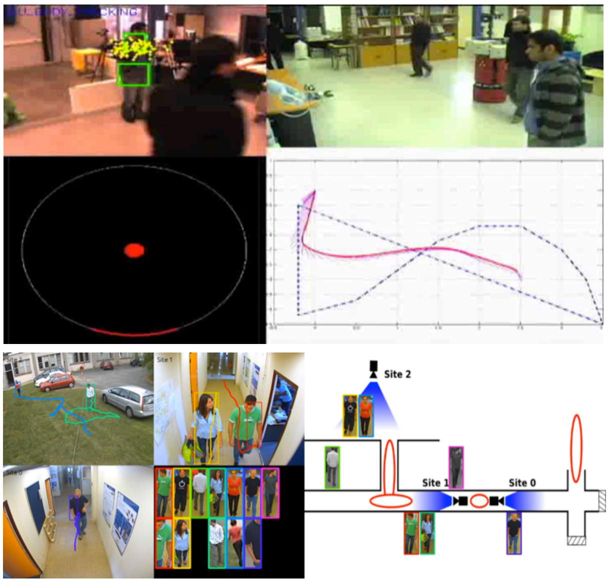


Figure 9: Top: Vision & RFID-based Tracking and Coordinated Motion of a Tour-guide Robot into Crowds. Bottom: Visual tracking and re-identification of people from cameras' non-overlapping fields of views.

Detection and tracking have mainly been addressed via probabilistic and Monte Carlo supervised classification and filtering methods, respectively. We have performed people detection from heterogeneous features via single-class methods such as boosting *(A.A. Mekonnen's thesis)*. Multiple-class methods like "random forest'" have been used to detect body limbs for posture recognition *(L. Marti's thesis)*. As for tracking, an original fusion of vision and RFID in a reversible jump Monte Carlo Markov Chain (MCMC) particle filter enabled the real time robust navigation of a robot in a cluttered human environment [RVSI13380] *(A.A. Mekonnen and T. Germa theses)*. We could track and re-identify people from a network of cameras with non-overlapping field of views, thanks to the coupling of local tracking and identification systems (one per camera, entailing a mixed-state particle filter) with a MCMC based supervisor in charge of the association of "tracklets" [MAI12419] [TH13134]. Recent work has concerned the reconstruction and tracking of posture from single and multiple Kinect sensors by Kalman filtering or smoothing *(L. Marti and J.T. Masse' theses)*.

Vision-based Object 3D Modeling, Detection, Segmentation and Recognition

The main application is vision-based manipulation, *e.g.*, for human-robot manipulation in domotics or industry.

We have developed a hierarchical approach to appearance-based recognition in order to efficiently focus on the most likely classes *(G. Manfredi's thesis)*.

We collaborated with ICA-Albi on Non Destructive Testing. First, we studied the inspection of large aircraft parts using a static system made of up to 8 cameras and illuminators (so as to reconstruct untextured objects). A fine and dense stereovision algorithm was extended to process more than two images while preserving edges, and led to a 0.05mm error standard deviation [RVSI13194] [TH10926]. Then, a dedicated version was integrated by the NOOMEO start-up. With NOOMEO, we performed object 3D modeling on the basis of the dense 3D images acquired by their hand-held sensor (composed of two cameras, an illuminator and an IMU) [RVSI11097] [TH11488]. Several variants of the ICP algorithm were evaluated in order to get a 3D accuracy around 0.1mm. Last, we contributed to thermal metrology on any convex 3D object. This requires, for each mesh of the shape, the orientations relative to the camera and the radiative properties. The 3D reconstruction was retrieved by an uncalibrated stereo NIR camera rig mounted on a Cartesian robot. We proposed an uncalibrated rectification algorithm, and a self-calibration approach for the hand-eye transform [TH11831].

An ongoing work aims at segmenting and tracking multiple static or moving objects for the control of a biological process (cooperation with the NBS team) or for food quality assessment. Statistical, filtering and variational methods have been combined to highlight the objects to be recognized, characterized and tracked *(S. Larnier's post-doc & P. Dubosclard's thesis)*. Other ongoing studies are devoted to the transverse topic of joint perception on humans and objects.

Self-localization of a Mobile Entity from Embedded Sensors

An application can be outdoor robotics, *e.g.*, navigation or automatic inspection with a mobile robot. During the past period, monocular and stereoscopic SLAM methods based on point landmarks and Extended Kalman Filter (EKF) were designed and validated. In collaboration with RIS and GEPETTO, a real time version (named RT-SLAM) was developed and validated on robots equipped with cameras, IMU and natural GPS. RT-SLAM is now open-sourced and used by other labs. Within RAP, it was used to learn and replay a trajectory, along two scenarios: either the replay task is posterior to learning, allowing changes in the environment, or the learn-replay tasks are executed separately by the leader and the followers of a convoy [TH12830].

The initial method was extended to process line landmarks, considering the undelayed initialization of a line as soon as it is detected [MAI09776]. Several representations for point or line landmarks were compared *(Solà & Ila Post-docs)* [RVSI10071].

The point landmarks based EKF-SLAM was re-coded so as to comply with aircraft embedded subsystems rules. The resulting C-SLAM was validated on multispectral sequences, enabling self-localization by night or under bad weather [TH13400]. To overcome EKF-SLAM's limitations, a work funded by SATT Toulouse Tech Transfer targeted an optimization-based SLAM. A RGB-D based prototype is under evaluation.

Last, we developed with industrial partners GPS-based localization methods. First we contributed in integrating a precise GPS localization, using low-cost, mono-frequency fixed and embedded receivers [TH13744]. Then an EKF-based localization of visually impaired pedestrian in urban environments, was performed by fusing GPS (prone to canyon effect), accelerometer, gyroscope and 3D magnetometer data. The prior dynamics relies on the pedestrian velocity *vs.* step frequency relationship, and captures walking-stop-transport transitions. The solution is commercialized, and reaches a <5m localization error 95 percent of time [MAI09111].

Mobility in Dynamic Environments: Obstacle Detection, Identification, Tracking

Visual self-localization is based on static landmarks. Dynamic environments require the detection of mobile objects (*e.g.*, obstacles). Restricting to monocular vision, obstacles were detected from sparse optical flow analysis. Tracklets were first extracted from a short image sequence. Then, static points (made available for SLAM) were discriminated from dynamic ones (associated to obstacles) by *a contrario* reasoning [TH11890]. Dynamic points were clustered to make explicit each mobile object model. Then, every detected object was tracked by an active strategy to make its model denser. Object tracking was performed either using KLT on points, or by a snake initialized from these points [TH13603].

As monocular vision did not enable to unambiguously estimate the obstacle position and velocity, a stereovision approach was proposed, using separate MOT (Mobile Object Tracking) for each detected object (Figure 10). In order to avoid false detections and robustify the SLAMMOT, an appearance-based detection relying on prior learning was proposed to identity the object classes (pedestrian, vehicle…) [MAI12421].

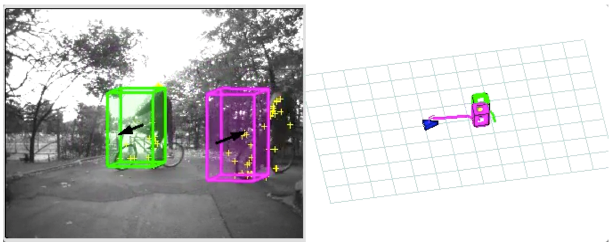


Figure 10: Active Visual-based Detection and Tracking of Moving Objects (SLAMMOT)

Robot Audition

Detection and localization of multiple broadband sources (*e.g.*, speech) have been studied, with microphone arrays or binaural heads (two microphones).

By mixing modal analysis and convex optimization arguments, we instantiated a coherent beamspace MUSIC (MUltiple SIgnal Classification) strategy for uniform linear arrays. In conjunction with our MAICE (Minimum Akaike Information Criterion Estimate) of the number of active sources, up to 3 sources can be detected and localized at reduced cost **[**MVSI09625**]** **[**MAI10181**].**

Then, we entered the field of binaural "active" audition [OPI13673**]** (with ISIR, Paris). The aim is to exploit a moving binaural head in order to overcome the limitations that occur in the static case (front-back ambiguity, distance non-observability…). Our approach involves three steps: detection of the sources activity and estimation of their spatial arrangement by binaural processing over small time snippets ("short-term detection"); fusion of these data with the sensor motor commands into a stochastic filtering scheme ("active/audio-motor localization"); feedback control of the sensor motion so as to improve localization ("active/information-based motion"). The first two steps were solved in the single source case by: a short-term maximum likelihood estimator of the source direction coping with head induced scattering; an information-theoretic source activity detector; a Gaussian sum unscented Kalman filter endowed with self-initialization, consistency, false measurements and source intermittence handling (Figure 11) **[**MAI12108**]** **[**MAI13671] [TH13745]. An Expectation-Maximization extension of multiple sources short-term detection has also been obtained.

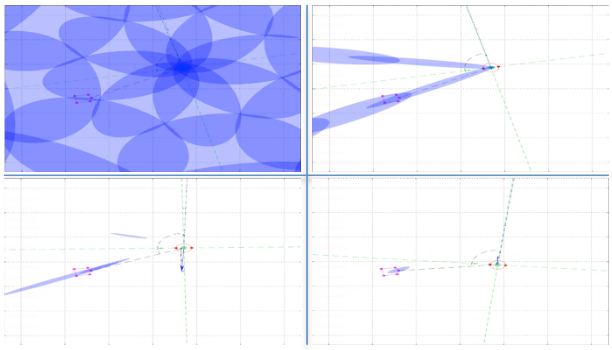


Figure 11: Active Localization of a Speech Utterance from a Binaural Head (Real data, in Nearly Acoustic Room)

An ongoing study concerns audio-motor localization of multiple sources and information-based motion *(G. Bustamante's thesis)*. At the confluent of visual human perception and binaural audition, the visio-auditive detection and identification of humans from the humanoid robot ROMEO in a proximal interaction context has also been investigated, together with the spatiotemporal analysis of their behaviors *(L. Fitte-Duval's thesis)***.**

Multi-sensor based Long Range Navigation in Poorly Known and Cluttered Environments

The reactive navigation of a robot towards a target has been considered, as a sequence of vision and laser based servoing tasks. A first contribution concerned the reconstruction of pointwise visual features to be used for feedback when they are not detected due to occlusions. The reconstructed values were computed as the solutions to the open-loop model (velocity screw to features velocities differential equation) initialized by the last extracted features and an estimation of their (unknown) depths. The depths estimates were themselves produced by an original predictor-corrector scheme. In comparison with the literature, our strategy is particularly suitable for real time application thanks to its light computational cost and its reliability. It was successfully validated by experiments [MAI10182] **[**MAI10119**]** [TH12163].

To enable navigation in a poorly known environment cluttered by occluding and non-occluding static and/or dynamic obstacles, we decomposed it into interconnected processes and defined a structure suited to the application. The involved processes are: a supervisor which triggers suitable local sensor-based controllers in view of the available data; a modeling of the environment by a topological map; an action process which synthesizes suitable controllers and sequences them. Similar ideas were used and experimentally validated for coordinated human/robot navigation, where a robot must keep behind a moving tutor continuously tracked by vision and RFID. [MAI11264].

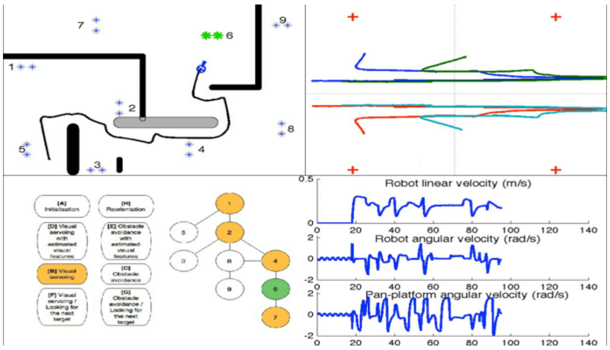


Figure 12: Long-range Navigation Tolerant to Signal Loss and Occlusions

Dual-arm Visual Servoing

The aim is to develop vision-based coordinated control of two robotic arms for object manipulation. Our approach involves three steps: an open-loop model uniting the motion of both arms to the visual features in the cameras image planes; a decomposition of the task into subtasks, each being performed by a local image-based controller; a sequencing of these controllers ensuring the control signals continuity.

Ongoing work along this approach aims at closing the cap of a pen. Visual features have been selected from an eye-in-hand camera and an eye-to-hand camera so as to account for the relative pose of the two end-effectors. The local controllers and their sequencing have been validated in simulation *(R. Fleurmond's thesis)*.

Multicriteria Analysis of Visual Servos

We temporarily pursued our work on the "multicriteria" analysis of visual servos (*i.e.*, including constraints such as target visibility, actuators' saturations, and exclusion of 3D areas) [OPI09368]. Keeping a transcription of the problem as the stability analysis of a nonlinear "rational" system under rational constraints, we showed how a "multicriteria basin of attraction" can be computed on the basis of piecewise-biquadratic Lyapunov functions and feasibility/-optimization programs subject to linear matrix inequalities (LMIs). More recent results concerned the design of less conservative solutions at reasonable computational cost *(S. Durola's thesis)*.

Embedded Sensor for Obstacle Detection, Identification and Tracking

The main goal is to co-design a hardware-software implementation of well-known vision-based obstacle detection, identification and tracking algorithms, suited to realistic robotic contexts. This leads to design smart vision sensors whose task is to extract information out of the scene and communicate it to a higher-level processing resource. Such sensors are highly constrained in term of size, power consumption, cost and throughput. Advanced Driver Assistance System (ADAS) and Autonomous Vehicle constitute application fields in which throughput is a limiting factor for the vehicle speed and reactivity [TH12681]. The research has been carried along three distinct methodologies: detection by pixel classification [TH11838]; detection by geometric transformation; detection by movement analysis. One of the key aspects of development is hardware prototyping on FPGAs (Field Programmable Gate Arrays) for which the algorithm-level and hardware-level optimizations are prevalent *(A. Alhamwi & F. Brenot' theses)*.

Hardware Accelerator for Vision Based Localization

This topic explores the design of hardware architectures to speed up existing vision based localization techniques like SLAM, by providing an image filtering front-end to feed the filtering/optimization back-end with high-level information. We have been working on a prototype which implements the whole set of image filtering operations for EKF-SLAM. This prototype provides real time, low latency, information on a vehicle embedding a single camera and an inertial measurement unit. It consists in the connection of programmable logic (FPGA) with an embedded processor (POWER-PC). A co-design flow was followed to partition the application between the two resources and evaluate the communication costs at run-time. This helped to modify the existing C-SLAM software [TH13400] to take advantage of the available processing parallelism.

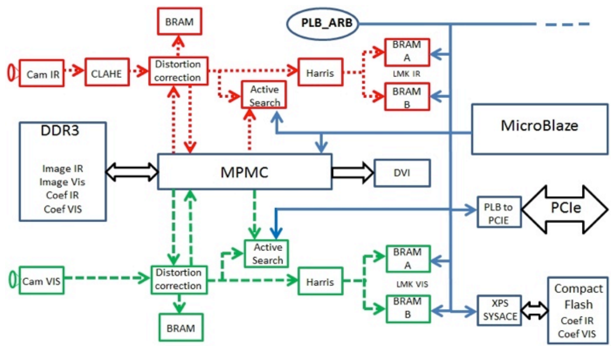


Figure 13: SLAM co-processor

Dataflow based Design Methodology for Hardware-Software Co-design

We have developed a methodology that guides the designer through the application prototyping process to produce a valid hardware-software implementation of a given algorithm. This methodology is integrated in the PREESM software and generates SystemC prototypes from a dataflow description for each step of the design flow. It helps to explore the optimization space for a given application on a given architecture.

The "Embedded Audition for Robotics" ("EAR") Sensor

In connection with robot audition, a new System-on-a-Programmable-Chip (SoPC) architecture was designed for our "EAR" smart auditory sensor [MAI12107]. A soft-processor and custom hardware modules designed for application-specific operations (co-processors for intensive operations, timers, communications…) were hardcoded on FPGA. This enables an efficient handling of resources, a progressive, flexible and fast development (C/C++-based SDKs, MATLAB/HDL toolboxes…), and a validation at each stage of the workflow. One cycle of MUSIC-MAICE detection-localization now takes less than 25ms. This architecture has also been adapted to binaural audition and MEMS microphones.

Signal Processing

Within the reform of the ARGOS localization algorithm system (with CLS, www.cls.fr), we contributed to the “Interactive Multiple Model” (IMM) paradigm for nonlinear Markovian switching systems [TH13676]. First, we extended the IMM filter to the case when state vectors have heterogeneous sizes and meanings [MAI10240]. Second, we investigated a new suboptimal solution for IMM fixed-interval or fixed-lag smoothing which is computationally cheaper and more reliable than known equivalent algorithms. Therein, the smoothed mean and covariance are obtained by combining the statistics produced by a forward-time IMM filter in a backward-time recursive process based on Rauch-Tung-Striebel formulae and an original specific interaction **[**MAI11527**]**. ARGOS location now includes the IMM filter and smoother as online and offline services.

A recursive algorithm was proposed to the computation of the Maximum A Posteriori of the state trajectory of a dynamic system. Strikingly, it can be expressed in closed form for a linear system whose dynamics and observation pdfs take the form of “maximum Gaussian mixtures”, *i.e.*, point-wise maximum of Gaussian pdfs **[**RVSI13075**]**. The method extends to nonlinear and/or hybrid systems.

The “operatorial transform” approach of dynamic problems tackles analysis, simulation, identification, estimation or control by handling the involved signals globally as time functions (trajectories) as opposed to the conventional viewpoint of vectors depending locally on time. These problems and the underlying models are then stated into mathematical functional spaces. Trajectories are transformed by operators, either local (*e.g.*, based on derivatives or static functions as in the conventional viewpoint) or more general (convolution-like operators, change of time, operatorial parameterization…). By using or combining such operators, many “difficult” problems can be turned into tractable equivalent problems: non-differential/discontinuous singularities, nonlinear control, predictive control… **[**RVSI13227**]**.

2.3 Robotics and Interactions

The "Robotics and InteractionS" (RIS) team conducts research on the autonomy of machines that integrate perception, reasoning, communication, learning, action and reaction capabilities. Our efforts are essentially oriented toward decisional, algorithmic and control architectural issues. Our approach proceeds from the need to consider the robot as a whole: perception and action abilities are studied in synergy with the other teams in ROB. RIS works along two complementary perspectives (Figure 14).

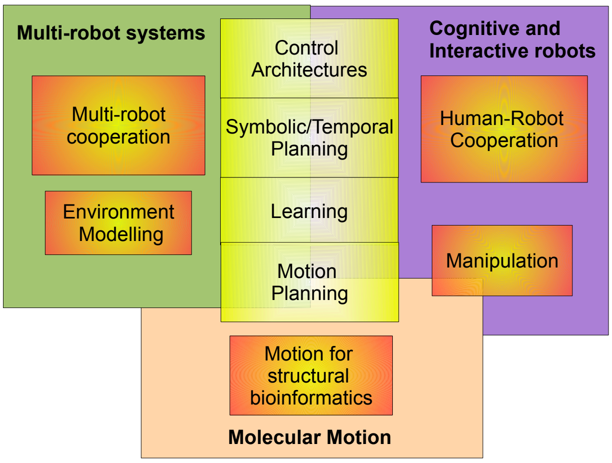


Figure 14: RIS Domains (in yellow) and Contextual Perspectives

1) A fundamental perspective where we develop models and algorithms for decisional problems. This concerns symbolic task planning and learning as well as geometric motion and manipulation planning for highly complex systems.
2) A contextual perspective where we investigate concrete subjects as challenging contexts and as sources of new scientific questions raised by confronting the available methods and tools to realistic and ambitious application domains.

The three contexts, in which RIS contributes and cooperates at the forefront of research, are:

- Cooperative multi-robot systems and more particularly the aerial-ground context involving several heterogeneous networked robots.
- The cognitive and interactive robot and more particularly the autonomous mobile robot assistant or teammate.
- Molecular motion problems using robotic algorithms to explore new computational routes for structural bioinformatics.

2.3.1 Highlights and Major Achievements

Robust and Dependable Architectures for Autonomous Robots

Deploying robots in environment, where close interactions with humans are desired (e.g., service robots, co-worker robots), requires a high degree of confidence and trust in the robots. This may result from appropriate mechanical design, collisions detection and reaction, or motion planning and control to avoid such collisions, but overall, one major risk rises from the integration of multiple functional components whose interactions cannot be fully tested nor qualified. The LAAS robots architecture relies on a number of generic tools (e.g., GenoM, PRS) and proposes a well-founded framework to develop and integrate functional modules. Until recently, this framework was merely a software engineering set of tools, and did not rely on any formal model. Jointly with Verimag, which has developed BIP (Behavior, Interaction, Priority), a component based framework for embedded real-time systems, we developed a BIP model of a generic functional module and we are now able to generate a complete BIP model of any GenoM based modules [RVSI12821]. The resulting model is functionally equivalent to the regular module, but it provides a fine-grained transition and interaction model of the module. This model can be used alone (for one module) or with the other module ones, by the BIP engine and run the complete functional layer. In such a mode, the BIP engine acts as an online controller that will enforce the specifications the user added to the module definition (e.g. the robot should not navigate with its arms opened, its maximum speed should not exceed 20cm/s when humans are around, etc.). These models can also be used off line with formal validation tools that automatically extracts component automata invariants, together with interaction invariants (e.g., D-Finder) to check for properties (e.g. deadlock free) [RVSI11875]. The most recent development (GenoM3) is template based and middleware independent. As a result, we can deploy the modules on various middleware (PocoLibs, ROS Comm, etc.) and the next step is a template to automatically produce the BIP model of our modules.

Overall, these recent developments in our architecture will allow the robot programmer to specify its functional modules, the undesired interactions between them, and check that the resulting functional level satisfies some critical properties with respect to the state of the various components.

Temporal Planning and Execution Control

Despite impressive performance results in action planning competitions, action planning remains seldom used on robotics platforms. There are a number of reasons that may explain the absence of this important deliberation function on robots [OPN13108, RVSI13126]. Among them:

- lack of adapted action model for robots (taking into account time, uncertainty, hierarchical representation),
- lack of proper plan execution and repair mechanisms,
- lack of proper integration of the planning/acting components in a complete robot architecture.

Planning for a robots goes beyond just producing a plan. It must also take into account the execution of such a plan, with the inevitable failures and need for online repair and replanning. The produced plan must take into account time, action duration, available resource, and remain flexible. The planning should take place at different levels of abstraction, possibly with different planning and acting techniques interleaved.

We are developing FAPE, a new planning/acting system which aims at properly interleaving planning and acting, taking into account time and hierarchical action representation (i.e. HTN). We use the ANML language to model actions and states as it provides the three key features we are looking for: state variables, time, hierarchical decomposition of tasks.

Algorithmic Motion Planning

This research axis concerns the algorithmic foundations of motion planning for complex articulated systems encountered in robotics and also in computational biology applications. Our past work has contributed to the development of the sampling-based methods, the Probabilistic RoadMaps (PRM) and the Random Trees diffusion variants (RRT), that have now emerged as an effective framework for facing the high complexity of motion planning problems. Our contributions during this period have mainly focused 1) on the extension of the RRT-based planning framework for computing solutions paths that are not only feasible but also optimal with respect to a given path-quality metric, 2) on improvements of the algorithms to better face the complexity of highly dimensional problems, and 3) on the application of the techniques to diverse path-planning problems in robotics and for applications to computational biology.

1) Regarding path optimality, we have developed a novel random-tree diffusion technique, called Transition-RRT (T-RRT) [RVSI13093], that first bridges the gap between cost-space and configuration-space planning for computing good-quality paths in configuration-space costmaps. The algorithm integrates a stochastic state-transition test, similarly to the Metropolis Monte Carlo method, which makes the exploration focused on low-cost regions of the space, together with a self-tuning mechanism that controls the difficulty of this transition test during the exploration. Several improvements have been investigated for enhancing T-RRT's efficiency for cost-spaces with narrow low-cost regions [MAI10628] (joint work with CMU), for cost functions that can be decomposed into terms associated with separate groups of degree-of freedom [MAI11197] and for problems in large-scale workspaces, with a multi-tree extension [MAI13165, MAI13078].

2) Regarding high-dimensional problems, we further extended the Manhattan-like RRT (ML-RRT) previously proposed for disassembly problems between complex articulated objects: the extension [RVSI10131] relies on a hierarchical model of the system with different degrees of mobility to enlarge the applicability of the algorithm. A variant algorithm [MAI09124] was developed for simultaneous (dis)assembly sequencing and path planning between multiple objects. Finally, in order to exploit multiprocessor architectures, we developed parallel versions of RRT-like algorithms and analyzed the efficiency of several parallelization paradigms on distributed-memory architectures [RVSI13093, MAI13165].

3) We have extended our work on manipulation planning to multi-arm robots. The roadmap-coordination technique [MAI09541] combines elementary probabilistic roadmaps computed separately for each arm and enables to significantly speed-up computations compared with a standard approach considering the whole system. This technique was integrated into a pick&place planner [MAI10263] developed for dual-arm manipulation and that is able to automatically plan re-grasping operations between the arms. In addition, we developed a novel technique based on a continuous surface-matching algorithm for computing enveloping grasps with multi-fingered hands [MAI10627]. In the frame of the SAPHARI project, we also designed a human-aware motion planner [MAI10262] based on the T-RRT algorithm to compute safe motions that also account for human-robot interaction constraints. Finally, we contributed in collaboration with UPC in Barcelona to an original approach [MAI13094] for object manipulation using aerial towed-cable systems (ARCAS FP7-project).

4) Regarding manipulation task planning, we have also developed efficient models for grasp planning of complex objects with multi-fingered hands. We proposed new methods to check the force closure [MAI10439] and new quality criteria [RVSI09911] to compare grasps. Based on these efficient tools, we have built modules to compute grasps [RVSI11521, MAI10627] and to choose grasp in real-time [OPI12378]. From these foundation elements an interactive manipulation tasks planner [RVSI10704, MAI13675] has been developed.

Cooperative Teams of Robots

Research on cooperative teams of robots has been conducted in the context of field robotics. A variety of applications are considered, that range from environments exploration and monitoring to civil security or defense. Such applications require systems operating over large scales of space and time, in GPS-denied areas and under communication constraints. This calls for advances in environment modeling and decisional processes that, in particular, must be distributed within the involved teammates. The main achievements are the following:

Mission planning and control: For coverage or observation missions, the mission planning problem mainly comes to allocate robots to vantage points while satisfying constraints, in particular regular communications with the remote mission control center. A distributed task allocation scheme based on the auction paradigm has been developed [MAI12167]: it explicitly considers observation, motion and communication models to interleave observation task allocation and refinement. The main characteristic of auction mechanisms is that they allow to dynamically redefine the tasks allocation as deviations from the initial plan occur -- which is unavoidable in the considered contexts. The particular task of multi-robot target tracking has been studied, and an efficient approach that anticipates tracking failures and allocates "trap" tasks has been proposed [MAI12863].

Robot localization: Localization remains a key problem in mobile robotics, and calls for the integration of a variety of processes, from several tens of Hertz position and speed estimates to lower frequency absolute position estimates. We have pursued the development of a general framework that integrates all the localization-based information, based on a local EKF-based SLAM approach complemented by an optimization scheme to ensure long-range and inter-robot position consistencies [RVSI11391]. This approach integrates inertial and visual information and has in particular shown its ability to estimate the 12-dimensions robot state at 100Hz frequency with a precision of a few meters over several kilometers [MAI12868].

Toward the Robot Assistant and/or Teammate

This reporting period corresponds to the consolidation of a topic which now contributes to the visibility of LAAS in robotics: decisional issues for human-robot interaction [CII13780]. One key element, in the LAAS approach, is that the human is explicitly taken into account. We have developed and instantiated at several levels the notion of “human-aware planning”.

Also we have been able to incrementally investigate, build and demonstrate complete robot control architecture specially adapted to human robot interaction.

We are now pursuing intensive collaboration with a number of excellent research teams covering several domains from robotics and Artificial Intelligence but also from development psychology. We summarize here below the main results.

Perspective-taking and reasoning on affordances: we have defined a computational framework that allows the robot to estimate the visual perspective of its human partner [RVSI10704, MAI11742]. This served as a basis to implement multi-modal human-robot dialog [MAI10718] best paper). The scheme was then extended to compute affordances in order to provide to the robot a basis for pertinent and legible proactive behavior [RVSI13804, MAI13674].

Motion and task planning for cooperative robots: We have deepened our previous contributions to human-aware navigation [RVSI13805,] by providing a more general scheme, based on cost-based planning, to elaborate human-aware task plans and their associated motion [RVSI12857, MAI10262]. This scheme has also been extended to situations where the robot has to compute and propose proactively where a task such as an hand-over could be performed. We have also devoted substantial efforts to user studies in order to validate and refine our contribution [RVSI11901, RVSI101009].

Elaborating Human-Robot shared plans: We have extended and fully implemented a task-planner, called HATP, specially dedicated to build and maintain human-robot shared plans. It explicitly takes into account not only robot actions, but also actions that can be achieved by the human, and opens to a large spectrum of types of interactions between the human and the robot [RVSI12877, CII14319]. This was further enriched the possibility to build a shared plan taking into account divergent beliefs between the agents (humans and robot) [MAI12823, CII11878]. Another extension is the elaboration of a new planning, paradigm that combines motion and task planning allowing a sophisticated interaction between a HTN based task planner and a geometric task planner, which both contribute to the incremental construction of a shared plan [MAI13677, MAI13674].

Projects to study issues in HRI: The reporting period corresponded also to a very intensive activity in building and conducting collaborative research projects linked to Human-Robot Interaction. The main FP7 projects in which we have been or are still very active are: CHRIS, DEXMART, SAPHARI and SPENCER.

We have also been involved in four ANR projects, which deal with HRI issues: ASSIST, I_CARO, MARDI and ROBOERGOSUM. In the more general domain of cyber-physical systems and networked robots, we have coordinated the ROSACE RTRA project.

Molecular Motion Algorithms

Structural biology and materials science are very interesting and challenging areas for the development of algorithms related to motion simulation and analysis. Doubtless, biological macromolecules (such as proteins or RNA) and polymers, at the atomic scale, can be seen as extremely complex systems, whose mobility is closely related to their physicochemical properties and biological functions. Methods for simulating motions of such systems are an essential complement to experimental methods to help their understanding and characterization. They are also of key importance for advances in application areas such as health (e.g. drug design), biotechnology (e.g. engineering enzymes for bio-catalysis) or nanotechnologies (e.g. development of molecular nano-devices).

RIS develops an original approach for the simulation of molecular motions. This interdisciplinary research topic, initiated over one decade ago, is reaching maturity and gaining visibility [RVSI12067]. These robotics-inspired methods are mainly aimed at providing qualitative information about large-amplitude conformational transition using very few computational resources in comparison with currently used simulation methods. For this, they exploit the efficiency of sampling-based exploration algorithms applied to simplified molecular models. Despite the simplifications, the results provided by this type of methods can be very useful to help undemanding molecular mechanics at the atomic scale. They can also be used as input for other classes of methods to perform a more accurate analysis of conformational transitions.

We have particularly investigated the application of these methods to model conformational transitions in proteins, both at a local level (e.g. loop motions) [RVSI12215, RVSI11306], and at a global level [RVSI13340], as well as protein-ligand [RVSI10131] and protein-protein [RVSI11019] interactions. In collaboration with researchers at the Laboratoire d'Ingénierie des Systèmes Biologiques et des Procédés (LISBP, UMR CNRS-INRA-INSAT), in the framework of the ANR GlucoDesign project, we have investigated the application of the aforementioned methods to rational enzyme engineering [RVSI09694]. Experimental results have shown the ability of our methods to identify interesting positions for site-directed mutagenesis, leading to new enzymes with improved activity and enhanced selectivity. Such an interesting research direction will be continued in the framework of the ANR ProtiCAD project, whose objective is the development of novel methods and computational tools for protein design.

Some Significant Implementations

A decentralized control architecture: A new control architecture that exhibits explicitly the management of hardware and information resources has been developed [MAI11275]. It is defined by a network of agents that interact through the exchange of constraints on the resource they embed. The inter-agent mechanisms guarantee the good use of each resource, solve resource conflicts and handle execution errors thanks to a logic layer implemented on each agent. Besides, the proposed architecture considerably eases the definition of supervision schemes, and can be extended to a multi-robot distributed context.

A strong will of our activities in field robotics is to integrate our developments on-board actual platforms and experiment them in realistic conditions. Two experimental achievements are noticeable:

Mobility in natural terrains. Autonomous navigation is a fundamental ability which we now fully master, having integrated various motion generation techniques and robust complementary localization abilities on board the two robots Mana and Minnie. This has been demonstrated through the participation to 3 editions of the European ELROB challenge, ranking second during the 2013 edition.

Aerial / ground robot patrolling. In the context of the DGA funded project Action and in cooperation with ONERA, numerous trials have been performed on a 10 hectares field, that involved mission planning, autonomous navigation without GPS, and target tracking.

Figure 15: Two Robots in Natural Terrains

A fully implemented architecture for a collaborative robot: We have incrementally developed a robot control system that has been especially designed for a cognitive robot which shares space and task with a human. We have adopted a constructive approach based on effective individual and collaborative skills. The system is comprehensive since it aims at dealing with a complete set of abilities articulated so that the robot controller is effectively able to conduct a collaborative task with a human partner in a flexible manner [CII11878]. These abilities include geometric reasoning and situation assessment based essentially on perspective-taking and affordances, management and exploitation by the robot of each agent beliefs (human and robot) in a separate cognitive model, human-aware task planning and human and robot interleaved plan achievement.

Figure 16: A Collaborative Robot Able to Estimate its Partners Perspective View of the Situation

We have also developed a library of functions named SoftMotion to efficiently generate and control trajectories and take into accounts constraints imposed by the robot dynamics. The trajectories are defined by series of cubic functions of time. They are of class C2 and consider bounds to the velocity, the acceleration and the jerk [MAI10308, MAI13114].

The full system has been implement based on the LAAS control architecture and was run on several platforms

(Jido robot equipped with a Kuka LWR arm as well as PR2 from Willow-Garage).

The MORSE Simulator Open software initiative: we have initiated the development of an open-source simulation infrastructure, nicknamed Morse, that has now become a generic robotics simulator [MAI112712, http://morse.openrobots.org]. Morse can be exploited to simulate scenarios in a variety of environments, and is independent from middleware and components architecture -- it is yet interfaced with the most common robotics middleware (ROS, Yarp, GenoM, MOOS). Morse is now used worldwide by about a hundred individuals, and its development involves people from a dozen laboratories.

MoMA-LigPath, a web server to simulate protein-ligand unbinding: Aiming to enable easy and wide access to our molecular simulation methods, we have developed a web application called MoMA-LigPath [RVSI13045], which is freely available at: http://moma.laas.fr/. Starting from the model of a protein-ligand complex, MoMA-LigPath computes the ligand unbinding path from the active site to the surface of the protein. In addition to the simulated motion, the application provides useful information about protein-ligand interactions identified along these paths, and that can help decision making for protein engineering. In only a few months, more than 300 jobs have been submitted to the server, and the positive feedback from external users encourages us to further develop such web applications as a means for diffusing our research results to the scientific community.

GOAC, a valid by design integration: The GenoM/BIP integration presented above has been deployed on Dala, an outdoor robot, mimicking an extraterrestrial rover mission. Two navigation modes are used (stereo based and laser based) to navigate in an a priori unknown environment. The rover takes science pictures uploaded later to an orbiter during visibility windows, and while navigating, the rover monitors opportunistic science phenomenon and reports them. Overall, the rover integrates 14 GenoM modules, with the BIP controller running the complete functional layer and enforcing inter modules constraints (e.g. to not move while taking high resolution pictures or while communicating with its antenna). We were able to check with D-finder that the 14 modules integration was deadlock free.

2.4 Significant Projects and Collaborations

ROB has conducted several collaborative research projects at the European and at the National levels. They are fully in line with the research axes of the three robotic teams.

European projects:

- URUS-STREP-FP6 (12/2006-12/2009): Networked autonomous robots in urban settings http://urus.upc.es
- PHRIENDS-STREP-FP6 (10/2006-10/2009): Physical Human-Robot Interaction: DepENDability and Safety http://www.phriends.eu
- COMMROB-STREP-FP6 (03/2007-10/2010): Advanced behaviour and high-level multimodal communication with and among robots http://commrob.eu
- GOP – ECHORD (2011-2012) Optimal paths for industrial and humanoid robots in complex environments http://www.echord.info/wikis/website/gop
- DEXTMART-IP-FP7 (02/2008-02/2012) Dexterous manipulation and Human-aware motion http://www.dexmart.eu/
- CHRIS-STREP-FP7 (03/2008-03/2012) - HRI - Cognitive architecture – Manipulation http://www.chrisfp7.eu
- SAPHARI-IP-FP7 (11/2011-10/2015) The teammate robot http://www.saphari.eu/
- ARCAS-IP-FP7 (12/2011-12/2015) – Assembly by multiple cooperative UAVs - http://www.arcas-project.eu/
- SPENCER-STREP-FP7 (04/2013-03/2016) – Human aware robot guide http://www.spencer.eu/
- KOROIBOT-STREP-FP7 (10/2013-10/2016), Improving humanoid walking capabilities by human-inspired models, optimization and learning http://orb.iwr.uni-heidelberg.de/koroibot/
- FACTORY IN A DAY ICT-FOT-FP7, (10/2013, 09/2017) Reducing the installation time of a new hybrid robot-human production line down to 1 day http://www.factory-in-a-day.eu/
- TWO!EARS-FETOpen-STREP- FP7 (12/2013-11/2017) Reading the world with two ears http://twoears.eu
- EUROC ICT-FOF-FP7 (01/2014-12/2017) 3 industry-relevant robotics challenges: Reconfigurable interactive manufacturing cell, shop floor logistics and manipulation, plant servicing and Inspection http://www.euroc-project.eu/
- ACTANTHROPE (2014-2019) ERC Advanced Grant by J.-P. Laumond, "Computational Foundations of Anthropomorphic Action"
- GOAC- ESA-ESTEC funding (09/2009-10/2011) Goal Oriented Autonomous Controller http://istc.cnr.it/it/project/goac-goal-oriented-autonomous-controllers.

ANR projects:

- 2RT-3D (June 2007 - June 2009) - Perception and Environment Modeling – Navigation
- LOCANTROPE (2008-2010) - Computational foundation of human locomotion.
- FAST (Feb. 2008 - Feb. 2011) - Perception - Perception - Environment modeling - Navigation
- AMORCES (2008 - 2011) - HRI - Cognitive architecture – Manipulation
- RINAVEC (Mar. 2008 – Oct. 2011) *Reconnaissance d'itinéraires et navigation en convoi de véhicules communicants* (Route recognition and navigation in a convoy of communicating vehicles)
- R3T (Apr. 2008 – Mar. 2011) Real Time, and True Temperature Measurement
- ASSIST (2008 - 2012) - RAP - Manipulation with two arms - HRI
- GLUCODESIGN (Jul. 2009 - Jul. 2012) bioinformatics - molecular motion
- RBLINK (2009-2011) "Young researcher ANR" Focused on reflex movements in humanoid robotics
- ANR-JST BINAAHR (French-Japanese, Mar. 2010 – Oct. 2013) – ROB coordinator - Binaural active audition for humanoid robots
- I-CARO (Sep. 2011 – Sep. 2014) – Robotic co-worker

- RIDDLE (Sep. 2012 – Aug. 2015) – ROB coordinator - Robots for perceptual interaction dedicated to daily life environment
- MARDI (Oct. 2012 – Sept. 2015) – Situated Human-Robot Dialog – Affordances
- FLECTO (2012-2015) Simulation of assembly tasks with numerical mockup of flexible rods.
- PROTICAD (2013 – 2016) Molecular motion
- ROBOERGOSUM (Jan. 2013 – Jan. 2017) Interactive and Cognitive robot architecture
- ENTRACTE (Jan. 2014 - Dec 2017) Anthropomorphic action planning and understanding.

Other National projects:

- TAROT – DGA (Oct. 2006 - Oct. 2009) - Perception and Environment Modeling – Navigation
- MARAE - FRAE (Jan. 2008 - Jan. 2011) - Architecture - Validation - Planning
- SCA2RS - FRAE (Jan. 2008 - Jan. 2011) - Control Architectures - Multi-robot cooperation
- ROSACES - RTRA (Jan. 2008 - Jan. 2012) – ROB coordinator - Networked multi-robot systems
- GOAC - ESA (Sept. 2009 - Sept. 2011) - Architecture - Validation - Planning
- ACTION PEA-DGA (2007 - 2014) - - Control Architectures - Multi-robot cooperation - Perception and Environment Modeling http://action.onera.fr
- ROMEO – FUI (2009 - 2011) First phase of development of the human-sized humanoid robot Romeo.
- SART – FUI+Région (2009 – 2012) Système d'aide au roulage tout temps (System for all-weather aircraft taxiing assistance)
- CAAMVIS - AEROSAT (2012 – 2013) Automated quality control of mechanical assemblies by artificial vision
- ROMEO 2 - PSPC (2012 – 2016) Second phase of development for the assistive companion robot Romeo http://www.projetromeo.com/
- AIR-COBOT – FUI+Région (2013 - 2016) Aircraft enhanced Inspection by smart and collaborative robot
- SERVAT - DGA Rapid (2014-2017) Suivi et Reconnaissance Visuels, Adaptatifs, Temps réel
- SkyScanner – RTRA-FRAE (2014 – 2016) Micro Air Vehicles Research Center
- DICTA – CLE Midi-Pyrénées Region (2013-2015) Development of Integrated Cameras for Transport Applications.
- CameraNet – CLE Midi-Pyrénées Region (2010 -2013) Networks of cameras for visual monitoring
- OnVisuPra – CTP Midi-Pyrénées Region (2009–2011) On-board Video Surveillance Platform for Railway Applications.

Other International projects:

- Cluster of Excellence iCeiRA - Taiwan http://www.iceira.ntu.edu.tw/en/.
- Cooperation CNRST-MAROC/CNRS-FRANCE with University Mohamed V (Rabat) on mobile robot navigation of a mobile robot in a cluttered human environment.
- TOYOTA (2009-2010) Industrial project for technology transfer and customization of the software platform HPP.
- NCTVS (2010-2011) Nonlinear control tools for visual servoing, Brazil-Chile-France.
- (Since 2012) International intellectual grouping AABBA (Aural assessment by means of binaural algorithms, lead. Prof. Jens Blauert, Bochum Univ, Germany): application of models of human binaural listening and understanding, particularly in the communication technologies and in robotics.

3 Academic Reputation and Appeal

The participation of ROB researchers to scientific events is exhaustively listed in the Annex. Here below, only the more salient facts are summarized.

3.1 Main International and National Collaborations

The research activities of ROB are performed in close cooperation with other teams or researchers of the national and international scientific communities.

3.1.1 International Collaborations

A number of international collaborations took place in a formal context defined by bilateral international agreements; it allowed us to work with the *Centre de Développement des Technologies Avancées* in Algiers, DZ, several universities in Brazil and Chile (STIC AMSUD), Pontificia Universidad Javeriana in Bogota, COL (ECOS Nord), Université Mohammed V Agdal in Rabat, MAR (CNRST-CNRS cooperation) and with Kyoto and Kumamoto University and the Honda research institute, JPN (ANR international project BINAAHR)..

ROB has maintained very strong exchanges that were formalized in previous periods, like our relationships with Beckman Institute, Univ. Urbana Champaign USA, with JRL and AIST in Tsukuba and YNL Tokyo Univ. JPN, with CIMAT and Univ. Guanajuato MEX, and with Beijing Univ. CN.

During the last years some new informal collaborations were initiated with Seoul National University KR and Ecole Polytechnique, Montréal CA, with Univ. Washington, USA, and with the CINTRA lab in Cordoba AR.

3.1.2 Europe

Besides collaboration in European projects, some historical connections with our close ES neighbors have been maintained: with IMEM at UPC, Barcelona, with Mondragon University, with CVC lab, Barcelona in Spain and with University of Coimbra, in Portugal.

Other collaborations were initiated from European projects: with University of Bremen, DE, with University of Napoli and IIT in Genova, IT, with PAL Robotics in Barcelona, ES, with DLR and TUM, Munich, DE, with the Zagreb University, HR, etc.

Finally, new cooperations have also been initiated thanks to the recruitment of European colleagues. Especially with the Modena, Siena, Cassino, Salento, Bari and Padova Univ., IT and the Max Planck Institute for Biological Cybernetics, DE, about aerial robotics, and with Univ. Heidelberg, DE, about motion optimization.

3.1.3 National Collaborations

ROB has developed "historical" collaborations with several regional labs: LGP at ENI Tarbes, IRIT, ICA at Mines Albi, ONERA Toulouse, ISAE, ENAC and CerCo (joint PhD students, joint participations to projects…).

Many collaborations took place at the national level: the more significant ones with ISIR Paris (co-advised PhDs, projects on audition), Lasmea Clermont, CerCo Toulouse, INRIA Rennes, INRIA Rhône-Alpes, LIRMM Montpellier, Verimag, Grenoble, CEA LIST Saclay and GREYC Caen.

3.2 Journal Editorial Boards

Eight ROB permanent researchers are associate editors for journals, especially for the IEEE Trans. On Robotics.

3.3 Organization of Major Conferences and Workshops

ROB researchers participated as members to more than 40 Technical Program Committees of conferences.

Let us mention the participations as chair or associated editors, especially for the IEEE Int Conf. on Robotics and Automation (ICRA), the IEEE/RSJ Int. Conf. on Intelligent Robots and Systems (IROS) and the IFAC World Congress in 2011.

Moreover, ROB researchers have been involved in the organization of about 20 scientific events, amongst them the *Journées Nationales de la Recherche en Robotique* (JNRR) in 2013, a number of ICRA, IROS or RSS workshops and the IEEE RAS Int. Conference on Humanoids (J.P.Laumond general chair in 2009).

3.4 Major and Long Term Visits

3.4.1 Sojourns of Researchers Abroad

Five ROB permanent researchers did long stays abroad, in Japan (AIST Tsukuba), Italy (La Sapienza di Roma), Spain (UPC Barcelona) and USA (University of Washington).

3.4.2 Researchers Hosted

Thirteen permanent researchers were hosted in the ROB teams; visiting postdocs, engineers and PhD students are mentioned in the personnel status.

Let us focus on the long stays (more than one year): K. Montbaur from University of Heidelberg DE (04/2008-03/2010), Y. Huang from University of Beijing, CN (06/2013-09/2014), W. Ruml from University of New Hampshire, USA (07/2013-07/2014), A. Marin Hernandez from Universidad Veracruzana, Xalapa MX (09/2011-02/2013) and A. Mouaddib from GREYC, Université de Caen, FR (01/2012-01/2013).

3.5 Major Roles in National Animation, Evaluation Structures and Scientific Societies

ROB researchers participated to several international scientific evaluation committees, especially for European programs (ECHORD, Factory of the Future, S-Fly…). They were involved in 13 national evaluation committees (AERES, INRIA, IRSTEA…).

ROB has been involved in several CNRS structures: section 7 of the “Comité National du CNRS” (T. Siméon), several Working Groups (GT) of the GDR Robotique, etc.

ROB has been strongly involved in the IEEE society on Robotics and Automation and in the IFAC society.

3.6 Awards and Distinctions

ROB obtained three PhD awards from the GDR Robotique: E.A. Sisbot in 2009, for his PhD defended in 2008; S. Lemaignan in 2014, for his PhD defended in 2012, and from EURON (2nd price of the 2013 Georges Giralt PhD award for A.K. Pandey.

Let us recall that J.-P. Laumond obtained the “Chaire Innovation Technologique Liliane Bettencourt” at Collège de France in 2011-2012.

4 Interaction with Social, Economic and Cultural Environment

4.1 Projects with Industrial Partners

ROB was involved in four CIFRE contracts with the regional SMEs Magellium, Navontime, Noomeo and CLS.

Three ones are on the way, with the regional SMEs Magellium, Alpha Mos and Orme, and two other ones with AKKA Technology and the AIRBUS groups.

The RAP team is involved with the PHOTO and OSE teams of the HOPES area, in the future joint lab with the ESSILOR group.

ROB is involved with other LAAS teams, in the “Filière Industrie Mécanique et Procédés, systèmes de production du futur” of the Carnot Institutes.

ROB has supported several starts-ups: first NOOMEO (created in 2007, closed in 2013) with a CIFRE PhD student and a regional project, then NAIO Technologies created in 2012 with a regional collaborative project.

ROB participates to the animation of the scientific and industrial communities on the topic “Factory of the Future”: DAS “Usine du Futur” of the Aerospace valley cluster. Rob participated to several meetings organized by the Toulouse CCI (Panel on Robotics and Factory of the Future, Forum de l’Industrie, Toulouse; 17/04/2014) or the Région Midi-Pyrénées (Club d’Analyse Economique).

ROB participates to the regional clusters GIPI and Robotics Place (member of the board).

4.2 Scientific Popularization

ROB researchers were involved in many popularization actions. Robotics is very attractive for the general audience. Let us mention especially:

- the show “Danse avec HRP-2”, 15 mn show with the HRP2 robot and a professional hip-hop artist, for more than 1000 attendants in 2011 and 2012,
- the participation to several popular TV programs for the general audience (“La tête au Carré”; “C dans l’air”; …)
- a number of demonstrations (Robopolis, Trophées de la robotique, Fête de la Science…)
- many conferences for people at large or some specific audiences (UPS students, Météo France, Pierre de Fermat association…).

5 Involvement in Training through Research

5.1 Leading Roles in Doctoral Schools

ROB permanent professors have several responsibilities in Master and Licence supervisions in the Toulouse III

Paul Sabatier Univ. (IRR Master2, Intelligent Systems Licences and Masters, Signal, Image and Applications (SIA) track of the EEA Master…). Let us mention especially the supervision of the Robotics specialization track for the UPSSITECH engineering school, validated by the CTI from 2014.

ROB participated to the management team of the EDSYS Doctoral School from 2009-2014.

5.2 Research Seminars in Training Programs

ROB permanent researchers participated to 12 seasonal schools or specific lectures in Universities abroad. They are involved in several advanced university courses in Toulouse schools or universities (ISAE, UPS) and in ENS Ulm in Paris.

5.3 PhD and Internship/Master Programs

5.3.1 Thesis Supervised

57 students obtained their PhD in ROB during this period, for about 25 permanent researchers: 16 in GEPETTO, 19 in RAP, 21 in RIS and one joint RAP-RIS.

On average, more than 2 PhD students by permanent on 5.5 years. All alumni have a job.

PhD name	Defence	Current Situation
O. Kanoun	10/09	Ingénieur, Square ENIX Tokyo
M. Poirier	10/09	ENAC Toulouse
A. Nakhei	09/09	MPB Communications, Québec
A. Herdt	06/10	Ingénieur Dyson
M. Tran	01/10	Ingénieur Amadeus, Sophia Antipolis
A. Truong	08/10	ENAC Toulouse
F. Montecillo	09/10	Ass. Prof. Univ. Guanajuato MX
M. Sreenivasa	04/11	Postdoc, Heidelberg Univ. DE
D. Flavigné	09/10	Postdoc ISIR Paris
S. Dalibard	10/11	Ingénieur, Aldebaran Robotics, Paris
C. Halgand	09/11	IR INRIA INCIA Bordeaux
N. Perrin	10/11	CR CNRS, ISIR Paris
L. Saab	10/11	Ingénieur EOS Innovation Evry
S. Hak	11/11	Postdoc ISIR Paris
T. Moulard	10/12	Ingénieur Google Tokyo
D. Dang	11/12	Ingénieur Amadeus, Sophia Antipolis
W. Ait-Fares	09/13	Ass.Prof. Univ. Mohamed V, Rabat, MA
D.L. Almanza-Ojeda	01/11	Ass.Prof. Univ. Tech. Celaya, MX
D.A. Botero Galeano	12/12	Engineer, MATIS, Paris
B. Burger	01/10	Engineer, CEA LIST, Saclay
J.-M. Codol	02/13	Start up creator, incubator Mines Alès
B. Coudrin	03/11	Engineer, R&D consulting, Paris
B. Ducarouge	09/11	Engineer, Nouméa
A. Durand Petiteville	01/12	Postdoc, Univ.Davis, Sacramento, USA
T. Germa	06/12	Engineer, Magellium, Toulouse
A. Gonzalez	07/13	Engineer, Magellium, Toulouse
J. Harvent	11/10	Engineer, R&D consulting, Paris
M. Ibarra Manzano	01/11	Ass.Prof. Univ. Guanajuato, MEX
R. Lopez	07/13	Engineer, CLS, Ramonville St Agne
D.A. Marquez Gamez	10/12	Engineer, IRT Jules Verne, Nantes
B. Meden	01/13	Engineer, Diotasoft, Massy
A.A. Mekonnen	03/14	Postdoc, LAAS, Toulouse
A. Portello	12/13	Postdoc, LAAS, Toulouse
Y. Raoui	04/11	Ass.Prof. Univ. Mohamed V, Rabat, MA
P.Theodorakopoulos	05/09	Engineer, Sterling Info Systems, Olso, NO
Luis Marin	11/09	Ass.Prof. Univ. Xalapa, MX
C. Berger	12/09	Research Associate, Univ. Linkoping, SE
D. Le	09/10	Engineer, Génigraph-Toulouse
M. Gharbi	11/10	Engineer, Diginext Toulouse
B. V. Pham	12/10	Engineer, Amadeus, Sophia Antipolis
A. Belbachir	02/11	Postdoc, IRSEEM, Rouen
S. Alili	04/11	Engineer, Software consulting,
B. Bounab	06/11	Engineer, Algeria
X. Broquère	07/11	Engineer, Magellium, Toulouse
N. Muhammad	02/12	Post-doc, Center for Biorobotics, Tallinn University of Technology, Estonia
Amit Pandey	06/12	Engineer, Aldebaran Robotics, Paris
M. Ali	07/12	Post-Doc, Pakistan
S. Lemaignan	07/12	Postdoc, TRUM, Munich, DE
Al Bluwi	09/12	Assistant Professo, Princess Sumaya University, Amman, Jordan
A. Degroote	10/12	Engineer, ISAE, Toulouse
M. Warnier	10/12	Engineer
J. Mainprice	12/12	Post-Doc USA - WPI
R. Boumghar	06/13	Associate, Big Data, Toulouse
C. Roussillon	10/13	Engineer, Robosoft, Toulouse
W. He	10/13	Engineer, Florida, USA

5.3.2 Co-Supervised Thesis

National

Several alumni were co-advised by colleagues from other labs in France or other areas in LAAS: D. Dang (with DO, LAAS), D.A. Botero Galeano and M. Ibarra Manzano (with NII, LAAS), L. Saab (with LGP, Tarbes), J. Harvent, B. Ducarouge and B. Coudrin (with Mines and ICA Albi), A. Portello (with ISIR, Paris), B. Burger (with IRIT, Toulouse).

Five on-the-way PhD students are co-advised with other labs: two with IRIT, one with LGP, Tarbes, one with ONERA, Toulouse, and one with Mines and ICA, Albi.

ROB has a growing cooperation with CEA LIST, Saclay; only one alumni was co-advised with a CEA engineer, two on-the-way PhD students are in this situation, and two others will start in 2014.

International

ROB permanent researchers have been advisors or co-advisors of 16 PhD thesis abroad, with colleagues in DE (Heidelberg, Max Planck Inst. for Biol. Cybernetics, TUM), IT (Bari), DZ (CDTA and Ecole Militaire Polytechnique, Algiers), ES (Barcelona, Mondragon), MAR (Université Mohamed V Agdal, Rabat) and Serbia (Novi Sad).

5.4 PhD/HdR Committees

ROB researchers were invited to evaluate PhD students or HDR applicants as a reviewer or a committee member abroad or outside the Midi-Pyrénées academy. They participated to:

- 28 PhD committees abroad (Australia, Spain, Portugal, Morocco, Switzerland, Belgium, Germany, Sweden), as reviewer (22) or member (6).
- 18 HDR committees, as reviewer (12) or member (6).
- 110 PhD committees in other French universities, as reviewer (86) or member (24).

5.5 Faculty Selection Committees

ROB permanent researchers were invited to participate to 20 Selection Committees in order to hire CR or Professors in national universities (9 for local ones: ENIT Tarbes, UPS, UT1, INSA, ISAE).

V - Decision and Optimization
(*Décision et Optimisation* — DO)

Leader: D. Arzelier

Research Teams: Diagnosis and Supervisory Control, Methods and Algorithms in Control, Operations Research, combinatorial Optimization and Constraints

Keywords: Constraint-based Reasoning, Continuous and Discrete Optimization, Control Theory, Diagnosis, Fault Detection and Isolation, Hybrid Systems, Robustness, Scheduling and Logistics

Personnel Status (as of June 30, 2014):

Team — DISCO	Diagnosis and Supervisory Control (*DIagnosis Supervision et COnduite*)
Leader	L. Travé-Massuyès (DR)
Permanent Researchers	J. Aguilar Martin (DR, émérite), F. Le Gall (CR), from [09/2012[, E. Chanthery (MCF), M. Combacau (PR), B. Dahhou (PR), A. Doncescu (MCF), C. Jauberthie (MCF), E. Le Corronc (MCF), [09/2013[, M.V. Le Lann (PR), F. Mora-Camino (PR, affiliated), Y. Pencole (CR), P. Ribot (MCF), [09/2011[, G. Roux (PR), A. Subias (MCF) Retired: A. Aichaibou (PR)]01/09/2012], G. Salut (DR) [01/02/2012-01/09/2012[
PhD Students (Arrival date)	F. De Mortain [12/11/2012[, Q. Gaudel [01/10/2013[, H.E. Gougam [01/10/2011[, S. Indra [15/10/2009[, M. Maiga [01/11/2011[, T. Monrousseau [15/11/2012[, T. Nguyen [08/03/2012[, Z. Qu [21/09/2012[, E. Roux [15/11/2012[, C. Ternon [11/02/2013[Alumni: N.M. Belard [02/03/2009-29/12/2012], N. Belkherchi [05/03/2007-05/04/2011], M. Benkaci [01/10/2007-28/02/2011], M. Figueiredo Fernandez [01/09/2010-30/07/2013], L. Hedjazi [01/10/2008-08/12/2011], J. Karim [01/06/2006-18-05-2010], T. Le [17/01/2011-28/05/2014], R. Leal Tejidor (visiting PhD) [15/05/2012-31/07/2012], E. Perin [15/01/2013-31/12/2013], F. Perrot [01/09/2005-01-07-2011], M.H. Pham [01/11/2011-31/12/2014], P. Ribot [04/09/2006-04/09/2009], F. Sallem [01/12/2009-04/10/2013], H. Sarmiento Maldona (visiting PhD) [10/06/2012-20/06/2014], J.I. Vento Maldonado (Visiting PhD) [12/04/2012-26-06-2012], G. Vinson [01/02/2011-31/01/2014], J. Vizcarrondo Rojas (Visiting PhD) [15/05/2012-31/07/2012], J. Xiong [01/10/2009-31/01/2013], N. Zhang [01/09/2006-26/06/2010]
Post-docs; Engineers	M. Bayoudh [05/02/2009-31/07/2010], A. Elena [01/01/2010-30/06/2010], M. Godichaud [14/09/2009-14/10/2010], L. Hedjazi [09/12/2011-31/08/2012], M.N. Kabbaj [15/01/2008-14/01/2010], T. Kempowski Hamon [01/05/2011-28/02/2013], R. Pons [15/11/2007-30/09/2011 and 01/10/2013-31/01/2013], P. Ribot [05/02/2009-31/07/2010]
Visiting Researchers (Affiliation, Country, Period)	J.L. Aguilar Castro (Universidad de los Andes, VE, 01/09/2010 — 31/08/2011), Z. LI (Guizhou University, CN, 01/03/2011 — 31/05/2011 and 01/02/2012 — 31/08/2012), R. Loukil (Ecole Nationale d'Ingénieurs de Sfax, TN, 02/10/2011 — 30/10/2011)
Team — MAC	**Methods and Algorithms in Control (Méthodes et Algorithmes pour la Commande)**
Leader	D. Arzelier (DR)
Permanent Researchers	Y. Ariba (ICAM, affiliated), L. Baudouin (CR-HDR), J.-L. Calvet (PR), D. Fournier-Prunaret (PR)]01/01/2010], G. Garcia (PR), F. Gouaisbaut (MCF), D. Henrion (DR), M. Joldes (CR)]21/01/2013], J.-B. Lasserre (DR), C. Louembet (MCF), V. Mahout (MCF), D. Peaucelle (CR), B. Pradin (PR, émérite), I. Queinnec (DR), A. Seuret (CR)]04/10/2011), S. Tarbouriech (DR), A. Théron (PRAG High School, affiliated), L. Zaccarian (DR)]01/10/2011] Moved: V. Andrieu (CR) [01/11/2007 - 01/02/2010], J.-M. Biannic (ONERA, affiliated) [01/07/2010 - 01/01/2013], C. Prieur (CR) [01/09/2004 – 30/09/2010] Retired: J. Bernussou (DR)]]
PhD Students (Arrival date)	L. dal Col [01/10/2013[, F. Ferrante [11/10/2012[, O. Lopez-Santos [01/02/2012[, S. Naldi [01/10/2012[, F. Niel [01/05/2014[, F. C. Ribeiro-Cardoso [01/01/2013[, R. Serra [10/12/2012[, L. S. Urbina Iglesias [01/10/2013[, S. Zaibi [01/10/2013[, M. Zardo Oliveira (visiting Ph. D.) [15/03/2010[Alumni: C. M. Agulhari (01/09/2010), D. Billy [01/10/2009-30/04/2010], J. Boada [15/10/2007-14/12/2010], F. Bugarin [01/10/2009-05/10/2012], M. Claeys [01/09/2010-11/10/2013], G. Deaconu [01/10/2010-29/10/2013], L. R. Douat [15/07/2008-14/12/2011], K. Feltekh [01/08/2011-31/03/2014], F. Fichera [05/11/2010-04/11/2013], G. Fumat [08/07/2011-02/12/2011], N. Jean-Baptiste [01/02/2008-21/09/2011], M. Kara-Zaitri [01/10/2007-30/11/2010], H. Kumeno [15/08/2011-24/09/2012], M. J. Lacerda (visiting Ph. D.) [01/10/2012-30/04/2013], T. Loquen [01/10/2006-28/02/2010], A.R. Luzi [01/10/2010-31/03/2014], H. Ma [20/08/2011-23/04/2014], Y. Pechaud (visiting Ph. D.) [01/09/2012-31/10/2012], T. Phan-Thanh [01/09/2009-31/10/2012], M. Pocquet [01/04/2011-31/03/2014], S. Rahme [01/10/2008-16/11/2011], B. Robu [01/10/2007-01/12/2010], T. Tognetti-Calliero [04/12/2007-06/11/2009], J. I. Torres – Zuniga [01/10/2010-30/06/2010], J.-F. Tregouët [14/10/2009-31/12/2012], G. Valmorbida [01/12/2010-30/06/2010], G. Zaibi [01/08/2011-31/12/2012]
Post-docs; Engineers	S. Agarwal [01/09/2008-31/08/2009], A. Arce-Rubio [15/07/2013-14/07/2014], A. Delibasi [02/03/2009-31/08/2010], M. Fiacchini [01/02/2010-30/09/2011], M. Mevissen [06/12/2010-01/08/2011], C. Olalla-Martini [01/09/2009-28/02/2010], S. Rahme [17/11/2011-31/08/2012], B. Robu [04/02/2010-31/08/2011], S. Sahin [30/08/2012-31/08/2013]
Visiting Researchers (Affiliation, Country, Period)	G. Blekherman (Georgia Tech., US, 20/06/2011 - 20/08/2011), Y. Ebihara (Kyoto University, JP, 15/11/2010 – 30/09/2011), V. Leite (UnED Divinópolis, BR, 07/02/2012 - 31/01/2013), L. Martinez Salamero (Universitat Rovira i Virgili, Tarragone, SP, 01/10/2010 - 31/03/2011), Y. Oishi (Nanzan University, JP, 01/03/2010 - 28/02/2011), Pedro Peres (Unicamp, Campinas, BR, 1/1/2009 - 30/01/2009).S. Robins (Nanyang Technological University, SG, 15/04/2013 - 15/12/2013), P. Antonio Teppa-Garran (University Simon Bolivar, VE, 01/09/2012 - 31/08/2013)

Team — ROC	Operations Research, Combinatorial Optimization and Constraints (*Recherche Opérationnelle/Optimisation Combinatoire/Contraintes*)
Leader	C. Artigues (DR)
Permanent Researchers	C. Briand (PR), P. Esquirol (MCF), L. Houssin (MCF), M.-J. Huget (MCF), N. Jozefowiez (MCF), P. Lopez (DR), C. Merce (PR), J. Moncel (MCF)]01/09/2010], S. U. Ngueveu (MCF)]01/09/2010], E. Hebrard (CR)]01/10/2010]
PhD Students (Arrival date)	J.T. Camino [11/2013[, C. Carbonnel [10/2013[, N. Chaabane [10/2012[, A. Cheref [10/2013[, L. Boche-Sauvan [01/2013[, Y. Gaoua [12/2011[, M. Nattaf [10/2013[, L. Malta [09/2012[, G. Scano [03/2013[, M. Siala [01/01/2012[, M. Trojet [07/2009[, L. Vargas [09/2013[, Alumni: M. A. Ayala [11/2007-06/2011], F. Baniel [10/2005-11/2009], A. Ben Hmida [09/2005-12/2009], T. Ben Rahhou [11/2009-06/2013], B. Gacias [10/2007-12/2010], H. Gharbi [11/2006-11/2012], F. Gueye [01/2008-01/2011], W. Karoui [12/2005-09/2010], K Kiatmanaroj [07/2009-07/2012], O. Kone [10/2006-01/2010], S. Lannez [12/2007-11/2010], S; Ourari [10/2006—01/2011], B. M. Sarpong [10/2010-12/2013], P. Tangpattanakul [09/2010-10-2013]
Post-docs; Engineers	H. M. Afsar [01/10/2008-31-08/2009], F. Baniel [13/11/2009-31/08/2010], M. Dugas [01/08/2009-30/09/2009], T. Garaix [01/01/2010-14/07/2010], C. Pira [03/11/2011-31/10/2012], G. Simonin [01/10/2011-31/09/2013], P. Šůcha [01/09/2011-31/08/2012]
Visiting Researchers (Affiliation, Country, Period)	A. Agnetis (Univ Siena, IT, 01/05/11—31/05/11 and 01/06/12—30/06/12), M. A. S. Aguilar (Univ Autónoma Nuevo León, MX, 7/01/2013—21/01/2013), I. Amorrortu (Univ Mondragon, SP, 13/05/11—31/07/11), L. Berghman (KU Leuven, BE, 06/09/11—31/12/11 and 19/04/12—30/06/12), J.-C. Billaut (Polyech'Tours, FR, 01/02/11—31/07/11), N. Bonifas (IBM/LIX, FR, 8/4/13—12/4/13), W. Dali (Univ Alger 3, AL, 01/10/13—01/03/2015), M. Frey (TU Munich, DE, 14/03/11—02/05/11), A.A. Juan (Univ Catalonia, SP, 15/07/13—15/08/13), S. Ourari (CDTA, AL, 25/06/12—20/07/12), V. Rodriguez (Univ Navarra, SP, 13/05/11—31/07/11), L.-M. Rousseau (Polytechnique Montréal,CA 01/03/12—31/03/12 and 03/06/12—04/08/12), J. Strnad (Technical University Liberec, CZ, 01/02/12—01/07/12)

1 Presentation

1.1 Objectives and Scientific Positioning

The Decision and Optimization (DO) area revolves around three disciplinary fields: Artificial Intelligence, Automatic Control and Operational Research. Scientific activities focus on the modeling and analysis of problems related to the control, supervision and optimization of dynamical systems along with the associated decision-making. In particular, the different phases of the life cycle of systems, associated to their definition, implementation, planning, scheduling, surveillance and maintenance are of interest. Problem-solving approaches that are used in DO quite naturally fall within the scope of Information Sciences while drawing some of its tools from Applied Mathematics.

In every study mentioned below, the members participating to DO share a common objective: Exhibit constructive theoretical conditions characterizing solutions to various control, diagnosis and optimization problems while providing effective efficient computational algorithms. The recent emergence of the field of rigorous computing (sometimes called validated computing) is a strong incentive to develop and extend these activities.

In this scientific context, the objective of DO is to carry out impactful research that ranges from fundamental theory to applied engineering. It includes both the development of fundamental theory in control, diagnosis and optimization, and the application of advanced tools to practical problems. This orientation is reflected in its income base that includes funding from projects involving the main operators of the aerospace domain, Airbus, Astrium, CNES, Eurocopter, MBDA, TAS and Google. Other types of funding originate from government programs (ANR, PICS-CNRS, PEPS-CNRS, PIE-CNRS), foundations (Simone and Cino del Duca foundation of the Institut de France, The Gaspard Monge Program for Optimization and operations research launched by EDF and the Jacques Hadamard Mathematical Foundation) and EU (Hycon, EDA NICE, ECO-INNOVERA), international programs (PCP, ECOS-Nord) or region bodies. The DO area is actively involved in the national programs such as GdR MACS, I3, ISI and RO.

The research conducted in DO is organized on the basis of three complementary topics: Control Theory, Diagnosis and Optimization Theory that will be detailed in the sequel.

1.1.1 Control Theory

The research in the field of control theory aims at developing generic theoretical and numerical tools for the analysis, control and estimation of complex systems, possibly affected by information limitations. Complexity may arise from essential features present in the system model to be controlled and its environment such as switches, jumps, isolated nonlinearities, uncertain parameters, delays or exogenous disturbances. The ability to propose new methods for analysis and design of robust control systems (extending this notion to observers, filters or pre-compensators) is therefore critical to the provision of heterogeneous performance requirements and certificates. For instance, when dealing with highly challenging applications such as space-borne control systems operating in an uncertain environment, the fundamental issue to be tackled is to guarantee robust internal stability of the closed-loop system. Lyapunov theory is a natural and powerful tool for obtaining computable stability certificates with the associated control laws, in different settings (robust stability tests for linear uncertain systems, identification of local stability domains for nonlinear systems…). The results developed in DO extensively rely on Lyapunov theory and its related extensions to hybrid systems. In addition to internal stability, passivity and small-gain properties as particular instances of a more general dissipativity theoretical framework may also be studied.

Measuring the challenges arising from the discontinuous and heterogeneous nature of dynamical systems involved in major current control applications, the class of dynamical models under study has been enlarged to include time-varying/nonlinear/hybrid models. By considering this particular class of models, the objective is threefold. First, the hybrid formalism is used as a new paradigm for representing various challenging characteristics (systems with impacts, systems subject to communication constraints) and to obtain improved analysis results. Second, the aim is to provide new controller architectures (hybrid control systems) in order to overcome the limitations of the usual continuous-time/periodic sampled-data control systems. Closely related to this last problem, the question of how the information coding and representation affect the control architecture is extremely challenging and is the opportunity to develop an active interdisciplinary program with the information theory community. Interestingly enough, the hybrid systems setting may be also very fruitful for studying and revisiting different problems of consensus and synchronization in cooperative control of multi-agent systems.

Besides the fundamental specification of stability, optimality of the designed control system with respect to a specific performance criterion is also of a major interest. (H_2/H_∞) worst-case analysis and design of feedback control systems for uncertain models (linear positive systems, polynomial systems) or contributions to impulsive optimal control theory for nonlinear constrained systems via direct and indirect approaches are two particular instances of optimality problems addressed by DO. This line of research involves analytical, numerical and computational activities that heavily rely on the developments on polynomial optimization and on the Generalized Problem of Moments (GPM), revealing strong fruitful relationships between optimization theory and control theory.

1.1.2 Diagnosis

The research conducted in the field of automated diagnosis aims at proposing theoretical and numerical methods for the analysis and design of efficient diagnosers, fulfilling the specific requirements of dynamic systems in varied environments. Diagnosis is crucial for systems safety, dependability, and maintainability, and it has echoes in all the engineering disciplines, so in the Automatic Control field. Diagnosis is also recognized as a difficult task that involves complex reasoning and it drives a lot of research in the Artificial Intelligence field. DO is well-known for its multidisciplinary research that relies on formalisms borrowed to these two fields [RVSI13182]. The research is organized along two lines: model-based diagnosis and data-driven diagnosis.

Diagnosers may take multiple forms depending on the targeted operational framework, resulting in rich and varied research that sometimes treads over other problems like control, planning and prognosis. On-line diagnosis requires monitoring capabilities that may introduce hard real time constraints and require preventive functions. The requirements are even stronger for on-board diagnosis and systems demanding some autonomy. On the other hand, off-line diagnosis, also known as troubleshooting, rather consists in the determination of a proper sequence of tests and measures at available control points, which drives to greedily localize the faulty components quickly and at the lowest cost. These multiple facets result in challenging scientific problems whose instances are given by the type of system at hand, continuous, discrete event or hybrid, taking as bases analytical redundancy, observer and estimation theories.

Complexity may arise from the nonlinear or hybrid nature of the system but also from the type of architecture to be deployed. Nowadays, distributed architectures become the standard in many domains. Diagnosis then relies on a set of diagnosers that elaborate local diagnoses. Globally consistent diagnoses are obtained by interlinking local results at a supervisory level or through communication among the local diagnosers. How to optimize such cooperative diagnosers is also at the core of our research, requiring the use of efficient optimization tools.

Equally challenging is the problem of taming the uncertainties affecting a system. These are sources of false alarms and missing detections that we aim to minimize. The ability to handle uncertainties appropriately and to provide methods that achieve guaranteed results, like set-membership methods, is one of our objectives. From another point of view, one may query the correctness of the model and of the diagnoser itself, this is why we have pushed two lines of research: meta-diagnosis and the automated learning of diagnosis models. This later issue bridges with our research based on machine learning and data mining tools. Given the amounts of data that are stored today, providing powerful data-driven classification based diagnosis methods able to deal with heterogeneous data and benefiting from efficient feature selection procedures has been one of the hot topics during the period.

Before designing any diagnoser, it is of prime importance to analyze the properties that support diagnosability certificates. In DO, set-membership identifiability and diagnosability have been given special attention for continuous systems, relying on interval analysis and differential algebra. For discrete-event and hybrid systems, diagnosability analysis has developed with contributions referring to distributed architectures and timed-oriented formalisms.

1.1.3 Optimization

Research activities of DO area in the field of optimization theory may be separated into two categories: Combinatorial Optimization related results and developments about continuous global polynomial optimization. Note that approaches designed in the second case may also have fruitful and unexpected side results in the first field [MAI11140].

DO carries out researches on models and methods for solving efficiently Combinatorial Optimization Problems (COP) and constraint satisfaction problems (CSP). To achieve this aim, DO area develops studies on the structure of fundamental problems in graph theory, scheduling, routing, constraint satisfaction, and integer programming on the one hand. On the other hand, the team aims at designing and evaluating generic solution search methodologies to cope with combinatorial explosion of the search space exploration while solving problems. The proposed models and methods first concern COPs in their deterministic and centralized form with a special emphasis on resource constrained scheduling problems (RCPSPs) and vehicle routing problems (VRPs). In addition, to increase the applicability of the developed approaches, DO seeks solutions to incorporate uncertainty through robustness considerations, multiple objectives/and or decision centers. Under the same objective, the team aims at confronting the proposed methods to the real world by considering industrial engineering and human aspects and/or applications to various domains including transportation, manufacturing and supply chain management, energy management, aeronautics and space. To favor the dissemination of its research and the confrontation of the developed methods to the international community, DO aims also to develop non-commercial solvers and participate to international competitions.

An original line of research explores the many emerging issues relating real algebraic geometry, convexity, certificates of positivity, measure representation and polynomial optimization. Deeply rooted in the framework of the Generalized Problem of Moment, these studies are carried out by extensively resorting to Lagrangian duality. It mainly aims at designing the most numerically efficient hierarchies of SDP relaxations of the original problem.

1.2 Organization and Life

The DO scientific area has its origin in the reorganization of the former scientific MOCOSY pole in 2010. It federates the activities of three research teams: *Diagnosis and Supervisory Control* (DISCO) focusing on observation of dynamical systems and its interpretations in terms of state estimation, fault detection and diagnosis, *Methods and Algorithms for Control* (MAC) dedicated analysis and synthesis of advanced control laws for complex heterogeneous dynamical systems including uncertainties, disturbances and nonlinearities and *Operations Research, Combinatorial Optimization and Constraints* (ROC) developing an upstream activity on combinatorial optimization and providing solutions to production planning, task scheduling, transportation systems and resource allocation problems.

1.2.1 Activity Profile

Table 1 depicts the activity profile for the DO area and gives also the profiles for the teams involved.

Table 1: Activity Profile

%	Academic research	Interaction with environment	Research Support	Training
DO	**55**	**15**	**10**	**20**
DISCO	45	25	10	20
MAC	60	10	10	20
ROC	55	15	10	20

1.2.2 Scientific Coordination

If every team composing DO has its own financial and scientific autonomy, coordinating, setting priorities and decision making at a higher level is mainly the role of the scientific council of DO. The DO scientific council (DOsc) includes two delegates for each team as well as the team leader and is gathered every month. To promote scientific collaborations between DO teams as well as between DO and other areas of the laboratory, an internal scientific seminar on specific crosscutting topics is scheduled. DOsc is also in charge of the organization of DO external seminars and workshops. The DO seminars are organized on a basis of 5 guests per year who are invited to give a talk and spend some days at LAAS to enrich the scientific and technical dialogue with members of DO. Here is a non-exhaustive list of some of the guests and topics having been held during the period:

- P. Baptiste, Ecole Polytechnique, “Mixed integer programming, branch-and-Cut and constraint programming: A comparison of three different approaches to solve the runway sequencing problem”;
- C. Bessiere, LIRMM, “Décomposition de contraintes globales en programmation par contraintes”;
- E. Bradley, Univ. Of Colorado, “Chaos and control”;
- F. Dufour, ENSEIRB-MATMECA, Université de Bordeaux 1, “Finite linear programming approximations of constrained discounted Markov”;
- J.C. Geromel, Unicamp, “Time-delay analysis and H-infinity design”;
- M. Nyberg, Linköping Univ., “Challenges of Model Based Diagnosis in Automotive System”;
- P. Pollett, Univ. of Queensland, “Modelling the long-term behavior of population processes”;
- L. Rodrigues, Univ. of Concordia, “Piecewise affine control systems”;
- R. Sirdey, CEA LIST, “Approches pour le partitionnement de graphes avec contraintes en probabilité de type sac à dos sur les partitions”;
- M. Staroswiecki, Univ. Lille I, “On reconfiguration based fault tolerance”;
- W. Tucker, Uppsala University, “Set-valued numerics for parameter estimation and beyond”;
- J.M. Vincent, IMAG, “Perfect Sampling of Non-Monotone Markovian Systems”.

Most of the budget of DO is dedicated to these invitations and to the organization of a topical workshop outside the laboratory, every two years (workshop on nonlinear techniques in 2011; workshop on robustness in 2013).

1.3 Salient Facts

This section describes 5 of the most salient facts relating to DO’s scientific activity for the reporting period. These salient features, shortly highlighted below, cover the complementary fields of international and national scientific recognition through the selection of members of DO for the organization of the 20th IFAC World Congress and international and national awards (Lagrange prize and Del Duca award) and through the open dissemination of technology for societal advancement (Google grant and prescription recommender system tool for oncologists).

1.3.1 Organization of the 20th IFAC World Congress

On July 2nd, 2010 France has been selected by the International Federation of Automatic Control council for the organization of the 20th IFAC World Congress. After Seoul in 2008, Milano in 2011 and Cape Town in 2014, the 2017 congress will be held in Toulouse. The French bid got ahead of Amsterdam and Yokohama proposals at the second and final stage of the designation process. The IFAC World Congress is the major event in the field of Automatic Control. It is held once every three years and gathers about 3000 participants form academic and industrial research centers worldwide. The proposal conception involved members of GdR MACS and about 15 members of LAAS, mainly from DO, with participation of ROB and LAAS administration staff. The reader willing to know more about the application may consult the official website of the conference www.ifac2017.org.

1.3.2 Google Grant 2011 - SAT-based Scheduling

In 2011, five French teams in Optimization were selected for a joint funding by Google and the CNRS among which the ROC team represented by C. Artigues, E. Hébrard and P. Lopez. 70 k€ where granted by Google while the CNRS offered a half PhD thesis funding. This funding recognizes the pioneering work of the team in constraint programming (CP) as well as in intelligent tree search methods that were recently proposed and allowed to close a significant number of open scheduling problems. The funding also promoted the development of promising hybridization between CP and SAT solvers via pruning explanations and clause learning.

1.3.3 Award from the Simone and Cino del Duca Foundation of *Institut de France*

Didier Henrion and his colleagues from the MAC team at LAAS-CNRS were the 2011 recipients of a 164.000 euro award from the Simone and Cino del Duca Foundation of Institut de France, in the topic of applied mathematics, upon recommendation by a committee of the French Academy of Sciences. The project, entitled "semi-definite programming and algebraic geometry for systems control", focuses on the development of tools of applied mathematics with potential transfer to the aerospace industry. The Simone and Cino del Duca foundation is a charitable foundation based in Paris, France. It was established in 1975 by Simone Del Duca (1912–2004), widow of publishing magnate Cino Del Duca (1899–1967). The Foundation has been a substantial and important contributor to the arts in France and humanities worldwide, and it has also provided very significant support for scientific research.

1.3.4 Jean-Bernard Lasserre's Lagrange Prize

The prize recognizes his work on polynomial optimization and in particular how to approximate simply and explicitly any nonnegative polynomial by sums of squares. The paper is a beautiful blend of modern optimization theory and deep classical mathematics, with striking computational implications. The Lagrange Prize in Continuous Optimization is awarded jointly by Mathematical Optimization Society (MOS) and the Society for Industrial and Applied Mathematics (SIAM). The prize was established in 2002 and was awarded for the first time at the Eighteenth International Symposium on Mathematical Programming in 2003. To be eligible for the prize, the work must be either a paper or book consisting chiefly of original results, which has appeared in the six calendar years preceding the year in which the award is made.

1.3.5 Leveraging of a Decision Support Tool for Oncologists

This tool achieves to split the intermediate “grade 2” tumor cases into “grade 1 like” and ”grade 3 like” cases in order for oncologists to better adapt and personalize the prescription for patients with breast cancer (mainly decision of chemo or no chemo). It is based on the data produced by a new type of microarray biochip, devised by LAAS NBS team, which are analyzed by molecular grade signatures, extracted during a previous project (INNODIAG project), and complemented by clinical data. Its relevance has been assessed by a team of oncologists of the Institute Claudius Regaud and an extensive testing program, via a web server application, covering almost all cancer centers of the Midi-Pyrénées Region (federated in the ONCOMIP network) has been launched supported by the ONCOGRADE project.

2 Scientific Production

The scientific activities of DO can be presented through four main core thematic areas that have several interactions: Optimization, Robustness, Constraint-Based Reasoning and Hybrid Systems. These interactions may come from concepts, methods and tools that are used (e.g., Lyapunov theory, set-membership approach, LMI formalism, Petri-net formalism, relaxation, constraint programming) or by the models that are considered (e.g., hybrid dynamics).

2.1 Optimization

DO realizations in optimization can be roughly divided according to the distinction between continuous optimization and combinatorial optimization. In the first direction, the many emerging issues relating real algebraic geometry, convexity, certificates of positivity, measure representation, polynomial optimization and the Generalized Problem of Moments[1] form the core of the problems addressed. Concerning combinatorial optimization, the contributions may be organized according to two characteristics of the problem at hand: its theoretical characterization (complexity, formulation and decomposition) and its category defining the context in which the optimal decisions are made (feasible set for instance) as well. Note that COP is also addressed via constraint programming approaches which will be dealt with in a dedicated section. In both cases, these activities are funded by Gaspard Monge programs for Optimization and Operations Research of the Mathematical Foundation J. Hadamard and EDF (PGMO FMJH/EDF): "*Polynomial optimization*" and "*Combinatorial Optimization with Multiple Resources and Energy Constraints*".

2.1.1 Continuous Optimization and the Generalized Problem of Moments

The GPM is an infinite-dimensional linear optimization problem on a convex set of measures, intractable numerically in its full generality. It has a great modeling power in various fields including continuous and discrete global optimization and is a useful theoretical tool to prove existence and to give characterizations of optimal solutions. When considering polynomial data for the GPM, relating real algebraic geometry, global polynomial optimization and positivity certificates, convergent and efficient numerical approximation schemes based on SDP may be designed. Putinar's based positivity certificates are particularly useful in any application where polynomials nonnegative on a basic semi-algebraic set are of primary interest. In particular, this has permitted to

[1] Handbook of Semidefinite, Conic and Polynomial Optimization, M. Anjos and J.B. Lasserre (Editors), Springer, 2012.

construct inner approximations (as close as desired) of robust stability regions, in terms of sublevel sets of a single polynomial [RVSI11210]. Using similar Putinar's positivity certificates[2], we have been able to provide a systematic numerical scheme to solve the inverse problem associated with a static polynomial optimization problem [RVSI11140]. Another important issue in the new emerging field of real algebraic geometry is concerned with efficient representations of convex semi-algebraic sets and semi-definite representation is of particular interest because minimizing a linear functional can be done efficiently on such sets. Appropriate hierarchies of LMI that approximate a convex basic semi-algebraic set (or the convex hull of a basic semi-algebraic set) have been defined in [RVSI07034], [RVSI08349], [RVSI10073].

2.1.2 Combinatorial Optimization - Structural and Complexity Analysis

A COP can be analyzed independently of the intended solution methods and even of the possible problem formulations to establish mathematical or computational properties that will be useful for subsequent solving. In this context, DO carries out researches to establish the computational complexity of open problems and of some relevant sub-problems. Looking at the COP as a mathematical object, we also analyze other structural properties, such as necessary existence conditions, general characterizations of the solution set, extreme cases and dominance relations. As already mentioned, all these results will subsequently drive the solution approach. In this category, we distinguish three fields of research, the first aiming at establishing fundamental properties of combinatorial objects, the second carrying our polyhedral studies of COP and the third one linked to complexity analysis and approximation theory. In the first category, we established fundamental properties on fasciagraphs and rotagraphs [RVSI11546], on the control of (max,+) linear systems via analysis of order-reversing mappings [RVSI09753], on minimum cardinality of covering codes [RVSI1140, RVSI11393], on the characterizations of large sets of near-optimal solutions in scheduling problems, using disjunctive graphs [RVSI07036] and permutation lattices [MAI11445, MAI12171]. For the second point, via polyhedral analysis, we characterized facet-defining inequalities for labeling variants of the traveling salesman problem [RVSI10233] and we designed efficient simplex-like methods for periodic scheduling problems [MAI13007]. For the last category, we established the complexity of several open COP such as complex insertion problems in scheduling [RVSI07678], graph partition problems [RVSI11401] and one-machine scheduling problems for which we also exhibited a polynomial approximation scheme [RVSI14001]. Under the light of parameterized complexity[3], we established original complexity results in constraint programming, concerning propagation of soft global constraints [RVSI11387], the task of finding "backdoors" [MAI13203] and of learning a model from examples [MAI13204].

[2] Putinar, M. Positive polynomials on compact semi-algebraic sets, Ind. Univ. Math. J. 42, pp. 969–984, 1993.

[3] Downey, Rod G., and Michael Ralph Fellows. Parameterized complexity. Vol. 3. Heidelberg: Springer, 1999.

2.1.3 Combinatorial Optimization - Formulations and Decompositions

Finding a good formulation for an NP-hard problem is a fundamental step of the solution process. This conditions the quality of the information one can obtain on the problem. In the design of an integer programming formulation, we are interested in obtaining a good LP relaxation, possibly after adjunction of valid inequalities. An intermediate step to obtain a good formulation, especially for large-scale problems, is to propose a decomposition of the problem[4]. We formalize and validate such decomposition methods and formulations on complex integrated task scheduling and vehicle routing problems with a special focus on multi-objective problems. Our results can be classified along four axes that we detail below: i) Novel compact mixed-integer linear programming formulations, that favor reduction of the search-tree size against LP relaxation quality, were proposed for project scheduling [RVSI09102, RVSI11085, RVSI12550], single machine scheduling problems [RVSI08377, RVSI09386] and production scheduling problems under energy constraints [RVSI11082]. They allowed to solve previously out-of-reach large-scale and/or complex problem instances ii) On the other side, we studied extended MILP formulations that yield tight LP relaxations but need iterative solving —under a decomposition scheme— due to an exponential number of variables and/or constraints. Advances on such extended formulations and branch-and-cut-and/or-price methods have been obtained for vehicle routing problems involving complex constraints and objectives. This includes the dial-a-ride problems with alternative paths [RVSI06695], fractional rational objective aiming at maximizing the vehicle occupancy rate in rural areas [RVSI11072], and vehicle routing with security constraints [RVSI12010]. We proposed in all cases branch-and-price approaches and efficient specialized algorithms to solve the column or cut generation sub-problem. Generic mathematical programming methods based on extended formulations obtained for general multi-objective problems leading to extensions of branch-and-cut [RVSI09551] and column generation frameworks [MAI13386]. iii) Alternative formulations to integer programming, based on disjunctive graphs, and/or (max,+) algebra, were designed for cyclic scheduling problems [MAI11116, MAI11662] and semiconductor manufacturing problems [RVSI10498]. In both cases, specialized algorithms on these graph-based structures allowed to obtain competitive results against standard methods. iv) Several hybrid decomposition schemes, where one part of the problem is solved through MILP and another part is solved though specialized algorithms or constraint programming, were designed and successfully applied to resource-constrained cyclic scheduling problems [RVSI11101], production scheduling under energy and human resource constraints [RVSI10485], integrated transportation/scheduling [RVSI12205], planning/scheduling [MAI12218] and employee timetabling/scheduling problems [RVSI06700]. With such a method, we obtained the 4th place in the MISTA 2013 computational challenge on multi-mode project scheduling. (http://allserv.kahosl.be/mista2013challenge/).

[4] F. Vanderbeck and L. A. Wolsey: Reformulation and Decomposition of Integer Programs. In 50 Years of Integer Programming, p. 431-502, Springer, 2009

2.2 Robustness

Despite the diversity of topics, both theoretical and applications-oriented, a system level viewpoint unifies a broad majority of the results developed in DO. It enables the analysis and the synthesis of controllers, observers, estimation filters and optimization algorithms through the theoretical tools of mathematical modeling. Decisive for the analysis and synthesis problems, this stage must realize a tight trade-off between complexity and precision of the model that is never a perfectly accurate representation of the real physical system, no matter how much detailed it may be. Taking into account the influence of the modeling errors, uncertain data and environment on the quality and feasibility of the proposed solution raises the natural question of robustness. Among the possible ways to tackle robustness issues, a deterministic conservative but guaranteed perspective is privileged. Our objective is therefore to provide certified guaranteed solutions (control and estimation systems, optimal decisions) for all instances of the uncertainty parameters in the feasible set. This goal may be achieved by resorting to worst-case approaches based on various relaxations (through the use of Lyapunov theory, scenario relaxations) and by the set-membership theory.

2.2.1 Robust Control Systems

For control-oriented studies, the main robust analysis results are now developed in the general setup defined by the topological or quadratic separation [5]. This concept provides a theoretical framework that unifies tools and notions related to internal stability and Lyapunov theory with those from the input-output viewpoint. Moreover, robustness conditions for a large variety of uncertainties and/or time-delay operators (static, time-varying…) may be derived for a wide variety of performances.

Descriptor Formulation, augmentation and SOS/Moments relaxations for Robust Analysis: As demonstrated on robustness problems including parametric uncertainties and/or time-delays in the loop, topological separation gives new possibilities to handle more complicated parameter-dependence of the Lyapunov certificate by considering an extended descriptor modeling of the problem. In particular, the descriptor formulation of these new robustness conditions allows drastic improvement of the trade-off between the numerical complexity of the tests and the reduction of their conservatism [MAI08585]. This extension happens to provide nice features in terms of handling more simply most applications that exhibit natural descriptor models [MAI10098]. For systems with uncertainties, this also provides new possibilities to handle rationally parameter-dependent systems without appealing to the Linear-Fractional Transformation (LFT) and to overcome some numerical issues usually exhibited by μ-analysis for parametric uncertainty. Combined to the descriptor model dedicated results, a second major result relies on the so-called system augmentation technique. The approach consists in adding to the system model some new equations derived by applying some informative operator, in particular the time-derivative operator. Applying recursively the system augmentation and generating the upper described analysis results for each of these, provides a sequence of solutions that prove to be of decreasing conservatism. It is shown that this sequence has a direct relation with SOS relaxations, i.e. with moments' relaxation sequences [RVSI07452].

Robust Analysis of Time-Delay Systems: When considering time-delay systems and Lyapunov-Krasovskii functionals, the derivation of stability conditions expressed in terms of LMIs generally requires using the well-known Jensen inequality in the frame of quadratic separation. This convex inequality has been seen for many years as the only possible way to derive LMIs stability conditions, yet introducing some conservatism for the obtained results. Thus, investigations on the construction of less conservative inequalities have been conducted. First, a new inequality resulting from the celebrated Wirtinger inequality has been provided [RVSI13333]. Then, an alternative approach using the Bessel inequality made possible the construction of a new set of inequalities. The interconnected model built for quadratic separation is provided by introducing a set of uncertainties that can be viewed as the projection of the delay operator onto the set of Legendre polynomials. Once the model is designed, the uncertainty set is embedded into a more suitable uncertainty by the use of Bessel inequality. Invoking the classical quadratic separation theorem, a series of less and less conservative LMIs conditions is exhibited as the sequence of Legendre polynomials is increasing. Jensen and Wirtinger-based inequalities are recovered as particular cases [MAI13349]. These new stability conditions are proved to be potentially non-conservative.

Robust Control and Analysis of Periodic Systems: For periodic discrete-time systems, descriptor modeling previously defined appears to be a very powerful tool to build a unified setup for robust stability and performance analysis and controller synthesis. Relying on a general formulation for state-feedback periodic memory controllers and a new time lifting, new sufficient LMI conditions for the existence of robust stability certificates and guaranteed cost control laws are derived [RVSI09453], [RVSI10450]. In addition, the general duality theory of LTI systems developed in the literature has been revisited and applied to this particular lifted representation [RVSI12430]. These theoretical achievements have been tried out on the problem of attitude control of micro-satellites with reaction wheels and magnetorquers [MAI13431].

Robust and Adaptive Control: The field of robust adaptive control has been revisited with the help of classical tools from robust control theory and new constructive methods for the design of simple adaptive control laws with true guarantees of robustness are provided [MAI10684], [MAI13042]. These results are expected to have significant impact for aerospace applications and could be a promising alternative to the switched-based strategy for attitude control when dealing different AOCS modes.

[5] Iwasaki, T. and Hara, S. Well-posedness of feedback systems: Insights into exact robustness analysis and approximate computations, IEEE Trans. Aut. Contr., 43(5), pp. 619-630, 1998.

2.2.2 Robust Diagnosis

For diagnosis-oriented studies, the main focus has been put on bounded uncertainty models using set-membership (SM) approaches [6] as well as on the integration of the probabilistic and SM paradigms for uncertainty representation.

Set-membership Identifiability: When basing diagnosis on parameter estimation, fault detection is achieved by checking the consistency of the estimated values against nominal parameter values. Identifiability is hence a sine qua non pre-condition for obtaining trustable results [RVSI08713]. We have proposed to extend identifiability to the SM framework with two complementary concepts, SM-identifiability and μ-SM-identifiability. These properties have been shown to decisively condition the properties of an SM-parameter estimation problem and the quality of the solution set returned by an SM-parameter estimation algorithm. Two methods for checking these properties, both applicable to nonlinear uncertain systems, have been provided [MAI10689] [MAI11588] [MAI12007] [RVSI 13085] (MAGIC-SPS ANR Project).

Set-membership Estimation and Active Fault-tolerant Control: Besides the above analysis work, we have been working for proposing error-bounded state estimation algorithms with low complexity meeting real-time constraints. The proposed method is based on a prediction-correction schema and uses the mean value and intermediate value theorems extended to interval analysis in the prediction step, requiring local monotonicity conditions. It has been extensively tested on an Oscillatory Fault Cases benchmark provided by AIRBUS and shown to meet the industrial requirements in the framework of the FRAE SIRASAS. Bounding the parameters by intervals also supports a new fault isolation and identification approach that is used for active fault-tolerant control [MAI12084][MAI10205]. Because the bounds of the faulty parameter are provided in a very fast manner, the fault tolerant control procedure can reconfigure the controller very early after fault occurrence. The bounds of the faulty parameter in the controller reconfiguration allow us to guarantee the performance indexes of the closed-loop system [MAI11049][MAI11071].

Hybrid Reachability Analysis: Reachability analysis for hybrid uncertain systems has also driven another line of research. Reachability consists in computing the set of states reachable by a system. We concentrated in solving the problem of flow/guard intersection triggering transitions in an effective and reliable way. The idea that we developed is first to derive an analytical expression for the boundaries of continuous flows, using interval Taylor methods and techniques for controlling the wrapping effect. Then, the event detection and localization problems underlying flow/guard intersection was expressed as a constraint-satisfaction problem [MAI13462]. The second problem addressed was the fusion of the numerous trajectories generated by bisection based algorithms into one single trajectory. An algorithmic solution based on a zonotopic enclosure of the boxes was devised [MSI13727], (MAGIC-SPS ANR Project).

[6] L. Jaulin, M. Kieffer, O. Didrit, E. Walter, "Applied interval analysis: with examples in parameter and state estimation, robust control and robotics", Springer, 2001.

Interval Kalman Filtering: Noises and disturbances are usually properly modeled through probability distributions but parameter uncertainties due to design tolerances and/or aging are better represented by bounds. This is the reason why we did consider the optimal filtering problem for discrete time linear models extended to bounded uncertainty on parameters. The Interval Kalman Filter proposed by Chen in 1997 was totally revisited in light of recent interval analysis and constraint propagation techniques [MAI12271]. Unlike the previous filter, the resulting filter provides guaranteed results and benefits from several mechanisms that limit the overestimation effects due to interval propagation within the filter recursive structure [MAI13100][MAI13477].

2.2.3 Robust Combinatorial Optimization

DO research activities in robustness for combinatorial optimization lie, in the first place, in the classical robust discrete optimization framework, which considers uncertain parameters via explicit or implicit scenario sets and worst-case objective functions[7]. We mainly focused on uncertain scheduling problems. Targeting genericity and applicability, we aim at proposing efficient robust methods for complex NP-hard problems while the literature generally considers robust counterparts of polynomial problems. Another original line of research is to establish and exploit the links between robustness and cooperation in two ways. First, by considering multiple autonomous decision centers (agents), robust optimization from the point of view of one agent is used to hedge against unexpected decisions of other agents. Second, through interdisciplinary research with cognitive ergonomics, robustness of the proposed decisions is a mean to facilitate human-machine cooperation.

Handling uncertainty and cooperation in planning and scheduling problems: DO aims at incorporating robustness and cooperation considerations in combinatorial optimization. In line with the ANR "BLANC' project (ROBOCOOP) that was carried out during the period, these issues where mainly address for planning and scheduling problems. For project scheduling problems with uncertain task duration represented by intervals, we proposed the first efficient algorithm for the fundamental problem to compute the minimum float of an activity, an NP-hard problem that assesses the possible criticality of a task [RVSI11083]. In the presence of resource constraints, we proposed a scenario-relaxation method based on MILP to minimize the maximum regret of a solution [RVSI11084]. We also published a state-of-the-art survey of the methods proposed to solve a stochastic maintenance and production scheduling problem in the context of the ROADEF/EURO challenge that we co-organized [RVSI10486]. In the context of the supply chain tactical planning problem, a two-level structure has also been defined to promote the robustness and the reactivity of the decisional system to face uncertain data [MAI10973, MAI11611]. We also participated in the ROADEF challenge 2009 on disruption management for commercial aviation, proposed by AMADEUS SA for which we proposed an

[7] D. Bertsimas and M. Sim. "The price of robustness." Operations research 52(1): 35—53, 2004.

efficient rescheduling algorithm based shortest path formulations [RVSI10183]. We aim at considering scheduling problems with cooperative or competing agents under the robustness paradigm. Considering that the agents manage their own local robust schedule, to build up the global schedule, we aim at finding a centralized policy that offers a fair sharing of the temporal flexibility among the agents [MAI11444, MAI13289]. The “Best paper award” was obtained at the ICORES 2014 Conference for complexity results on multi-agent min cost flow problems [MAI14071]. Last, an interdisciplinary study with cognitive ergonomics was conducted to enhance human-machine cooperation in transportation scheduling [RVSI12028]. A work domain analysis is done to facilitate the identification of the problem constraints through an abstraction hierarchy, which facilitates an ecological user-interface design and the implementation of a decision support system [MAI10372, RVSI12296]. This work obtained the 2011 prizes of the best Ph. D. thesis of GdR MACS.

2.3 Constraint-based Reasoning

In the late seventies, pioneering researches were carried out at LAAS on constraint-based scheduling approaches that were, years later, widely generalized in the Constraint-Based Reasoning (CBR) area of Artificial Intelligence. In DO, we exploit CBR to propose generic constraint satisfaction or optimization systems via constraint programming and model-based diagnosis systems. An original line of research on integration of CBR and learning techniques yielded significant advances both in problem solving and diagnosis via intelligent tree-search and chronicle learning.

2.3.1 Constraint Propagation in Sequencing and Scheduling

In CP, decomposing a problem into constraints is a critical issue, as the propagation algorithms associated with each such constraint perform domain reductions that can substantially reduce the search tree. DO aims at finding efficient propagation algorithms for different families of global scheduling and sequencing constraints under the constraint-based scheduling framework[8]. For disjunctive scheduling problems, where tasks assigned to the same machine cannot overlap, we proposed generalized disjunctive constraint propagation algorithms, and several new heuristics that obtained state-of-the-art results for solving the job-shop problem with generalized precedence constraints [RVSI10373, MAI11650, MAI12286]. For cumulative scheduling problems, where activities assigned to the same resource may overlap under the limits of the resource capacity, we extended the polynomial energetic reasoning feasibility test to scheduling where the instantaneous amount of energetic resource assigned to a task can be dynamically adjusted, while preserving the polynomial complexity of the test [RVSI10595]. For the same class of problems, an energy-precedence constraints, which is a new way to model precedence between activities in a concurrent engineering-based project, was studied and validated in a decision support system for design teams for the aerospace industry [RVSI11871]. For data transfer constraints in the context

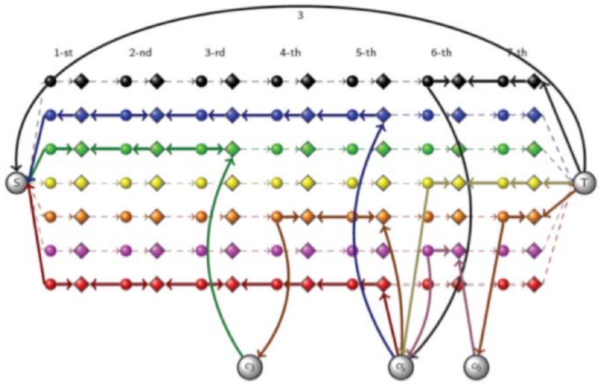


Figure 1: Network Flow-Based Global Constraint Propagation

of the scheduling of space experiments on a comet, we proposed a particularly fast constraint propagation algorithm [MAI12344]. Moreover, we introduced a linear optimal algorithm for achieving arc consistency on a particular case of sequencing constraints [MAI12343, RVSI13519]. These two results on constraint propagation were awarded at the CP 2012 conference, with the “Best application paper award” and the “honorable mention award” respectively.

2.3.2 Learning Mechanisms and Alternative Strategies in Tree Search

We explored learning strategies inspired by SAT solvers and algorithms[9] for solving scheduling and other constraint satisfaction problems. In particular we showed the power of weighted heuristics in tree search, which consist in changing dynamically the weights given to variables and values for orientating the search. This allowed us to propose generic frameworks that we successfully applied to various problems for which we outperformed the state-of-the-art results. We mainly cite an efficient chronological backtracking algorithm that optimally solved hard variants of the job-shop problem [MAI10856, MAI11496] and intelligent discrepancy-based search that obtained tight upper bounds on parallel machine problems with setup times [RVSI09104], hybrid flow shop [RVSI10748, MAI11155, RVSI12186], flexible job shops [RVSI10138] and general CSP [RVSI12169]. Each time, the results show that weighting mechanisms reduce the tree size and then speed up the solving time, especially for the discrepancy-based search method. The Google/CNRS grant 2011 was awarded on the basis of the results we obtained with these weighted heuristics. We used this grant to carry out new researches in a closer hybridization between SAT clause learning principles and CP based on a new way of exploiting explanations. This allowed us to obtain breakthrough results on hard instances of the car-sequencing problem [MAI14206]. The open-source award-winning solver MISTRAL implements these aspects. (http://homepages.laas.fr/ehebrard/mistral.html)

2.3.3 Meta-Diagnosis Reasoning

Reiter's theory introduced the model-based diagnosis problem (SD, COMPS, OBS) as a reasoning framework where SD (the system description) and OBS (the observations) are defined as a set of first-order

[8] P. Baptiste, C. Le Pape and W. Nuijten. Constraint-based scheduling,Springer, 2001.

[9] J. Marques-Silva, I. Lynce, and S. Malik, S. Conflict-driven clause learning SAT solvers. Handbook of satisfiability, 185, p. 131—153, 2009

sentences and COMPS (the set of components) are terms. The diagnoses are identified by computing the health status of components consistent with the model and the observations that we formulate as a constraint propagation problem. For such a reasoning system to perform correctly, strong assumptions are required: SD, OBS must be sound and complete as well as the underlying theorem prover. In the real world, these assumptions may not hold, and therefore the reasoning system may have some defects. We introduced the meta-diagnosis problem (M-SD, M-COMPS, M-OBS) as a generalization of the diagnosis problem [MAI11310]. Meta-diagnosis can be used, for instance, to determine if the system description of a diagnosis problem is sound or not. Meta-observations can aggregate observations of the system (OBS) and/or the diagnoses D computed by the diagnosis system completed by the real health status D' of the components resulting from maintenance test procedures. Thus an inconsistency between a sentence $M\text{-}SD_i$ of the meta-model and the meta-observations points out that sentence SD_i of the diagnosis system is false. Interestingly, the choice of the meta-component is free and can focus on the observations or on the diagnosis algorithm, and that the correctness is not the only property that can be meta-diagnosed. Our software tool MEDITO implementing the meta-diagnosis was successfully tested on an Airbus landing gear extraction and retraction system.

2.3.4 Learning Temporal Patterns

Chronicles are temporal event-based patterns defined by a set of events linked by temporal constraints. They are well suited to capture the behavior of dynamic processes at a high level of abstraction. They have been shown efficient for diagnosis in several works, coupled to a chronicle recognition engine [10]. The bottleneck of this approach is the chronicle base. Indeed, the huge amount of data stored in nowadays applications implies that mining specific signatures in these data must be automatized. The proposed chronicle discovery algorithm aims at discovering frequent chronicles common to multiple sequences, i.e. chronicles that are frequent in each sequence of a collection. This is motivated by the fact that a given situation may have variations in its representative event sequences. In collaboration with the SARA team, we tested our algorithm successfully for assessing the behavior of IP networks by characterizing abnormal situations such as congestions, packet losses, etc. from QoS parameters [MAI12615].

2.4 Hybrid Systems

Generally speaking, a hybrid system can be regarded as a combination of continuous dynamics and discrete events interacting within a unique system. Due to the wide interpretation of the term “hybrid”, it is necessary to precisely define the specific subclasses of hybrid systems at hand as well as the scientific communities involved. While DO’s contribution clearly falls within the Systems and Control community, two different angles provide complementary motivations.

2.4.1 Hybrid Control

For control oriented-studies, hybrid dynamical systems denote dynamics that combine continuous-time evolution (i.e. flow) and discrete-time evolution (i.e. jump) thus merging two separated mathematical fields historically connected to differential and difference equations, respectively. While several mathematical frameworks have been proposed in the last 20 years to represent hybrid systems, the new framework introduced recently by collaborators of DO, A. Teel, R. Goebel and R. Sanfelice [11], provides a suggestive baseline for the formalization and enhancement of control architectures and the development of new ones. This framework together with the classical Lyapnuov-based nonlinear control context offered several interesting research directions for DO.

Hybrid controllers: The design of hybrid controllers based on observers was considered, with the objective of overshoot reduction [RVSI12545]. The hybrid loop consists in a continuous-time dynamics when the estimate of the state leads to a non-increase of a suitable Lyapunov-like function, and in a jump equation when this condition is not satisfied. The jump equation is defined by means of a static state feedback law from the observed state. Four techniques based on different reset maps and flow and jump sets are proposed. All of them exploit suitable dwell-time logic. For the proposed designs, global exponential stability of the origin was proved [RVSI13198].

Control of systems with impacts: Using hybrid formalism, a new paradigm for representing impacts and the arising state and output feedback tracking scheme is introduced in [RVSI13012]. The advantage of this novel representation is that for the considered class, a suitable error variable evolves like an autonomous LTI continuous-time system, so that uniform convergence to zero can be concluded and effective hybrid control and estimation algorithms can be developed.

Hybrid Formalism and Communication Constraints: The use of hybrid systems for representing feedback control systems subject to communication constraints such as in networked control systems has been investigated [RVSI13475], [MAI13311].

First Order Reset Elements: The use of simple first order dynamical systems to obtain control loops for linear plants having a very simple architecture has been pursued already in the 1960s by Clegg and Horowitz. The hybrid systems tools that are used enable to establish important properties of these simple, yet challenging control schemes in terms of achievable performance by way of simple hybrid output feedback control structures [MAI10313].

Nonlinear and Hybrid Systems: In parallel to the previous developments, the study of nonlinear and hybrid systems including linear systems interconnected with isolated nonlinearities, has been carried out. The controllers developed are nonlinear and guarantee the regional stability of the origin or of a closed attractor around [RVSI11326], [OAI11375], [RVSI12360]. On the

[10] C. Dousson, P. Gaborit, M. Ghallab, Situation recognition: representation and algorithms, Int. Joint. Conf. on Artificial Intelligence (IJCAI’93). Vol. 93, pp. 166-172, 1993.

[11] Goebel, R., Sanfelice, R.G., Teel, A.G. Hybrid Dynamical Systems: Modeling, Stability, and Robustness, New Jersey, Princeton University Press, 2012.

hybrid systems side, properties of suitable classes of systems have been studied and characterized [RVSI12252], [RVSI13012], [RVSI13102].

2.4.2 Hybrid Diagnosis

The well-known hybrid automata formalism that couples differential equations/difference equations with finite state machines was adopted by DO to sign up an original approach based on an abstracted hybrid model, in which, continuous dynamics are present through specific events. This framework initiated several directions of work.

Hybrid Diagnosis Based on Event Abstraction: Hybrid diagnosis based on event abstraction interlinks a standard diagnosis method for continuous systems, namely the parity space method, and a standard diagnosis method for Discrete Events Systems (DES), namely the diagnoser method [RVSI12649] [RVSI12518]. The continuous approach provides the means to generate residuals and signatures for each operation mode. These latter are abstracted in the form of specific events, called signature-events, that enrich the discrete part of the system model. The diagnoser method is applied to the resulting abstracted hybrid system to build a diagnoser able to follow on-line the behavior of the hybrid system (work supported by CNES and Thales Alenia Space [MAI08693] [MAI09160]). The approach was successfully tested on the ADAPT testbench of NASA Ames with the files of the DX competition [MAI11610]. A variant of this method using qualitative mode signatures and causal graphs to retrieve the faulty components in non-anticipated faulty situations was adapted for troubleshooting coupled to a test selection procedure. It produced an original iterative diagnosis method for hybrid systems that iteratively reduces down diagnosis ambiguity [MAI11589][MAI11642].

Active Diagnosis: One way to improve the performance of the diagnosis process comes from the system's embedded control capabilities. As a matter of fact, faults may be discriminable in some behavioral regions corresponding to particular operation modes but not in others. The problem of synthesizing control laws that drive the system towards more diagnosable modes is called *active diagnosis*. Our method uses the abstracted hybrid system diagnoser to compute the best conditional control plan with respect to a cost criterion and accounting for safety constraints [MAI08691] [MAI09201]. The approach has been implemented with an AO* algorithm and validated on the module (hotspotter) of a fictive satellite with 13538 discrete states (CNES-ONERA AGATA project) [MAI09201].

Coupling Diagnosis and Prognosis: The integration of diagnosis and prognosis was investigated [RVSI11188] and used to develop a monolithic HMS on hybrid systems.

The above abstraction framework for hybrid systems diagnosis has been enriched with knowledge about aging or degradation. Our method, implemented with Matlab, uses aging laws in the form Weibull probabilistic models to compute the sequence of future fault dates leading to the system failure [MAI13110][MAI13412] (CORAC EPICE Project).

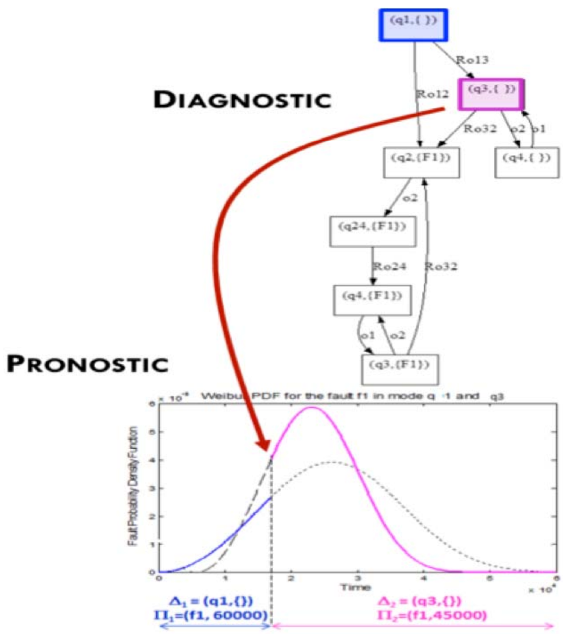


Figure 2: Coupling Prognosis and Diagnosis for Hybrid Systems

2.5 Solving Real World Problems

One of the objectives of DO is to provide its expertise to solutions of applied problems defined in partnerships with industry, inducing corporate funding, or with some institutional bodies (e.g. region, DPAC). It is important to underline that these projects are of mutual interest. Moreover, it should be emphasized that some of these applied problems are part of the ADREAM scientific prospective, concerning energy systems management and embedded and autonomous systems.

2.5.1 Control, Diagnosis and Optimization for Space Embedded Systems

One important challenge when considering the continuous increase of space embedded systems complexity is to propose a corresponding increase in the capability of designing fault-free control and scheduling systems, maintaining the very high level of security and safety already achieved in existing space systems with unaltered performances. Do area has proposed several algorithmic solutions to various problems ranging from the optimal and robust guidance and control of space trajectories to the design of decentralized diagnosis architectures or the synthesis of scheduling algorithms for the frequency allocation problem.

Guidance and Control of Spacecraft: DO area has a long history of promoting control technology transfer for application in the aerospace domain. A particular attention has been paid to the study of new robust and optimal control schemes for Attitude and Orbit Control System (AOCS).

The main contribution concerning orbit control is related to the far range rendezvous problem around an elliptic reference orbit[12]. Different guidance schemes

[12] Fehse, W. Automated rendezvous and docking of spacecraft, Cambridge Aerospace Series. Cambridge University Press, Cambridge, UK, 2003.

based on direct and indirect approaches for the impulsive linearized minimum-fuel rendezvous problem are proposed and coded in a friendly-user design interface PolyRDV. For direct methods, emphasis is placed on robustness and safety issues since constraints on the rendezvous path (typically collision avoidance constraints) and uncertainties or execution errors (dates, amplitude and directions of thrusts) may be accounted for in the optimization process. Indirect methods are mainly based on primer vector theory and new numerical schemes using extensively results from real algebraic geometry and polynomial optimization have proven to be very efficient to exhibit theoretically certified optimal trajectories [RVSI10510], [RVSI12204], [RVSI14136]. Finally, it has also be shown that, even in the case for which infinitely many instantaneous constraints are imposed on relative trajectories involved in proximity operations between a chaser and a target, the admissible trajectories may be described by polynomial non-negativity constraints and resorting to the solution of an SDP for the rendezvous problem [RVSI12679], [RVSI13051].

Considering that the most widely spread configuration of actuators for attitude control of low orbit satellites is often characterized by control systems with redundant actuators, one essential step when dealing with AOCS synthesis is to design a control allocation scheme with the goal of employing each actuator in a suitable way, based on its saturation limits. In the case of redundant thrusters, allocation functions adapted to an original anti-windup design for high precision control of the angular axes of a micro-satellite have been explored [MAI09888], [MAI10207], [MAI10411], [OPI12412]. In addition, the problem of momentum dumping via magnetorquers when achieving attitude stabilization has been completely revisited. The new proposed allocation scheme is proved to be successful for taking maximal advantage of magnetorquers and hence partly alleviating the stabilization burden of the reaction wheels [MAI11379], [MAI13431]. Yet, it does not solve another important issue related to reaction wheel speed saturation. In order to get small pointing errors, an aggressive highly accurate controller is needed. Unfortunately, when the pointing error is large, this implies high magnitude control inputs that may saturate the reaction wheels, eventually leading to a possible destabilization of the satellite. One existing solution is to switch to a non-aggressive controller when this situation occurs. The switching policy may generate disturbing discontinuities. For that problem, we have proposed a continuously adaptive strategy that was moreover theoretically proved to be robust by using Lyapunov-type certificates. The results have been validated on high precision simulators and tested onboard the PICARD satellite in January 2014 [MAI13095].

Analytical Redundancy Based Decentralized Diagnosis and Fault Isolation on Request: Decentralized diagnosis architecture can be viewed as a step towards bridging the gap between model-based diagnosis research and practice for space systems because it can be mapped to their functional architecture. In the framework of collaboration with CNES and Thales Alenia Space, we proved the equivalence between decentralized and centralized residual generation using the structural approach. This approach consists in

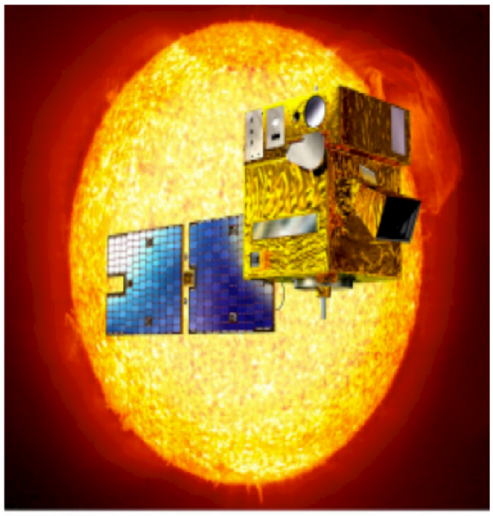


Figure 3: PICARD Satellite

finding complete matchings on the bipartite graphs of the structural abstraction of the model. The focused decentralized residual generation advantageously results in a strategy of *fault isolation on request* [MAI11754] [MAI12116]. Algorithms were tested with success on simulations of the Attitude Determination and Control System of the Cassini satellite [MAI13107] [OPI11754] [MAI12532].

Resource Allocation and Scheduling for Aerospace: On the combinatorial optimization side, DO was involved in several contracts mainly linked with resource management in telecommunication or earth observation satellites or related to optimization of scientific space experiments. In the context of contracts with Thales Alenia Space, we demonstrated that complex frequency allocation problems arising in satellite telecommunication could be solved by integer programming and heuristic methods, which yielded substantial improvements compared to other systems [RVSI09752]. In the same project and in collaboration with IRIT, we proposed an integrated optimization of frequency assignment and beam positioning that we solved by alternating discrete and continuous optimization methods [RVSI12284]. For earth observation satellites, in the context of the THEOS program with Thailand, we proposed a multi-objective evolutionary algorithm allowing scheduling observations in a search for a compromise between profits and fairness [MAI12340, MAI13363]. With CNES, ONERA and AIRBUS Defense & Space, we proposed a method for satellite download management under uncertainty [MAI14251]. As already mentioned, we also had several CNES contracts on the ROSETTA project for scheduling the experiments on a comet, for which we published an award-winning paper [MAI12344].

2.5.2 Diagnosis and Control in Aeronautics

Among the emerging new trends promising to shape the future directions of embedded system design for aeronautics applications, the DO area has contributed to the studies concerning various analysis and design problems of the in-flight auto-pilot and related to health monitoring of aircraft components.

Analysis and Design of In-Flight Auto-Pilot: From 2008 till 2012, in the frame of a joint laboratory AirSys and under different designations (NGCI, OCKF, COKPIT), MAC has been involved in joint studies with Airbus and Onera, partly funded by DGAC.

The actual dynamics of an aircraft are nonlinear and highly dependent of the flight conditions (Mach number, centering of masses etc.), but this nonlinear model is not useful in general, except for numerically expensive simulations. Based on a linear approximation of the nonlinear aircraft model, augmented with a model of uncertainties affecting the system, robust analysis gives worst-case certificates of stability and performance properties. Methods provided by LAAS included polytopic type modeling of uncertainties in a neighborhood of a flight operating point and two levels of conservatism analysis. Using these, it was possible to discriminate the operating points having acceptable performances and those that did not satisfy predefined requirements [MAI10120].

Taking into account the presence of magnitude and rate saturation in the actuator, we have analyzed the stability and the performance of the closed-loop system with a predefined pilot behavior. In order to prevent PIO (Pilot-Induced-Oscillations), some ad-hoc filter can be built. Aiming at developing a generic approach, anti-windup techniques have been used [RVSI08424]. LMI conditions to design structured anti-windup compensators have been proposed. These anti-windup compensators ensure closed-loop stability and prevent the PIO phenomenon [RVSI09082].

Considering that the nonlinear dynamical model of the aircraft is affected by bounded uncertainties, the technique of feedback linearization has been revisited in order to confer some robustness property to the resulting closed-loop system. Hence, we have modified the control law with two new schemes, by adding a Robust Multi-Inversion (RMI) loop. These schemes allow guaranteeing a good robustness level for the closed-loop but at the expense of the possible degradation of the nominal performance [MAI12394].

Health Monitoring of Aircraft Components: One of the levers that aircraft manufacturers want to use to make their products more attractive in the eyes of airlines is the optimization of maintenance. A path increasingly explored by industry is Health Monitoring. In this context, our partner Messier-Bugatti-Dowty has proposed the electro-hydrostatic actuators motor-pump unit that is pushed to meet the needs of future all-electric aircraft technology actuators as a case study. More precisely, the study has focused on two critical elements: The permanent magnet synchronous machine and the hydraulic pump [MAI12845]. Aging models have been determined, based on physical laws and/or historical data. These represent the system degradation over time including the effect of damaged components on the others, and the propagation of performance losses through the system. Health monitoring has been achieved by coupling a diagnosis method that provides the initial conditions for predicting the system's health evolution over time as a function of the stress it is expected to undergo [MAI12820] [MAI13123]. The experiments that have been carried out prove the soundness of our approach.

2.5.3 Control and Observation of Networks

Transmission Control Protocol (TCP) is a protocol that handles reliable data transfer through networks. Many events in TCP networks deviate from the expected behavior such as network overload, flash crowds, worms, port scans, risky internal user behavior, Denial of Service attacks (DoS), network intrusions, etc. These abnormal patterns are in general called network anomalies. Whether malicious or legitimate, anomalies can have an impact on a router by creating congestion and can reduce significantly the Quality of Service (QoS) of a whole network[13]. Following previous works and collaborations with RC area, which were seminal for the introduction of feedback control theory in networks control, we have proposed to use the control theory [RVSI09057] and especially the design of observers to cope with anomaly detection [MAI09141]. Two different types of observers have been considered. Firstly, assuming that usual perturbations can be modeled as polynomial functions, linear observers for time-delay systems have been designed [RVSI09655]. Secondly, assuming that the anomalies are bounded, unknown input observers for time-delay systems based on first and second order sliding mode observers have been designed [MAI09456], [MAI10245]. A real experimental setup, replaying TCP traces has been used for realistic simulations of these strategies [RVSI12502] and has shown that they are able to detect anomalies occurring in the network in finite time.

Network traffic can also be modeled with an event-based point of view in which traffic QoS evolutions are represented by specific events. Event patterns, also called supervision patterns, can then be used as signatures of specific QoS situations or network anomalies. Within this paradigm, DO has been investigating how to assess the detectability and diagnosability of supervision patterns given by chronicles. In a first phase, supervision patterns have been considered without the duration between events. A method to automatically analyze whether a set of chronicles are mutually exclusive, i.e. for a given run, the chronicle recognizer recognizes at most one of them, has been developed [RVSI08689]. The originality of this work is the use of Petri net unfoldings to determine infinite ambiguous runs of a distributed discrete-event system, these being the sources of the non-detectability of supervision patterns [MAI13170]. In a second phase, the knowledge about the durations has been introduced by considering time Petri nets, and time has been shown to improve detectability and diagnosability [MAI11586].

2.5.4 Fast Algorithms for Passenger and Freight Transportation

Passenger and freight transportation face new challenges, linked to increase in transportation demand and the possibility of using various sources of data available in real time to optimize its management. With two contracts with the MOBIGIS society, we developed algorithms for multimodal passenger transportation that were integrated in the Mobianalyst software. We solved in this context a bi-objective variant of the regular

[13] Srikant, R. The Mathematics of Internet Congestion Control, Birkhauser, 2004.

language-constrained shortest path problem that allows us to model a search for compromise between mode transfer and travel time in multimodal itineraries [MSI11485], that we extended to 2 way paths [MAI13295]. In the context of the AMORES ANR project (collaboration with IC theme), we considered shortest itineraries algorithms for real time applications of carpooling [MSI13328]. For these problems, we propose efficient methods based on several shortest path algorithms in forward and backward ways, with special difficulties to handle the time dependency of the network in backward. In the context of vehicle routing, we also worked in the context of a contract with SNCF on maintenance vehicle routing problems on railways, for which we proposed efficient column and cut generation heuristics [MAI10843]. We also solved several other realistic variants of the vehicle routing problem[14], including dial-a-ride problems (with alternative path [RVSI06695] or with the objective aiming at maximizing the vehicle occupancy rate in rural areas [RVSI11072]), vehicle routing problems with security constraints such as in money transports where no path should be used twice within a period [RVSI12010] and covering objectives such as minimizing the walking distance to dispensaries in third-world countries [MAI13386]. For freight transportation, we currently work on a door-to-door transportation context, notably with the DHL Company, in the context of the ANR project RESPET (2011-2014).

2.5.5 Energy

The different studies carried out by DO in the field of energy management and energy issues may be roughly divided into two different directions: Low level works dedicated to robust and hybrid control of converters and high level developments for energy resources management via combinatorial optimization.

Converters Control: In the context of high frequency, low current and voltage levels, the switching converters play a fundamental role and are involved in a lot of applications such as transport systems, computer science and telecommunications. Models for such switching converters can be derived following different ways, closely related to their uses and specificities leading to uncertain linear or nonlinear models obtained by averaging methods and switched linear models with a number of modes depending of converter architectures. The methods to design control laws (switching strategies) follow the well-known phases of modeling, simulation and implementation. In this context, several works have been developed in collaboration with the University Rovira I Virgili of Tarragona, Spain. Methods based on sliding mode theory, hybrid control or robust control theories have been compared and studied to derive adequate control laws, taking into account uncertainties, voltage regulation, and flexibility. A special attention has been devoted to the derivation of well-qualified controls, in terms of stability, performances and efficiency with the associated rigorous proofs going beyond the approaches usually considered in this context by the power electronic community [RVSI10625], [RVSI12460], [RVSI12659].

[14] T. Vidal, T. G. Crainic, M. Gendreau, C. Prins: A unified solution framework for multi-attribute vehicle routing problems. European Journal of Operational Research 234(3): 658—673 (2014)

Resource Allocation and Scheduling under Energy Constraints: DO is historically involved in resource allocation problems and production scheduling applications. Over the years the stakes of such applications have evolved towards a more responsible management of resources, in particular energy resources, in line with the LAAS research axis "ADREAM" and on the growing interest on power management in scheduling literature which was however previously concentrated on computer systems[15]. We obtained during the period a CNRS PIE Energie grant (GIMEP) for the Integrated management of energy and production, an INSIS exploratory project (OCRE) and then a FMJH/EDF PGMO project (OREM) to solve scheduling problems under energy production and consumption constraints. We considered in particular models in production scheduling where the energy can be modulated at each instant of task processing, in particular to avoid picks of electrical consumption. We solved these models via pure integer linear programming formulations [RVSI11082] or hybrid constraint and integer programming based methods [RVSI10485, RVSI10595]. In transportation applications, DO had several contracts with NEXTER (2012-2014) to optimize the use of multiple sources of energy in hybrid electric vehicles. We identified the flaws in existing modeling hypotheses that led to significant gaps between the solutions costs from the algorithms of the literature and the optimal solution costs of the original energy management problem. We designed global optimization-based heuristics that outperformed the prior state-of-the-art [MAI12318, MAI13264]. As an alternative to non-linear modeling yielding suboptimal solutions and important computation time, we proposed a new and efficient combinatorial modeling [MAI13217] that we extended to on-line dispatching of electrical energy and battery discharge minimization in case on unknown mission profiles via a fuzzy approach [MAI13115].

2.5.6 Biological Models and Health Monitoring

At the boundary between control theory and biology, complex systems and multi-scale systems offer a wide variety of problems to the control and diagnosis communities.

Modeling and Analysis: In the framework of intensive collaboration with a biological lab (LISBP), different problems of control theory and nonlinear behaviors have been tackled, e.g. bio-filter control, bio-films growth [RVSI12619] or omic modeling of translation efficiency and protein stability [RVSI12618]. For some ecological and biological models, particular regions of parameter space where the Allee effect is obtained can be defined [RVSI13373]. Symbiotic interactions may also be defined and analyzed using the same tools.

Data Driven Diagnosis: Feature selection and pattern recognition: machine learning methods are recognized efficient to tackle problems for which explicit knowledge models are not available. This is often the case in the biological domain. The second issue in this domain is high dimensionality. These two issues converge to the necessity to process simultaneously mixed-type data (qualitative, quantitative, interval,...) which are present in most of the daily produced datasets. A unified principle for reasoning about *heterogeneous data* has

[15] Albers, S.: Energy-efficient algorithms. Communications of the ACM 53(5), 86–96 (2010)

been developed based on a simultaneous mapping of data from initially heterogeneous spaces into only one homogeneous space based on a relative measure using appropriate characteristic functions expressed in the fuzzy logic framework [RVSI10362]. Once the heterogeneous data are represented in a unified space, a single processing for various analysis purposes can be performed using simple reasoning mechanisms. The second challenge related to high-dimensionality appears as a topical problem that justifies the success of the “Machine Learning” approach in particular for statistically ill-posed problems involving a large amount of features. Feature selection methods seek to choose a small subset of features that ideally is necessary and sufficient to describe the target concept. We proposed a new approach based on a similarity margin maximization to estimate the relevance of each feature whatever its type: qualitative, quantitative or interval [RVSI10054] [MAI10234] [RVSI13023].

The developments of advanced methods for feature selection and processing heterogeneous data yielded the design of two software prototypes: P3S (Process Sensor Selection & Situation assessment) for feature/sensor selection and process monitoring/diagnosis and InnoGRADE used for diagnosis tumor grade in breast cancer enabling classification of tumors grade into grade 1-like or grade 3-like [MAI11014][MSI12596].

2.5.7 Tools and Demonstrators

To supplement and contribute to spread the research conducted in DO, a number of numerical tools and Matlab-based toolboxes have been developed by members of the area and colleagues from other institutions. These numerical tools are freely available via the web site of the lab or available upon request. A complete list with a short description is given in Table 2.

3 Academic Reputation and Appeal

3.1 Main International and National Collaborations

The research activities of DO are often carried out in collaboration with academic partners and, for some, in an international context. DO fosters collaborations with researchers from other French and international labs and Universities. Scientific academic international and national collaborations are intended to enrich the fundamental baseline of the area, through different formal or informal modalities.

3.1.1 International Collaborations (outside Europe)

The international collaborations may be built into a formal context provided by national bodies (bilateral or multilateral international projects) and are materialized through numerous academic visits and seminars. International formal collaboration within the DO area are mainly focused on South America with Brazil (Unicamp, UFRGS, CEFET), Chile (Univ. de Concepcion, CMM, Univ. de Chile, CONICYT), Columbia (Univ. of Antioquia) and Venezuela (Univ. de los Andes) using dedicated programs (Math-AmSud, STIC-AmSud, PCP, CAPES-COFECUB, ECOS-SUD, ECOS-Nord). Bilateral cooperation and PICS programs have also been utilized to build strong and lasting links with different academic partners in Australia (NICTA, Univ. of Sidney), Japan (Univ. of Tokyo, National Inst. of Informatics of Tokyo, Tokyo Inst. of Technology) and Russia (Russian Academy of Science, N.I.Lobachevsky State Univ. of Nizhni Novgorod).

The informal international collaborations are illustrated through co-signed papers, co-edition of books, co-

Table 2: Tools and Demonstrators

Acronym	Description
CA-EN	A model-based simulation and diagnosis tool devoted to complex dynamic systems
CAUSALITO	Causal graph generator
DIADES	Software that models and diagnoses discrete-event systems (component-based)
Gloptipoly 3.0	Matlab parser for generalized problems of moments
H2 for HIFOO	Extension of HIFOO (Matlab package for H∞ fixed-order controller synthesis) to H2 performance
HYDIAG	An analytical redundancy based diagnosis engine for hybrid systems
InnoGRADE	This tool achieves the split of intermediate “grade 2” tumor cases into “grade 1 like” and ”grade 3 like” for oncologists to better adapt and personalize the prescription of patients with breast cancer
Koala	A model-based diagnosis engine for a diagnosis-oriented language describing a system of uncertain hybrid components
MEDITO	Generic Meta-diagnosis Engine based on a CSP solver (Java)
MISTRAL 2.0	A C++ library for constraint satisfaction and optimization
MuPaRo	Software for multiple participant routing, computing minimum cost carpooling itineraries
NUMBERJACK	A modeling package written in Python for constraint programming
P3S	Extension of SALSA for sensor/feature selection and process monitoring/diagnosis with addition of interval type data
PolyRDV 1.0	Matlab codes for impulsive linearized minimum-fuel rendezvous between two spacecraft around an elliptic reference orbit
ROA	Matlab codes for computing estimates of the region of attraction of a polynomial control system
RoMuLOC 2.0	LMI-based Matlab codes for modeling, robustness analysis and multi-objective feedback design of uncertain linear system
SALSA	Tool for Situation Assessment using the LAMDA Classification Algorithm
SatawTool 1.0	Matlab codes for analysis and controller design for systems involving isolated nonlinearities

edition of special journal issues or sections, organization of workshops and symposia or co-design of some dedicated software. A short list of regular collaborators classified by geographical area and country is given below.

Australia: J. Jeyakumar (UNSW), D. Nesic, Univ. of Melbourne.

North America: *Canada* – L. Rodrigues (Concordia Univ.) C-G. Quimper (Univ. Laval); *USA* – M.M. Peet (Arizona State Univ.), S. Gumussoy (The Mathworks Natick), M. Putinar (UCSB), G. Blekherman (Gorgia Tech.), A. Serrani (Ohio State Univ.), R. Sanfelice (Univ. of Arizona), D. Liberzon (Univ. of Illinois at Urbana-Champaign), A. Teel (Univ. of California at Santa Barbara), M. Overton (Courant Institute of New York Univ.).

South and Central America: *Brazil* D. Coutinho (UFSC); *Chile* – E. Cerpa and A. Mercado (Universidad Santa Maria, Valparaiso), A. Osses (Univ. of Chile), V. Parada and L. Pradenas (Univ. of Conception); *Mexico* – S. Mondié (Cinvestav- Mexico City).

Asia: *Japan* – Yoshio Ebihara (Univ. Kyoto), M. Sato (JAXA), Y. Nishio (Univ. of Tokushima); *Singapore* – S. Robins and D. Pasechnik (NTU).

3.1.2 Europe

The majority of our international collaborations, naturally enough, is composed of relationships with academic European institutions. Bilateral collaborations, PICS, ERASMUS and ECO-INNOVERA programs are major instruments for developing strong connections with some of our nearest neighbors: Belgium (KU Leuven), Czech Republic (Academy of Science, Technical Uinv., Prague), Germany (Technical Univ. of Munich), Great-Britain (Univ. of Oxford, Univ. of Kent, UK royal Society), Italy (Univ. Politecnica delle Marche, Politecnico di Torino, CNR) Spain (Univ. de Navarra), Sweden (Univ. of Skövde, KTH). Note also that one member of DO is associated member to the Faculty of Electrical Engineering of the Czech Technical University in Prague while another is associated to the Department of Industrial Engineering at the University of Trento.

European Networks: Concerning European Networks, the DO area is involved in HYCON2, gathering several partners in Europe: CNRS, INRIA, ETH and TU Delft.

In addition, an international GDR DELSYS dedicated to time-delay systems, hosted by DO plays an active role for making our laboratory highly visible on this topic.

It is also worth mentioning the European project EDA-ICET between LAAS (CNRS), Dassault, ONERA and University of Rome Tor Vergata on Nonlinear Innovative Control designs and Evaluations.

These formal international collaborations are strengthened by the high number of informal exchanges as it is illustrated by the following list.

Austria – L. Del Re, H. Kirchsteiger, H. Waschl (Univ. of Linz); *Belgium* – A. Van De Wouver (Univ. of Mons); *Czech Republic* – J. Heller, T. Pajdla, T. Vyhlidal (Czech Tech. Univ. Prague) M. Kruzik (Academy of Sciences Prague); *Finland* – C. Riener (Alto), *Germany* – T. Theobald (Frankort Univ.), S. Streif, R. Findeisen (Univ. Magdeburg), D. Marx (Humbolt Univ. of Berlin), P. Brucker and S. Knust (Univ. of Osnabruck); *Ireland* – O. Feely (Univ. College of Dublin), M. Mevissen (IBM Dublin), B. O'Sullivan (4C, Cork); Italy – A. Garulli (Univ. of Siena), A. Bemporad (IMT Lucca), S. Savaresi, M. Corno, S. Formentin (Politecnico of Milano); S. Galeani, M. Sassano (Univ. of Rome Tor Vergata), R. Baldacci (Univ. of Bologna); *Portugal* – C. Gracio (Univ. of Evora); *Slovenia* – M. Kovse (Univ. of Maribor); *Spain* – A. Barreiro (Univ. of Vigo), S. Dormido (UNED, Madrid), M. Ait Rami (Univ. Valladolid), T. Alamo (Univ. of Sevilla), L. Martinez-Salamero (Univ. Rovira I Virgili of Tarragona); *Sweden* – K.H. Johansson (KTH), W. Tucker (CAPA); *Switzerland* – C. Briat (ETHZ, Zurich), M. Korda, C. N. Jones (EPFL); *The Netherlands* – M. Laurent (CWI, Amsterdam), S. Bennani (ESA-ESTEC Nordwijk), W. Aangenent, M. Heemels, R. Van de Molengraft, M. Steinbuch (Eindhoven Univ.), C. de Persis and B. Jayawardhana (Univ. of Groningen); *UK* – D. Wagg and S. Neild (Univ. of Bristol), M. Claeys (Univ. Cambridge), R. Sepulchre and F. Forni (Univ. of Cambridge), M. Turner and I. Razgon (Univ. of Leicester).

3.1.3 National Collaborations

The national collaborations are sponsored by government agencies following different programs (PEPS and PIR CNRS, DGA, ANR, RTRA, GdR), foundations or directly funded by DISCO, MAC or ROC. They may result in direct collaborations or co-advising of Ph.D. thesis (see also next sections).

Here is a non-exhaustive list of some important examples. Here is a list of representative ANR projects (DO is leader on 4 of them underlined below). The total amount of ANR projects in which members of DO are involved as partners, is of 14 on the period.

ANR: ATHENA on optimization methods for the integrated study of complex decisional problems with UTC, LIMOS, University of Tours; **GEOLMI** (blanc 2013) on "*Geometry and Algebra of Linear Matrix Inequalities with Systems Control Applications"* with LJK-CNRS and INRIA, Univ. Grenoble, INRIA Univ. Nice, LIP6-CNRS and INRIA Univ. Paris, LMA-CNRS and Univ. of Pau, IRMAR-CNRS and Univ. of Rennes; **INNODIAG** on "*Discrimination of Biomarkers by Fuzzy Logic"* with DENDRIS, ITAV, INNOPSYS, ICR, LAAS-CNRS (NBS); **LIMICOS** on "*Synthesis and Analysis of Control Systems with Limited Information"* with GIPSA-lab, LAGEP, L2S; **MAGIC-SPS** on "*Guaranteed Methods and Algorithms for Integrity Control and Preventive Monitoring of Systems"* with ECS ENSEA, Cergy, IMS CNRS, Bordeaux, PRISME, Orléans, and LMAH, Univ. Le Havre; **ROBOCOOP** on *robustness and cooperation in scheduling* with IBM, University of Tours, University of Le Havre.

DGA: VORACE on "*Verified Fast Optimization for Embedded Control"* with Rockwell-Collins, ENAC/INP, ONERA, IRIT/ENSEEIHT.

PEPS: INSIS on "*New Methods for Flow Control*" with LML and IMFT; INSMI/INSIS/INSII on "Semidefinite Programming for 2D and 3D Optimal Shape Design" with LJK and INRIA Grenoble; INSIS on "*New LMI Modeling and LMI Solvers in Automatic Control*" with LJK and INRIA Grenoble; INSIS on "*eco-FriendLy cOntrol and energy aWarE simulator*" with ICAM and Univ. of Pau; INSII on "*Graphs for Combinatory Games*" with LaBRI, Institut Fourier, GAMA and LIMOS; INSIS on "*Set-membership estimations and application to detection*", with LIRMM-CNRS, ECS, LAPS and LAG.

Regional and Local Collaborations: PICAN on "*Inverse problems and numerical approximations*" with IMT; RTRA CARPE on "*Robust Flow Control with a Thick Plate*" with ONERA, IMT, IMFT, ISAE; MIC-PAC on "*Preconditioned set inversion for the enhanced estimation of dielectric relaxation parameters*" with CIRIMAT; RTRA ROSACE *Project* on "*RObots and self-adaptive Embedded Communicating Systems"* with IRIT and ONERA.

Collaborations within LAAS: NBS on "*Molecular in vitro diagnosis using recent innovations in nanotechnologies: application to breast cancer prognosis*"; SARA on "*QoS situation assessment in self-adaptive architectures for autonomous communicating systems*", N2IS on "*Use of chaotic signals for localization3*"; RAP on "*The problem of positioning a 3-DOF camera with respect to a mobile visual target*"; TSF on "*Carpooling: the 2 synchronization points shortest paths problem*"

Informal Collaborations, through co-signed papers and co-advising of PhD theses are with ISAE, LIP6, GSCOP, LIPN, LIRMM, EMSE Gardane, LIMOS, LAMSADE, LISBP, LAGEP, LAGIS, GIPSA-LAB, CRAN, ONERA, CHU Rangueil, PRISME Univ. of Orléans, ECS Lab, ENSEA Cergy, Univ. Le Havre, ENSI Bourges, LI Tours/Polytech. Tours, Heudyasic, ENAC, LAPLACE, IRIT.

3.2 Journal Editorial Boards

3.2.1 National

The national communities in which the members of DO are involved are relatively poor in terms of national journals. That being said, it is worth mentioning that the Editor in Chief of JESA (Journal Européen des Systèmes Automatisés) is a member of DO while another is member of its editorial board. DO is also represented in the editorial board of RIA (Revue d'Intelligence Artificielle).

3.2.2 International

Members of DO are currently (or have been during the last five years) involved in editorial duties as associate editors or members of the editorial board of international journals among the most recognized in three different scientific fields covered by DO.

Artificial Intelligence: Artificial Intelligence.

Control Theory: Automatica, European Journal of Control, IEEE Transactions on Automatic Control, IEEE Transaction on Control Systems Technology, International Journal of Robust and Nonlinear Control, Mathematics of Control, Signals and Systems, Systems and Control Letters.

Optimization Theory and Operational Research: SIAM Journal on Optimization, European Journal of Industrial Engineering, Journal of Scheduling, RAIRO Operation Research, Revista del Instituto Chileno de Investigacion Operativa.

3.3 Organization of Major Conferences and Workshops

Do area is largely involved in the organization of international and national conferences and workshops. This is evidenced by the organization of the 9th IFAC Symposium NOLCOS, on NOnLinear COntrol Systems (130 attendants, 135 papers), 4-6 September 2013, Toulouse. Members of DO are also very active in the different IPC of the major conferences and workshops of the different fields composing DO: Automatic Control (ACC, CDC, ECC, IFAC Workshops and Symposia – CPDE, DCENS, ROCOND, TDS, SSSC), Diagnosis (DX, QR, Workshops and Symposia – Safeprocess, DCDS), Operational Research (ICORES, CPAIOR, MISTA) and Artificial Intelligence (CP, AAAI, ECAI, IJCAI).

International visibility and scientific recognition of DO area are confirmed by the success of the application of Toulouse to welcome IFAC World Congress in 2017 (about 3000 attendees expected). Indeed, many members of DO have been involved in the application process and will be in charge of prominent positions in its organization: IPC Co-Chair, NOC Chair, Financial Chair, Publication Chair, General Secretary, Demonstrations Chair.

At a national level, Toulouse and LAAS have hosted ROADEF (420 attendants, 270 papers) in 2010 and JFPC (Journées Francophones de la Programmation par Contraintes) in 2012 with a high degree of involvement of members of DO (General Chair, NOC). Members of DO have been involved at different levels (President, member of TPC) in the main national conferences (CIFA, JFPC, ROADEF).

3.4 Major and Long Term Visits

3.4.1 Sojourns of Researchers Abroad

There is a deeply rooted tradition in DO area to foster international exchanges based in particular on extended stays in Universities or academic institutions abroad. More than 30 stays lasting more than one month can be recorded during the period. One can mention in particular the following stays (Institutions, duration).

- Univ. College, Dublin, 3 months;
- Univ. of Bristol, 6*4 months;
- Technical Univ., Munich, DE, 1 month;
- Univ. Rovira I Virgili, SP, 6 months;
- Science academy of Russia, RU, 1 month;
- Courant Inst., NYU, US, 3 months;
- IPAM, UCLA, US, 1 month;
- CIRRELT, Montréal, CA, 2*1 months;
- NTU and IMS, SG, 2*1 months;
- National Inst. of Informatics, Tokyo, JP, 4*3 months;
- UFGRS, Porto Alegre, BR, 1 month;
- UANL, Mexico, MX, 1 month;
- Univ. of Newcastle, AU, 1 month;
- NICTA, Camberra, AU, 2*5 months;
- Univ. of Sidney, Sidney, AU, 1 month;

PhD students from the DO area have largely taken advantage of funding afforded by the EDSYS Doctoral School for student mobility. Indeed, a policy (each team of DO pays a part of the expenses, typically flight tickets) systematically proposing one stay abroad lasting from one month to three months to PhD students has been operating during the period. Around 15 students have benefited from this system. Here is a short list of some examples of these visits (topic, institution, duration):

- "*Mode set focused hybrid estimation*", Graz University of Technology, AT, 2 months;
- "*Robust Periodic Controller with Memory",* Univ. of Kyoto, JP, two months;

- "*Benders Decomposition Algorithms for Multi-Objective Vehicles Routing Problems*", CORMIS University of Southampton, UK, two months;
- "*Hybrid control system design in the presence of limited information*", Univ. of California Santa Cruz, US, two months;
- "*SAT and hybrid models of the car-sequencing problem*", NICTA, AU, 1 month;
- "*MPC for Space Trajectories Optimization*", Imperial College, London, GB, three months;
- "*Algorithms of Real Algebraic Geometry and Linear Matrix Inequalities*", UC Berkeley, US, 2 months.
- "*Network flows problems and game theory*" Computer Engineering Dpt., U. Siena IT, two months.
- "*Stochastic Optimization for Collision Avoidance*", J.P.L, CalTech, US, three months.

3.4.2 Researchers Hosted

During the period, the DO area has accommodated more than 100 scientific visitors including senior researchers, Post-Docs and visiting PhD students. These partnerships are made possible by using official and formal frameworks provided by CNRS (bilateral collaborations, "postes rouges"), Univ. of Toulouse and others but also thanks to the policy of the area which intends to develop these stays lasting from a few days to several months. Let us mention a few among them Researcher, Institution, duration).

- S. Robins, NTU, SG, 6 months;
- T. Peynot and C. Brunner, Australian Center for Field Robotics, AU, 3 months and 4 months;
- V. Leite, UnED, Divinópolis, BR, 12 months;
- B. Polyak, Russian Academy of Science, RU, 1 month;
- J.A. Gonzalez Prieto, Univ. of Vigo, 2 months;
- F. Perez Rubio, Univ. Murcia, SP, 2 months;
- C. Bravo, J. Vizcarrondo, R. Leal and E. Camargo, Univ. los Andes, VE, 2 months;
- J. Blesa, J.I. Vento, Univ. Politecnica di Catalunya, SP, 3 months.
- H. Sarmiento, J. Botia Valderrama, C. Isaza, Univ. of Antoquia, Medellin, CO, several months;
- A. Agnetis, Univ. degli Studi di Siena, IT, 1 month;
- W. Dali, Univ. Alger, DZ, 18 months;
- M.A. Alvarez, Univ. de Sevilla, SP, 2 months;
- J. Lunze, Ruhr-Univ. Of Bochum, DE, 1 month;
- P. Šůcha, Czech Technical Univ., CZ, 12 months;
- K. Inoue, NII, Tokyo, JP, 6 months.

3.5 Scientific Evaluation Committees

3.5.1 International

Recognized for their expertise in the fields of control, optimization and diagnosis, researchers of DO have been commissioned for assessing international projects and participating to different councils mainly in Europe (FWF, AT; FWO, BE; SNF, CH; ISF, IL; SFI, IR; MIUR, IRA, IT; RC, NO; NOW, NZ; NSC, PL; UEFISCDI RO; IRA SP) and in North America (NSF, US and NSERC, CA) .

3.5.2 National

CNRS researchers and faculty members of DO have participated to various and numerous selection committees for projects (ANR, AERES), for funding PhDs (ANRT-CIFRE), for staff recruitment (INRA, INRIA) and visiting committees of different academic institutions and laboratories.

3.6 Major Roles in National Animation and Evaluation Structures

3.6.1 CNRS, University,

The DO area has a representative at scientific council of INSIS and INSII and in the "Comité National" (06 section) at CNRS. One of the DO members has also served as a "chargé de mission" at INSIS.

Members of DO chair prominent positions in some components of the University of Toulouse as exemplified by the following list:

- Head of QLIO department, Institute of Technology, Rodez;
- Deputy Director at FSI, Univ. P. Sabatier, Toulouse;
- Head of M2R, SAID, Univ. P. Sabatier, Toulouse;
- Head of Electrical and Computer Engineering Department, INSA of Toulouse;
- Head of AIP-PRIMECA (inter-university computer-aided manufacturing, computer resources and mechanics service), Toulouse;

They also serve as board members in the various councils (UT3PS, INSAT) and manage also Bachelor and Master of Science degrees.

- Council of pole MSTII, Univ. P. Sabatier, Toulouse;
- Scientific Councils (EEA, PCA), UT3PS, Toulouse;
- Steering Committee, UT3PS (IUT GEEI), Toulouse;
- Board of Directors (CA), INSA, Toulouse;
- Scientific Council, INSA, Toulouse.

3.6.2 GDRs, …

The **GdR MACS** dedicated to the modeling, analysis and steering of dynamical systems is currently headed by one member of the DO area while the **internationa**l **GdR DelSys** dedicated to studies on Time-Delay Systems is ruled by another member of DO. A researcher of DO is member of the GdR RO scientific council.

3.7 Scientific Societies

3.7.1 International

DO researchers are member of several technical committees of IFAC (1.5, 2.3, 2.5, 5.2, 6.1, 6.4, 8.3, 8.4) and one is the chair of IEEE Technical Committee on Computer Aided Control System Design. One member of DO has been nominated as SIAM fellow in 2013.

One DO member is part of the board of the ROADEF/EURO challenge an international industrial optimization competition.

3.7.2 National

A part of DO researchers are members of the French OR society ROADEF. One of them is member of the ROADEF Board.

3.8 Awards and Distinctions

During the period, one journal paper and 4 conference papers were recognized and awarded.

Best papers: Best paper in the journal Optimization Methods and Software; Best paper award – ICORES 2014 (Lisbon, PT); Best Application paper award – Constraint Programming 2012 (Quebec, CA); Honorable Mention – Constraint Programming 2012 (Quebec, CA); Best Student Paper Award - International Conference on Bioinformatics Models, Methods and Algorithms 2011 (Rome, IT); Best Ph. D. GdR MACS 2011.

Some members of the area have also been honored either individually or collectively with grants and distinctions:

Grants: Google Grant (SAT-based scheduling); Cino del Duca Foundation of the Institut de France Grant (Optimal control and polynomial optimization)

Distinctions: Lagrange Prize (SIAM and Mathematical Optimization Society) 2009; SIAM fellow 2014; 2nd prize of the 2010 SCM (Société de Calcul Mathématiques).

Finally, one of the members of DO received the first price in 8 categories and first overall in the International CSP Solver Competition for the software Mistral.

4 Interaction with Social, Economic and Cultural Environment

4.1 Projects with Industrial Partners

The projects conducted with industrial partners within the DO area may be distributed in 5 fields of different range: Space, Aeronautics, Transport, Energy and Healthcare.

Space: Besides the usual academic collaborations, several of applied projects in the space domain are sponsored by government agencies such as CNES (French Aerospace Agency) with DCT/SB/PS (AOCS) and DCT/SB/MO (Orbital Mechanics) Services, ONERA, ESA-ESTEC and leading industry companies such as Astrium, EADS ST and Thales Alenia Space. These collaborations follow different modalities ranging from direct contracts to Ph. D. thesis supports. Some examples of direct scientific collaborations are given:

- CNES-Thales Alenia Space grant on "Distributed Diagnosis for Autonomous Satellites";
- CNES 115689/00 (10/11 - 09/12) and 127898/00 (12/12 - 12/14) on "Evolution of the software for scheduling scientific experiments of Philae lander in ROSETTA project";
- Thales Alenia Space (10/9 - 3/10) on "*Frequency allocation in a SDMA satellite system*" (in collaboration with IRIT);
- Thales Alenia Space (12/13 - 02/14) on "*Discrete optimization of link budget*" (in collaboration with LAPLACE);
- CNES 71372/00 (12/2007 – 12/2009) on “Autonomous and robust guidance algorithms for the Rendezvous problem in elliptic orbits”;
- CNES 104057/00 (09/2010 – 03/2011) on “Linear programming for embedded orbital rendezvous optimization”;
- SAFE-V (01/2011 – 09/2012) on “Positive polynomials, integral quadratic separators and LMIs for robustness analysis of launchers in atmospheric flight and orbital maneuver”;
- CNES 104148/00 (10/2010 – 12/2012) on “Robust guidance algorithm for the orbital rendezvous”;
- CNES 130841 (07/2013 – 12/2014) on “Robust and optimal 6DOF control for space proximity operations”.

Some PhD topics are summarized below:

- Astrium/CIFRE grant on "Design and planning of communication satellite payload tests";
- Astrium/CIFRE grant on "Co-optimization of satellite payload and communication system";
- CNES - Thales Alenia Space grant on “*Satellite control with saturating inputs*”;
- CNES – Astrium grant on “Periodic control for attitude control”;
- CNES – Astrium grant on “Trajectory design, guidance and control for spacecraft rendezvous and proximity operations”;
- CNES - ONERA grant on “Time-varying attitude control for satellites”;
- CNRS - Astrium grant on “*Collision avoidance control*”;
- Midi-Pyrénées - CNES – TAS grant on “6-DOF robust guidance and control for proximity operations”.

Aeronautics: Application of research in nonlinear and linear robust control systems, diagnosis and aeronautics to avionics has been carried out during the last five years. The aim is to associate our more fundamental research with the major European industry companies in this field:

- ARCHISTIC (2007-2009) on “*Architecture for distributed diagnosis and prognosis*”, within the AIRSYS common laboratory with AIRBUS and ENIT;
- EPICE CORAC Project on ”Adaptive Prognosis” with Liebherr and Airbus;
- SIRASAS (FRAE foundation Project) on “*Novel and Robust Strategies for the Autonomy of Aeronautic and Space Systems*” with IMS, SATIE, CRAN, LRI, ONERA, CNES, Thales Alenia Space, Airbus;
- Airbus PhD grant on "Reasoning about models: detecting and isolating abnormalities in diagnostic systems”;
- Amadeus via ENAC subcontract and challenge ROADEF 2009 on "*Disruption management optimization for commercial aviation*";
- OCKF (Operational Concept and Key Functions): (2008 – 2012) on “Robust analysis and synthesis of non-fragile flight control laws, Antiwind-up design of flight control laws, Robust nonlinear flight control laws” with ONERA, Airbus;
- Eurocopter (05/2011 – 09/2012) on “Discretization of control loops involving hydraulic actuators of a helicopter”.

Transport: DO is involved with industrial partners for freight or passenger transportation, especially to what concerns multimodal itineraries and vehicle routing problems:

- ANR TTD RESPET (2012-2015) with DHL, INRIA Lille and LIA on "Efficient Door-to-door network management for freight transportation";
- MOBIGIS/CIFRE grants (2007-2010) and (2012-2015) on "Algorithms for multimodal shortest paths" and "Algorithms for multimodal and carpooling itineraries";

- AMIC-TCP OSEO Project (2009-2012) on "*Architecture Multiplexed Informatics Communication for Public Transport*", with ACTIA, Aton, Sodielec, IRIT, Asscot, Citilog, PME-3, Trialog;
- SNCF/CIFRE grant (2007-2010) on "Optimization of railway inspection vehicle routing".

Energy: DO collaborate with the industrial sector in the search for energy-efficient solution in transportation and production problems.

- ECO INNOVERA EASY (2012-2015) with FAGOR, U. Skövde, U. Navarra on "*Energy-aware feeding systems*";
- NEXTER (direct contract) (2012-2014) on "Energy management optimization for hybrid electrical vehicles".

Healthcare:

- ONCOMATE (InNaBioSanté Foundation) on "Elaboration of diagnosis aided tool based on selection of biomarkers form machine learning on public data sets" with IMRCP, LBB, Platform BIOPUCE, INNOPSYS SA, LAAS-CNRS (NBS);
- ANR BIOSTEC INNODIAG (2011-2014) on "*Discrimination of biomarkers by fuzzy logic*" with DENDRIS, ITAV, INNOPSYS, ICR, LAAS-CNRS (NBS).

4.2 Other Major Innovation Activities

Coordination of the Aerospace Valley Cluster - DAS G2MCO (Maintenance Repair and Overhaul): This cluster deals with the tools and means to improve MRO activities and is co-managed by a member of DO. It covers all airborne (planes, helicopters, UAVs) and space-borne systems and their supporting equipment.

Scientific Council of Actia Group: The DO area is represented in the scientific council of the Actia Group.

4.3 Scientific Popularization

Members of DO are quite naturally involved in the different actions promoted by the laboratory for informal science education like open lab days and dedicated events like "fête de la science" through demos (optimize your trip, control of an helicopter mockup), mathematical games and puzzles. Two articles in the popularization journal of CNRS "Images des Mathématiques" have also been published: "Les ovales des spectraèdres" and "Les coupes des spectraèdres". Finally, note also a popularization talk at the "13ème forum des jeunes mathématiciennes" and several visits in local high schools for "Maths en Jeans" workshops as well as involvement in the "Math à Modeler" group for popularization of Mathematics.

5 Involvement in Training through Research

5.1 Leading Roles in Doctoral Schools

A very large majority of researchers from DO are members of the EDSYS doctoral school (Systems Doctoral School) and very few are members of the MITT (Mathematics and Computer Sciences) Doctoral School. It is therefore natural enough that a strong involvement of DO area in EDSYS pops up. The deputy Director of the Doctoral School, two members of the steering committee, three members of the board and one head of scientific domains out of 4 are members of DO.

5.2 Research Seminars in Training Programs

5.2.1 Summer Schools

Participations to six summer schools abroad and in France may be mentioned:

- VI Escual de Verano en Matematicas Discretas Valparaiso, CL, 2011;
- DICOP, Piura, PE, 2012;
- AMST Brisbane, AU, 2011;
- Diagnosis Summer School, Madrid, SP, July 2010 and 2013;
- Summer Medical and Dental Education Program, Duke University, US, June-July 2013
- International Summer School on Automatic Control Grenoble, FR, 2013

5.2.2 Advanced University Courses

Apart the statutory mandate of professors and associate professors, CNRS researchers of DO as well participate to advanced courses in different academic institutions composing the University of Toulouse (Doctoral Schools, ISAE, UPS) and have also been invited to give advanced lectures in other university sites in France and abroad. Here is a short list of some examples.

- PhD course: "*Nonlinear Dynamical Hybrid Systems*", EDSYS, Toulouse, FR, 2012;
- PhD course: "*Model-based Diagnosis*", EDSYS, Toulouse, FR, June 2012;
- MS course: "*Nonlinear and Hybrid Control*", ISAE, Toulouse, FR, January-February 2014;
- MS course: "*Optimal Control*", ISAE, UPS FR, since 2009 and 2012;
- MS course: "*Robust Control*", ISAE and UPS, FR, since 2006 and 2012;
- MS and PhD course: "*Anti-Windup*", UUFRGS, BR, June 2013;
- PhD course: "*Nonlinear Systems*", J. Kepler Univ., Linz, AT, March—June 2011;
- Course : "*Time Delay Systems*", JDMACS Marseille, FR, 6-8 Juin 2011;
- Master Class: "*Scheduling & Linear Programming*", CPAIOR Conference, Nantes, FR, 2012;
- Mini-course: "*Polynomial Optimization and Control*", MODE 2014, Rennes, FR, March 2014;
- Course: "*Moments, Positive Polynomials and LMIs for Optimal Control*", EECI Graduate school on Control, Paris, FR, 17 - 21 February 2014;
- Course: "*LMI, Optimization and Polynomial Methods*", HYCON-EECI Graduate School on Control, Paris, FR, 7-11 February 2010 and 2011;
- Course: "*LMI Optimization with Applications in Control*", Belgian Graduate School on Systems, Control, Optimization and Networks Leuven, BE, April-May 2010.

5.3 PhD and Internship/Master Programs

5.3.1 Thesis supervised

The number of current PhD students is 38 for 40 agents in the permanent staff, corresponding to a current supervision rate of almost 1/1 (0.95). Note also that around 60 PhDs have been defended during the period.

5.3.2 Co-Supervised Thesis

10 co-supervised PhDs with an external co-advisor (2 national and 8 international) have been defended during the period.

A short list of some examples is given below.

- "Stability and Control of Time-Varying Linear systems with Uncertain Parameters", INSA-UNICAMP, BR;
- "Control of Dynamical systems: Absolute Stability, Saturation and Bilinearity", INSA-UNICAMP, BR;
- "Discrepancy-based search for constraint satisfaction and combinatorial optimization problems", INSA-Faculté des Sciences de Tunis, TN;
- "Tree search methods to solve flexible scheduling problems" INSA-Faculté des Sciences de Tunis, TN;
- "Methodologies for hybrid systems diagnosis based on the hybrid automaton framework", UPC SAC, SP.

5.4 Teaching and Education Materials

5.4.1 Published Notes and Books

- "Optimization on linear matrix inequalities for polynomial systems control", C.I.R.M., Vol. 3, No. 1, C. No. I, pp. 1-44, 2013;
- "Modélisation, analyse et commande des systèmes linéaires". Presses Universitaires du Mirail, 2009.

5.4.2 E Ressources

DO area has promoted education material on the different fields of our research and made available through electronic resources. A specific web page dedicated to the presentation of the material available has been created to this end:

https://www.laas.fr/public/fr/ressources-pédagogiques-do

This page, organized according to some main scientific domains, connects to individual staff web pages where the educational material may be downloaded.

Control Theory:

- "Modelling and Simulation of Complex Systems";
- "LMI in Control";
- "Random Signals" and "Estimation Theory";
- "Nonlinear Systems";
- "Robust Control";
- "Optimal Control".

Scheduling and Constraint Programming:

- "*Scheduling*", M2, Univ. P. Sabatier;
- "Constraint Programming";
- "Constraint-based Scheduling";

Mathematics:

- "Graph Theory";
- "Integer Linear Programming";
- "Popularization".

Diagnosis:

- "Model-based Diagnosis".

5.5 PhD/HdR Committees

DO members attended to more than 130 Ph. D. defenses (more than 100 in France and around 20 abroad) and around 10 HDR committees. They were involved as referees in 65 cases and as president in 10 cases for Ph.D. defenses.

5.6 Faculty Selection Committees

5.6.1 National and International

CNRS researchers and faculty members of DO have been involved as members or experts in more than 15 selection committees dedicated to the hiring process of associate professors and professors in more than 10 different Universities in France (Bordeaux, Grenoble, Lille, Lyon, Nantes, Nancy, Paris, Poitiers, Tours, Troyes) during the period. Three of them have been or are currently members of CNU 61. Two have also participated to the selection committee for PEDR and PES in 2009, 2010, 2012 and 2013. One member of DO has been a member of CNU 27.

5.6.2 Local

At the local level, members of DO are active in the hiring process of associate professors and professors of the different components of the University of Toulouse (INSAT, INPT, UT3PS) as president, members of selection committees or ad-hoc councils (UT3PS).

VI - Microwaves and Optics: from Electromagnetism to Systems (*Hyperfréquences et Optique : de l'électromagnétisme aux systèmes* — HOPES)

Leader: F. Lozes-Dupuy

Research Teams: Micro and Nano Systems for Wireless Communications, Microwaves and Opto-microwaves for Telecommunications Systems, Optoelectronics for Embedded Systems, Photonics

Keywords: Nanotechnologies, Micro and Nano Systems, Optoelectronics (Components and Systems), Photonics, Optical Sensors, Sensor Networks, Microwave Components, Integration of Microwave Systems, Opto-microwaves, Electrical Noise and Reliability, Wireless communications

Personnel Status (as of June 30, 2014):

Team — MINC	Micro and Nano Systems for Wireless Communications
Leader	P. Pons (DR)
Permanent Researchers	H. AubertT (PR), D. Dragomirescu (PR), R. Plana (PR)] 01-2013], A. Takacs (MCF) [09/2011[
PhD Students	F. Perget [10/2010[, J. Lomine [10/2011[, A. Rifai [10/2011[, A. Traille [11/2011|, G. Vigneau [03/2013[, J. Fourmann [10/2013[, M. Gastaldi [10/2013[, J. Valleau [10/2013[, Z. Yang [10/2013[Alumni : M. Jatlaoui [10/2005-04/2009], F. Pennec [10/2005-06/2009], H. Achkar [11/2005-07/2009], F. Khalil [10/2006-12/2009], H. Shaarawy [10/2006-12/2009], T. M Vu [09/2006-04/2010], A. Ali Mohamed [09/2006-04/2010], J. Ruan [10/2006-06/2010], A. Rashid [10/2006-08/2010], A. Lecointre [10/2006-10/2010], H. Youssef [01/2007-11/2011], M. Kraemer [04/2007-12/2010], A. Kara Omar [10/2007-04/2011], J. Henaut [10/2007-04/2013], B. Ouagague [10/2007-09/2014], E. Tchikaya [10/2007-10/2010], F. Chebila [12/2007-03/2011], A. Broue [12/2007-06/2012], U. Heiba [01/2008-09/2011], F. Tahir [09/2008-09/2011], T. Beluch [10/2008-04/2013], M. Pigeon [10/2008-11/2011], A. Berthe [11/2008-01/2012], M. Alexandru [10/2009-10/2012], S. Bouaziz [10/2009-02/2013], M. Ercoli [10/2009-12/2012], D. Medhat [10/2009-10/2012], H. Liu [10/2009-05/2013], N. Fonseca [11/2009-10/2010], N. Torres [11/2009-01/2013], C. Leclerc [10/2010-10/2013], O. Ripoche [10/2010-11/2013], G. Vincenzi [01/2011-01/2014]
Post-docs; Engineers	R. De Paolis [02/2012-12/2014], S. Vivies [07/2012-12/2014[, E. Debourg [09/2012-08/2015], D. Henry [04/2013-09/2014], V. Prudovsky [09/2013-08/2015] Alumni :M. Al Hamad [09/2006-04/2009], V. Puyal [01/2007-09/2011], C. Villeneuve [11/2007-08/2011], S. Aouba [01/2008-06/2011], S. Hebib [11/2008-09/2011], A. Takacs [01/2008-12/2010], H. Bad El Din [12/2009-08-2011], M. Ding [02/2009-07/2010], L. Hamelin [04/2009-03/2010], M. Jatlaoui [05/2009-08/2011], S. Pacchini [01/2009-10/2011], F. Pennec 06/2009-11/2011], H. Wang [06/2009-05/2011], I. ElGmati [11/2009-06/2010], A. Ali Mohamed [05/2010-11/2011], G. Deligeorgis [4/2010-3/2014], F. Khalil [04/2010-03/2011], J. Ruan [07/2010-12/2010], R. Tocque [01/2010-12/2010], Chebila [03/2011-12/2012], M. Alexandru [01/2013-06/2014], R. Petre [09/2013-12/2013], A. Luca [11/2013-03/2014]
Visiting Researchers (Affiliation, Country, Period)	A. Ferrand (MC, ICA, [01/2004-12/2013]), D. Leray (MC, ICA, [01/2004-12/2013]), C. Villeneuve (MC, LAPLACE, [09/2011-12/2013]) S. Brida (Auxitrol, [10/2006[), F. Coccetti (Fialab, [09/2008[) D. Dragoman (IMT Bucharest, RO, [07/2009-09/2009]), M. Dragoman (IMT Bucharest, RO, [07/2009-09/2009]), F. Udrea (Univ. Cambridge, GB, [11/2013-12/2013]), Papaioannou (NKUA, GB, [06/2008-12/2009]), C. Ravariu (University Polytechnica of Bucharest, RO, [10/2012-11/2012]), M. Tenzeris (GeorgiaTech, US, [01/2012-12/2012])
Team — MOST	Microwaves and Opto-microwaves for Telecommunications Systems
Leader	O. Llopis (DR)
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Team — OSE	Optoelectronics for Embedded Systems
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Team — PHOTO	Photonics
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1 Presentation

1.1 Objectives and Scientific Positioning

HOPES theme tackles the challenges driven by the vision of the future Internet of Things and the M2M communication world, in an area of research combining microwaves and optical approaches.

The general goal is to advance the state of art of electronic and photonic components that are expected to have a large impact in the development of cyber-physical and smart systems. Activities aim at providing new knowledge and innovative solutions for embedded and autonomous systems, where interconnected objects will be able to communicate and interact with their environment. Moreover, interdisciplinary research, combining these advancements with physical, chemical or biological principles open up further exciting opportunities for environmental sensing and health monitoring.

For this purpose, research activity spans a wide area, investigating materials, devices and systems for applications where electromagnetism energy plays a crucial role: communication networks, embedded systems, sensing, imaging… The activities cover the core-building blocks of electrical and optical engineering, from in-depth understanding of physical phenomena and material properties, to the development of new concepts, novel modeling techniques, fabrication technology, testing, and validation of some prototypes.

HOPES draws on the expertise of four teams investigating complementary aspects of electronics and photonics to address needs in miniaturized, multi-functional and low-power building blocks enabling their further integration into networked components and intelligent systems. Research in these areas takes benefit from the growing convergence between optical and electronic studies and their cross-fertilization through a common application field. Furthermore, emerging nanotechnologies reinforce the opportunities to build a common vision of systemic integration, based on the implementation of generic technologies enabling the heterogeneous integration of electronic and photonic devices into smart systems. HOPES investigates new fabrication technologies at the forefront of advanced nanotechnologies and emphasizes interdisciplinary research that connects these technological developments to alternative device concepts and societal needs.

Technological work builds upon the resources available in the LAAS facility and contributes to develop the key technologies aimed at system integration. These skills are well recognized amongst the Renatech network, and open up for fruitful collaborations.

The interdisciplinary approach gets HOPES naturally integrated to the ADREAM and ALIVE axes. More specifically, HOPES conducts important work in the field of space and embedded systems research areas, contributing to strengthen the "innovative chain" in the main industrial sectors of the Region. HOPES was involved in several projects funded by RTRA STAE, CNES, Midi-Pyrénées Region and has established local partnerships with the aerospace and the aeronautics industry. HOPES played also an important role in fostering 4 start-up creations over the last 5 years.

A strong collaboration network has been developed at the national level, with several major actors of the HOPES research field, in particular through 24 ANR projects conducted over the last period or scientific collaborations through the participation at several GDR or thematic networks.

At international level, HOPES has established strong and fruitful collaborations through the participation in 2 LIA, 6 COST actions and worldwide partnerships. HOPES has conducted 14 European projects and has been involved in the research consortium of the flagship project "Guardian Angels for a smarter life", one of the 4 finalists in the European FET Flagship Initiative.

HOPES endows an original and futurist scientific positioning through its broad research area, joining the optics and electronics worlds, enabling therefore a multidisciplinary vision in Information and Communication Technologies and the achievement of highly collaborative projects. This activity competes with most of national and international academic groups, mainly when focusing on one of its 5 core area domains described hereafter, which are also at the heart of most ICT labs.

1.2 Organization and Life

The HOPES theme federates the activity of four research teams:

- MINC: Micro and nano systems for wireless communications
- MOST: Microwaves and opto-microwaves systems for telecommunications
- OSE: Optoelectronics for embedded systems
- PHOTO: Photonics

MINC objectives are focused on RF wireless communication and sensing, developing research and innovation in the field of RF electromagnetic energy engineering from material to system level.

MOST is focused towards the design and modeling of microwave circuits and systems, including mixed microwave-optical systems, with a specific knowledge on noise performance.

OSE investigates the physical limits of optoelectronic sensors for both solid and fluidic targets by exploring methodology of design as well as algorithms of data processing. OSE research team was an associated team on 2009-2010 and joined officially LAAS on January 2011.

PHOTO carries out research on innovative concepts for photonic devices, with high performance as well as new functionalities, targeting the challenge of photonic integration into systems.

1.2.1 Activity Profile

The activity profiles for HOPES and the composing teams is depicted in Table 1.

Table 1: Activity Profile

%	Academic research	Interaction with environment	Research Support	Training
HOPES	55	20	10	15
MOST	55	20	10	15
OSE	55	20	10	15
PHOTO	60	15	10	15
MINC	55	20	10	15

1.2.2 Scientific Coordination

A Scientific Council, composed of the representatives from each team and two members from technical services, meets each month or two, to discuss the research coordination, the means for the technological and experimental platforms, the recruitment profiles, the responses to different calls … It tends to develop a common understanding of the issues and strategies of the HOPES research area and foster scientific collaborations within or outside the lab.

Several regular seminars are given on the initiative of the scientific council of each team, all HOPES members are invited to participate. Specific plenary meetings, organized at the HOPES level, are dedicated to presentations of PhD works, focus on emerging research topics discussed internally or with invited external speakers. Focused meetings, with one-day research and technical presentations, are dedicated to foster the HOPES links with its various partners and prepare future collaboration projects (DGA, CNES, industrial partners from aeronautic and aerospace field …). A special effort is also devoted to increase the links between HOPES and the other themes, as well as other local research units, at the frontier of microwaves and optics, to encourage innovative interdisciplinary research. For example, HOPES has contributed to build the OPTIM (Optics and Images) scientific network of the RTRA, gathering the academic and institutional actors of this field in the local campus.

1.3 Salient Facts

The highlights selected in this section are not intended to be a comprehensive review of the entire HOPES research activity. Nevertheless, they aim to provide a global picture through several performance indicators based on the quality, the scope and the impact of the breakthroughs made in the following four relevant fields:

- RF wireless communications
- Electronics for embedded systems
- Metrology and advanced sensorics
- Development of novel materials and devices

1.3.1 RF Wireless Communications

Started in 2006, studies on **Wireless Sensors Network** led to the development of a wireless communication board on flexible substrate. IR-UWB 60GHz reconfigurable digital radio (hardware and software) [RVSI11463] with high energy efficiency (150mW for 500 Mbps [RVSI10828]) and precise clock synchronization (<1ns, over state of the art [RVSI12476]) has been validated. These expertises led to the management of the French ANR-NANOINNOV-NANOCOM project (09/2009-06/2011) with 7 partners, to the participation of preselected Flagship-Guardian Angels project (01/2011-12/2012) and to a 8 months French fellowship with Cambridge University (02/2014-09/2014).

Started in 2005, studies on **Wireless Passive Chipless Sensors** are focused on electromagnetic transducers with radar interrogation. LAAS is pioneer in the world in this subject with 3 first worldwide publications on new RF transducers (pressure sensor in 2007, micro-fluidic temperature sensor in 2011 [MAI11788], nuclear radiation sensor in 2013 [MAI13532]) and 9 Invited communications since 2011 [CII13494]. Collaboration started in 2011 at the request of GeorgiaTech Athena Group (Pr. M. Tentzeris) that led to PhD internships and Professor visit (01/2012-12/2012) at LAAS for 1 year. An European ERANET-DOSIMEMS project (06/2012-05/2015), coordinated by LAAS, is still on going. In parallel discussions are underway with industrials partners (EDF, Thales Alenia Space, CEA) for valorization.

RF Energy Harvesting and Wireless Transfer Power (WPT) are very promising solutions that allow sensors, electronics and wireless smart systems to operate autonomously from the energetic point of view. LAAS studies focused on satellite health monitoring applications that involve high frequency (> 8 GHz) for which accurate models of Schottky diodes are not available [RVSI13445]. Thanks to this expertise, LAAS chairs the working group "Space Applications" of the COST-WIPE action (WIreless Power Transmission for Sustainable Electronics) started in October 2013.

1.3.2 Electronics for Embedded Systems

Mixing analog and digital approaches in RF integrated circuits allows us to reach high performance and unsurpassed frequency reconfigurability. An example is our patented technology [BR0908 and BR1103] for the design of an UWB source based on a direct digital synthesizer (DDS). This mixed approach is at the core of modern complex RF integrated circuits and SoC.

We have also designed the **electronic autofocus in the instrument on-board of Curiosity**, the martian rover. The set-up has been tested at CalTech in 2011. For his participation, Marc Lescure has received the NASA Group Achievement Award. We have also designed an ASIC displaying better performances than the Amptek A111 used in most of universe observation missions [RVSI14135]. This circuit is selected for a CNES space mission (Instrument IDEE in TARANIS) and is candidate for the NASA space mission (Solar Probe +).

1.3.3 Metrology and Advanced Sensorics

In 1998, LAAS was pioneer in France in RF micro-switches gathering state of the art competences in RF switch (technology, design, characterization) and in reliability (at component level from 2002 and at material level from 2006), leading to the management of FP6-NoE-AMICOM (01/2004-12/2007). These investigations led to the **transfer of a reliability test bench for RF switches** to Thales Alenia Space in 2007. Between 2009 and 2012 several breakthroughs and high publication records (16 international Journal papers) have been accomplished on **RF-MEMS contact studies at the nanoscale** (collaboration with NKUA Greece, Ohio Univ. USA and Fialab). In addition, LAAS managed the European Laboratory SMARTMEMS (01/2009-12/2012) in collaboration with IMT Bucharest (RO) and FORTH (GR). This LEA focused on bridging RF microsystem technology to RF nanotechnology, and the strong collaboration between the partners led to significant achievements on carbon based RF electronics and more specifically on graphene. Moreover it triggered the successful participation of HOPES into the FP7-NANORF project (09/2012-08/2015).

Our expertise on **noise modeling and metrology**, from single device to complex systems, gives us an original position in the scientific community, at the crossroads of different scientific fields such as electron devices physics and reliability, RF circuits design, time and frequency metrology and optical devices and systems. Our experimental platform allows us to investigate on noise mechanisms from low frequencies up to the millimeter wave and optical ranges. These facilities include the metrology of low frequency noise, microwave noise parameters, phase noise in frequency sources or devices and optoelectronic devices noise.

Also at the crossroads of scientific fields, microwave-optics allows new approaches for high quality microwave frequency generation, and **a new type of optoelectronic oscillator (OEO) based on a fiber ring resonator** has been proposed. Through the control of the noise, and particularly the one related to the optical nonlinear effects inside the resonator, a state of the art performance has been obtained with this OEO for both close to carrier phase noise and far from carrier spurious signals. The short length of fiber involved (100 m) makes this OEO suitable for compact design. A compact version of this system is thus under study and may be implemented in Thales radar systems (on-going EDA "HIPPOMOS" contract).

As a worldwide leader in the field of Optical Feedback Interferometry (OFI) for sensing applications (16 publications in international journals), we have received the **European Mechatronics Award (Research Category, 2010) for an embedded OFI vibrometer** supported by an ANR Emergence program and Toulouse Tech Transfer (protected by 2 patents). In the field of fluidics, OFI velocimetry for blood flow measurements is investigated for early melanoma detection (3 EC projects) and for anemometry (1 start-up created, 3 patents).

Lines, an optical fiber hydrostatic levelling sensor, was first supported by the ANR RiskNat programme with the CERN as an end-user. We have developed a sensor (tested during 2 years in a cavern) to be exploited for the alignment of the 8 particle accelerators [RVSI12774]. This project is now supported by Toulouse Tech Transfer for prototyping this scientific experiment as a demonstrator to be installed at CERN for in-situ validation. This is resulting from a collaboration with Geosciences Montpellier, l'Institut de Physique du Globe de Paris and the LAUM (Le Mans).

1.3.4 Development of Novel Materials and Devices

A **low temperature, low cost, multi-layer, 3D copper interconnect process** has been developed and patented [BR1005]. This process, based on standard photolithography and electroplating techniques, avoids wire-bonds, through-die via and micro-bumps. It is ideal for System-in-Package, Wafer-Level-Packaging and above-IC passive integration. Given the breakdown provided by this technology, a startup "3DiS Technologies" has been created and is today hosted by LAAS-CNRS (project selected by Midi-Pyrénées incubator in October 2012, and awarded within the OSEO emergence in 2013).

Research on the **emerging GaAsBi alloys** began at LAAS in 2010 in a close collaboration with LPCNO. These promising semiconductors aim to extend the GaAs bandgap deeper into the near-infrared (IR) than the

GaInAs alloys by changing its valence band. Incorporation of Bismuth induces states in the bandgap due to Bi clusters formation or alloy disorder and increases significantly the spin-orbit interaction. Up to now, we have investigated strained layers and quantum wells, with the following results [RVSI13010, RVSI13554]. The emission peak energy variation with temperature exhibits the S-shape behavior [RVSI13010] related to localized states, as found earlier with dilute nitrides. The luminescence can be improved by applying ex-situ annealings, but Bi out-diffuses if the annealing temperature is too high. The luminescence properties are in agreement with state-of-the-art results [RVSI14031]. The Landé factor (g) for these alloys was measured for the first time [RVSI13281]. Moreover, record long-wavelength emission reaching 1.23µm at room temperature was obtained from elastically-strained 7nm-thick GaAsBi-GaAs quantum wells [RVSI13554]. Now, we plan to exploit these alloys in combination with dilute nitrides to beneficiate from their complementary properties in order to study their potential for solar cells and IR laser diodes.

A significant research activity at LAAS has been dedicated to studying **III-V semiconductor oxidation**, an unrivaled technology to make a variety of photonic devices by introducing, in a fully monolithic and integrated manner, 3D modulations of the optical and electrical properties of these materials [1] [RVSI14069]. The team has gained international recognition for its technological and scientific contributions. A key result was the development of a specific oxidation furnace with in-situ optical monitoring allowing reproducible and high-precision control of the process [2]. Fostered by a high interest from photonic device manufacturers, this innovative technology has recently been transferred to industry through a fruitful collaboration with the SME AET Technologies. In parallel, we have deepened the physical understanding of the AlOx oxidation by revealing the effect of embedded strain in laterally oxidized structures [RVSI11163, [3]], by transferring and improving this technique to antimonide-based mid-infrared lasers [RVSI13371]. We have also recently demonstrated the extensive versatility of the AlOx integration technology for other emerging applications such as integrated non-linear optics[4] or sub-wavelength high-contrast photonic structures [RVSI13372].

At the component level, a research activity on **Grating Mode Resonant Filters (GMRFs)** has been engaged since 2005 in close collaboration with Institut Fresnel and CNES. Over the period, several significant theoretical and experimental breakthroughs have been made in this field of sub-wavelength periodic structures for free-space optical applications. Among these are the study of reflectivity limiting factor [RVSI10430], a proposal of novel structures for high finesse polarization-independent GMRFs [RVSI11226], as well as the study of small-size variants which exhibit exceptionally high angular acceptance [RVSI12220]. These results triggered two patent submissions (one having been granted [BR1101] and the second being under review [BR1402]) which are at the heart of current activities on photonic integration in systems, either for hyperspectral imaging applications with CNES and ASTRIUM, or for future display systems (ESSILOR) or for laser diode stabilization with DGA [RVSI12677].

[1] J.M. Dallesasse, D.G. Deppe, "III–V Oxidation: Discoveries and Applications in Vertical-Cavity Surface-Emitting Lasers," *Proceedings of the IEEE*, 101, pp.2234-2242, 2013.

[2] G. Almuneau, R. Bossuyt, P. Colliere, L. Bouscayrol, M. Conde, I. Suarez-Alvarez, V. Bardinal, C. Fontaine, Sem. Sci. Technol. 23, 105021, 2008.

[3] F. Chouchane, G. Almuneau et al, “Local stress-induced effects on AlGaAs/AlOx oxidation front shape”, Appl. Phys. Lett. 105, 041909, 2014.

[4] G. Lafleur, A. Larrue et al, “Vertically-coupled AlGaAs microdisks using selective lateral oxidation”, *European Conference on Integrated Optics (ECIO)*, poster P011, 2014.

2 Scientific Production

HOPES conducts research across a wide scientific continuum from the nanoscale to the embedded system, from process technology to characterization tools and evaluation methodologies, both for photonics and electronic systems.

Research area is carried out in 5 core area domains:

- New RF devices
- Complex RF circuits
- Complex wireless RF systems
- Optoelectronic systems
- Photonic integration into systems

2.1 New RF Devices

2.1.1 Reconfigurable RF Components

The objective is to introduce agility in the RF communications circuits and systems to reduce the system size and/or increase the functionalities while maintaining low power consumption and minimum losses. We started this activity in 1998 studying micro-switches (capacitive and resistive contact), following by ferroelectric material (2007) and microfluidics (2007).

Intensive technological developments have been performed in order to provide internal RF-MEMS technology which includes both capacitive and resistive switches [RVSI10943]. Although considered as a low TRL process, it has been instrumental to carry out a systematic investigation of the failure mechanisms from device down to the material level. Next step has been to invest this body of knowledge in the design and modeling of more advanced modules and circuits (absorptive switches, SPDT, switching matrices, phase shifters) by exploiting higher TRL technology (CEA-LETI, IHP company-Germany). Worth of note is the achievement of a very accurate and large band (DC to 120GHz) lumped element model for the IHP RF-MEMS which has enabled on the one hand the design of original devices like the 40 GHz absorptive SPDT redundancy switch and on the other, the possibility to carry out real time yield control of the technology obtained by introducing the process tolerances in the electrical lumped element model [RVSI12577]. Thanks to these results IHP has been able to enlarge the existing component library and to carry out process control and optimization, which resulted in improved reliability.

Important studies on the reliability of capacitive and resistive [RVSI09953- RVSI12044] micro-switches have been performed in the framework of International (EDA), National (ANR-FAME) and Regional (STAE-

SYMIAE) projects. In micro-switches, mechanical contact between movable free thin films and electrodes (dielectric or metallic) is performed under weak forces (<< 1mN) and the surface roughness affects the contact quality. The nano-scale roughness description is then necessary to understand the failure mechanisms of these components. The main results have been obtained on nano-scale characterization of dielectric charging under high electric field generally used for the micro-switch actuation [RVSI11286-RVSI11287-RVSI11285-RVSI11544]. LAAS was one of the first labs in the world introducing AFM tool for both charge injection and charge evaluation versus time. These studies allowed the identification of the keys parameters that govern the dielectric charging, including the influence of the environment (humidity, gas …) and the coupling between electrostatic forces and the formation of the water meniscus at asperities. These works have been performed in collaboration with B. Bhushan, head of "Nanoprobe Laboratory for Bio- and Nanotechnology & Biomimetics" (Ohio State University) and with Prof. Papaioannou (NKUA, Greece).

Another solution to achieve agility concerns ferroelectric materials. In particular, innovative and state of the art implementations of doped Barium-Strontium-Titanate (BST) based thin dielectrics with record low losses (tanδ <1.5% @10GHz) have been carried out, in collaboration with leading laboratory in the field of material synthesis (CNRS-ICMCB -Bordeaux) and a major industrial processing and integration provider (ST-Microelectronics-Tour) in the framework of ANR-ABSYS2 project. This material can provide extremely high tuning range (>70% @10GHz) with relative permittivity ranging from 100 to 400 at 15V and 0V respectively [RVSI13503]. Thanks to these superior features we demonstrated variable capacitors showing measured tunability of 72% under 0-15 V bias and tunable filters featuring a tuning of 88% (657 MHz-1235 MHz) of the filter center frequency and an almost constant fractional bandwidth of 30% upon the application of a 0-15 V bias. The insertion loss is between 5.8 and 3.2 dB, and the return loss is better than 9 dB [MAI13276]. These very promising performances open the way of reconfigurable circuits into the millimeter band, which will be at the core of future activities.

2.1.2 Antenna Miniaturization

Reduction of antenna size, while keeping high radiation performances, is a crucial challenge in a lot of wireless communication systems to improve their integration. In our research work, highly irregular, space-filling or folded patterns are investigated for designing innovative small antennas with high radiation efficiency. These patterns have been specifically applied to helical antennas, spiral antennas, retrodirective antenna sensors and beam forming Networks of multibeam antennas.

Helical antennas (from few 100MHz to few GHz) are extensively used in satellite systems for their naturally pure circular polarization as it avoids polarization tracking. Different pattern techniques have been used allowing size reduction between 40% and 70% [RVSI10579]: a single sinusoidal pattern [BR1203], a superposition of sinusoidal patterns, a superposition of fractal and Euclidian patterns.

Spiral antennas are particularly used in wide band applications as its offers a good compromise between size and performances with also the advantage of circular polarisation. The main challenge in UHF-VHF applications is to reduce the lowest operating frequency while keeping constant the antenna size. By stacking, below the antenna plane, resonant metallic rings with highly irregular and space-filling contours we obtained a 30% reduction of the lowest operating frequency while keeping constant the antenna size [MAI11787,BR1201].

Retro-directive antennas, due to their self-steering capability, present an excellent candidate for passive antenna sensors with robust performance under a wide range of reader-sensor orientation scenarios. However few implementations can be found in literature addressing compact and multiband retro-directive antennas that offer broader readability band for RFID technology. We reported the first millimeter-wave passive Van Atta retro-directive antenna array with enhanced Radar Cross Section (RCS) using Substrate Integrated Waveguide (SIW) technology. The double-layer configuration is exploited to obtain a more compact design while providing the same re-radiated pattern of the corresponding single layer configuration. Measured results have shown more than 10 dB enhancement in the monostatic RCS of the passive retrodirective tag over an angle of ±60°, compared with the equal-size reference rectangular metallic sheet.

Multi-beam antennas (MBA) have become a key element in nowadays wireless communication systems where increased channel capacity, improved transmission quality with minimum interference and multipath phenomena are severe design constraints. In order to reduce the number of reflectors associated with MBA in communication satellites, Multiple Feed per Beam (MFB) focal arrays are good candidates. We developed an original compact BFN for feeding a Ka-Band multiple feed per beam focal array. This BFN is composed of tri-dimensional interleaved couplers made of circular waveguides and interconnected by thin radial rectangular waveguides. The gain (15dB) obtained is higher than the gain provided by the Single Feed per Beam (SFB) focal array having analogous size [RVSI14188].

2.1.3 Carbon-based RF Components

Since 2006 MINC has engaged an original research program (FP6-AMICOM 2004-2008 and then LEA-Smart MEMS 2009-2011) aiming to explore the fundamental capabilities of carbon nanotubes (CNT) and graphene at microwave and millimetre waves. Most of the activity dealt directly with either inkjet printed randomly distributed CNT or with "ordered" CNTs. The aim was the miniaturization and enhancement of basic RF functionalities (interconnections, detector, filters, phase shifters,…). MINC research focus was moved then to an emerging carbon based material such as the graphene (FP7-NANORF 2012-2015). Being flat, hence more compatible with conventional planar technologies, and commercial availability, it provided a very fertile ground for experimental investigation. The focus on graphene for microwave applications was the original aspect of the research at LAAS back in 2010, since most of the interest worldwide was rather devoted to the DC and the optical properties.

The activities carried out at LAAS on graphene focused essentially on three topics that represent the major challenges for the development of graphene based devices: i) the transport at the metal-graphene contact interface, ii) the transport mechanisms (diffusive vs ballistic) within the graphene and from DC to millimetre-wave, iii) the effect on transport due to dielectric surrounding material or pollutant agents. As a matter of fact, the doping operated on graphene by the contact with metal may result in a prohibitive series resistance [MAI13235]. At the same time graphene's record high mobility enables the so called ballistic transport based electronics for which important modelling achievement have been carried out at LAAS in collaboration with FORTH (Greece) and UPM (Italy) [RVSI12357]. For what concerns the effect of surrounding dielectric material and/or pollutant agents, their main role is to introduce defects or scattering centers, which reduce mobility and hence overall speed performances. Analytical modelling of these phenomena is the subject of a fruitful collaboration with UPM (Italy) [MAI11757]. Ballistic capabilities has been explored to demonstrate an original Y-Branch Junctions zero bias detector, successfully working with signals up to 50GHz with a maximum response at 10GHz (the device is theoretically capable to work in the THz range). The response measured at room temperature show a linear response in the measured power range (-40dBm – 0dBm) and a sensitivity as high as 10 Volts/Watt of input power.

2.1.4 Reliability and Noise of Wide Bandgap Technologies

Investigations on new wide bandgap devices for Ku-Ka band applications (20-30 GHz) have been developed on AlInN/GaN technologies (ANR project "Genghis Khan"). Electrical and noise characterizations have been performed with cross analyses between several technological alternatives. Frequency dispersion of small-signal parameters has been evidenced over a very large frequency range for the first time, and an analytical modeling method has been proposed to account for these effects [RVSI13081].

The use of low frequency noise (LFN) measurements during the application of a stress can stand as a very powerful non-invasive technique to track the evolutions of the defects potentially involved in the degradation of the performances of electron devices dedicated to high frequency and high power applications. Within the ANR "ReAGAN" project (UMS and Thales RT foundries), we have evidenced the effects of the leakage current on virgin and aged devices, through the analysis of lag on gate and drain terminals, as well as the LFN associated signatures [MAI13499]. An original method has been proposed to accurately extract the Schottky diode parameters [MAI12707]. It is obvious that the gate leakage improvement represents the keypoint for enhancing the performances both at and after the application of a stress.

2.1.5 High Performance Microwave Inductors

Investigations on the development of a technological process for 3D integration of high quality components and interconnections have been carried out. We have developed a low temperature, low cost, multi-layer 3D copper interconnect process, based on standard photolithography and electroplating techniques (BPN and SU8 photoresists), which avoids wire-bonds, through-die via and micro-bumps. This process is ideal for System-in-Package, Wafer-Level-Packaging and above-IC passive integration, such as 3D solenoidal or toroidal inductors and transformers [RVSI13617, MAI11005, MAI11522, MAI12440]. As an example of result, this process demonstrates the integration of high-Q power inductors (55 @ 5 GHz) above a 50 W RF power LDMOS device (Figure 1).

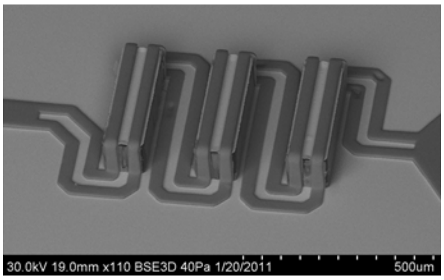


Figure 1: 3D Solenoidal-type Microwave Inductor

This original technological process has been patented [BR1005] (see also salient facts) and is at the origin of a start-up company (3DiS Technologies) which was selected by the incubator Midi-Pyrénées in October 2012, and was awarded within the emergence competition of OSEO in June 2013.

2.2 Complex RF Circuits

2.2.1 Low Noise Microwave Circuits and Systems

Cyclostationary noise has been investigated in various RF devices. Particularly, the shot noise in diodes pumped by an RF signal has been carefully studied and it has been found that the classical approach (taking into account the average current) is not valid to describe this noise contribution under cyclostationary conditions. A more appropriate formulation of shot noise under nonlinear conditions has been proposed [RVSI09684]. These fundamental studies lead to improved CAD approaches and, as an example, have been used to simulate a 3.5 GHz sampling phase detector circuit (Thales Alenia Space contract), which is involved in PLL systems. The noise contributors in this circuit have been clearly identified [MAI09392], and the circuit phase noise has been successfully simulated, in spite of the circuit complexity (five active devices) and the high level of harmonic number on which it is operating (10 to 40). Then, the noise and the long term reliability of the sampling phase detector have been improved thanks to the substitution of the noisier active device for a less noisy one.

2.2.2 Millimeter Wave Integrated Circuits

The simulation and optimization of relatively complex circuits at millimeter wave frequencies is a difficult task, which mixes electromagnetic and circuit modeling. This is even more difficult if the active devices are operating close to their intrinsic limit in frequency, which is the case in the circuits we have realized for automotive applications near 77 GHz.

As an example, a 77 GHz NMOS resistive ring mixer has been integrated using a 130 nm process of ST Microelectronics (ANR project “VELO”). Thanks to a specific design methodology, the mixer accommodates with MOS device frequency limitations to provide state-of-the-art performances in terms of noise figure: NF = 6.5 dB for 15 dB conversion gain [MAI09311] (Figure 2).

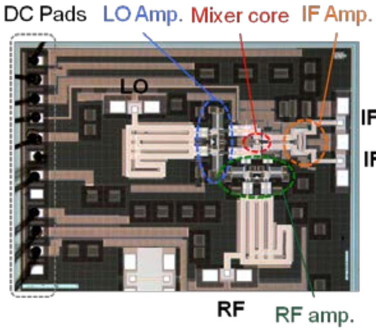


Figure 2: 77 GHz NMOS Resistive Mixer (NF = 6.5 dB)

2.2.3 Mixed Analog and Digital Integrated RF Circuits and SoC

Mixed analog & digital circuit design is one of the key of success for highly dense and reconfigurable integrated RF circuits. Our work in this field has been focused on the modeling and design of some original frequency synthesis approaches. The state-of-the-art background we now have on high frequency Direct Digital Synthesis (DDS) has led us to register a third patent, which extends to low cost CMOS technologies the capabilities of increasing frequency and decreasing consumption we had previously demonstrated in a BiCMOS-DDS.

A first work (FUI “FAST”) focused on the closed loop fractional frequency divider to allow high resolution steps in an avionic transceiver communicating with satellites, whereas in a second work, we optimized also the phase/frequency detector to improve the frequency spectrum purity of the whole synthesis (by minimizing both spurious and phase noise) for spatial applications (TAS/CNES project).

We mostly use in these integrated systems standard BiCMOS technologies on which we apply original approaches to overcome their limitations, by design or by post-process above-IC techniques [CIN11016, OPI12358]. By mixing both analog and digital circuit, we are able to take full advantage of each. For example, we designed a patented state-of-the-art DDS, which was the first one on a BiCMOS technology to work beyond the RF domain (> 5 GHz) together with a reduced consumption, and able to generate UWB-like impulses [BR0908]. This result could be obtained on a standard 0.25 µm BiCMOS technology, thanks to a new design technique, which replaced a power hungry and frequency limited phase-to-amplitude converter from the digital domain to the analog one. This technique allowed us to dramatically drop the consumption from a few watts to only a third of watt. The drawback was that only square, triangle and sine waveforms could be generated, which are yet the most interesting ones. Since then, many high frequency DDS have been designed in BiCMOS by the worldwide scientific community, many of them being inspired by our work to lower the consumption. They all exhibit the same limitation of generating only a few waveforms. Our more recent activities were done to overcome this limitation. We partially did it in 2010 with the design of a reconfigurable BiCMOS-DDS, which adds in a very simple manner a Gaussian shape to be generated as well as the square, triangle and sine shapes [MAI11196]. This result allows, for example, the generation of true UWB impulses. In 2012, we fully broke the limitation on the obtainable waveforms with a completely new topology adding the arbitrary waveforms generation capabilities of standard low-frequency high-consumption DDS. Furthermore, this topology is fully compatible with CMOS-only process. This full-featured high frequency CMOS DDS has been patented in 2012 [BR1103]. We also worked at improving the performance of more standard PLL, regarding resolution and spectrum purity. Based on our knowledge about DDS, a DDS-based fractional frequency divider has been developed to improve both the frequency resolution and spurious generation when used in the feedback loop of a PLL [MAI11146].

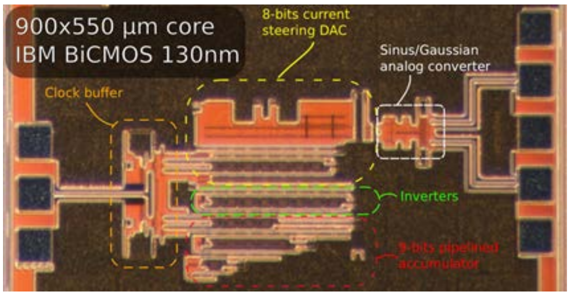


Figure 3: 16 GHz Clock Frequency Direct Digital Synthesizer (DDS) with Signal Shaping Stage for Sinusoidal or Gaussian Output

2.2.4 Embedded electronics for spatial applications

Earth observation from satellites with passive microwave radiometers needs an embedded precise calibration procedure. To this purpose, we have demonstrated the possibility to use an Active Cold Load (ACL) at L-band with a SiGe HBT (ESA and Astrium contract) [RVSI10013, RVSI10457]. A dedicated and ultra-stable radiometer has been realized to evaluate its long-term stability [RVSI11351] in the laboratory. The main performances of the ACL are a noise temperature less than 65 K and stability less than 0.35K over 4 months. In the continuity of this work, we have evidenced the presence of a relaxation process with very long time constant (up to 30 s) in microwave amplifiers, which degrades their gain stability. An original method has been proposed to derive an analytical expression of Allan’s variance to take into account this low-frequency noise source [RVSI11645].

Particle sensors based on micro-channel [RVSI14135] or semiconductor plates are used to detect and quantify both the density and energy of space particles (electrons, protons, heavy ions). The necessity to improve both spatial and spectral resolutions as well as noise performances requires the design of multichannel integrated electronics. As power consumption is an issue for space embedded system (also to avoid heating up the detectors close by), low power techniques should be employed. One of the challenge is thus to develop specific design methodologies (such as radiation hardening by design (RHBD)) that should be employed in order to go beyond the performances obtained by circuits designed using dedicated space technologies, without any compromise on the required radiation hardness level. For this purpose, we are exploiting standard CMOS technology in order to design ASICs dedicated to sensors. Our Analog Front Ends circuits are designed to perfectly adapt the readout circuits to each sensor and can operate in harsh environment. Firstly, technologies providing gate oxide thickness less than 10nm but thicker than 2nm should be chosen in order to be immune to total ionizing doze (tunneling effect) but also to be less prone to gate rupture phenomena due to heavy ions. In addition, such technologies allow an interesting trade-off between dynamic output range and bandwidth. Secondly, isolated technologies are preferred as they provide isolating wells that can be used to temper latch up events. Finally, specific layout topologies are required. For instance, regarding switches, enclosed NMOS transistor (to reduce further leakage currents) should be used when PMOS transistors (inherently immune to parasitic current leakage) cannot fulfill the requirements. A 13 channel semiconductor sensor ASIC has been designed to fit the TARANIS (Tool for the Analysis of RAdiations from lightNIngs and Sprites) space mission. This ASIC is the readout circuit (including the analog front-end down to the analog to digital converter) for Si and CdTe semiconductor plate detectors. It can detect electrons with energy ranging from 50keV to 4MeV with an equivalent input charge noise of 3100e- and a power consumption of 3mW/channel, which is a threefold improvement compared to the current discrete approaches in terms of power consumption. A readout circuit for micro-channel plate detectors was also designed for observing solar wind. Such design is considered to be a serious candidate for future space mission such as Solar Probe + (NASA). It can achieve a total ionization dose higher than 360krad without any performance loss. This ASIC displays better performance than the Amptek A111, a commercialized noise optimized charge-sensitive CMOS amplifier for capacitive radiation detectors, used in most of universe observation missions.

2.3 Complex Wireless RF Systems

2.3.1 Advanced Computational Electromagnetics

Nowadays global electromagnetic simulators are indispensable for accurate predictions of the overall electromagnetic performances of radiofrequency systems. When it involves both large structures (in terms of wavelength) and fine details, the system is said multi-scale or complex. We developed two original approaches for rigorous electromagnetic simulation of such systems (Scale Changing Technique, Grid Computing) that provide very fast tools for the study of complex circuits and systems.

In order to overcome the limitations of numerical approaches, we proposed an original monolithic formulation for the electromagnetic modeling of multi-scale planar structures, called the Scale Changing Technique. This new technique consists of interconnecting Scale-Changing Networks, each network models the electromagnetic coupling between adjacent scale levels. The cascade of Scale Changing Networks allows the global electromagnetic simulation of multi-scale structures, from the smallest to the highest scale. Multi-modal sources, called Scale-Changing Sources, are artificially incorporated at all scale levels for the derivation of the network. This method has been applied with success to the design and electromagnetic simulation of specific planar structures such as reconfigurable phase-shifters, multi-frequency selective surfaces, discrete self-similar (pre-fractal) scatterers and patch antennas.

The modeling of obstacles in the propagation channel is often crucial for the optimization of link budget in wireless communication. A numerical tool is then necessary for the rigorous calculation of the electromagnetic scattering phenomena inside very large (or oversized) structures (tunnels, airplane cockpit and fuselage), containing large electrical size and complex shapes. Conventional full-wave electromagnetic simulation requires enormous amount of computational resources. We proposed a time-domain hybrid method based on computing domain decomposition (according to diakoptics procedure) for the rigorous calculation of the electromagnetic field inside a propagation channel with very large dimensions compared to the wavelength. This method has been applied successfully to propagation inside a plane cabin and homogeneous tunnel by performing the simulation on a Grid Computing (Grid5000 French platform), [RVSI09479, MAI12115].

2.3.2 Radio-localization

The objective is to develop new technological solutions for low cost and portable reader systems allowing radio-localization for different applications.

The first topic concerns the ground water detection for geophysical studies, particularly in rugged environments such as the arctic, desert, uneven mountainous terrains or space and is performed in collaboration with Electronics Research Institute in Egypt. We proposed an original technological solution for conformal and miniaturized radar systems to be rolled up in a “poster-like” container using additive printing technology. The proof-of-concept system performed the most fundamental operations of the FMCW radar including signal generation, amplification and correlation of the LO and RF signals for GPR frequencies. The simplicity as well as the multilayer/multimaterial capability of the proposed additive printing (fully printed passive, diodes, vias) combined with flexible mounting would enable the realization of highly dense interconnects as well as enhanced miniaturization and conformability of practical GPR systems of the future like wearable geodetection systems [MAI13703].

The second topic concerns the indoor accurate localization of objects for two different applications: the first application deals with the localization (with few cm accuracy) of objects by a robot to offer memory assistance and search/carry services to people (ANR-CONTINT-RIDDLE in collaboration with RAP team of LAAS) and the second application is about the localization (with few mm accuracy) of industrial parts for assembling (OSEO-SPHERE). We proposed a new simplified architecture for radiofrequency reader using an active/collaborative tag. It consists of applying a double windowing on the radiofrequency Local Oscillator signal of the reader. The measurement of the phase difference between the received signal VRF and transmitted signal VTX is performed by the means of an I/Q demodulator. From this difference the reader-to-transponder distance can be derived. A proof-of-concept experiment at 5.8GHz has validated the double windowing principle applied on Local Oscillator signal and has theoretically predicted standard deviation associated to the multiplicative noise generated in the RF-reader. The estimation of the localization accuracy versus the duration of the measurement is underway.

2.3.3 RF Energy Harvesting / Power Transfer

RF energy harvesting and Wireless Power Transfer (WPT) are very promising solutions that allow sensors, electronics and wireless smart systems to operate autonomous for energetic point of view.

RF energy harvesting techniques are based on the harvesting/scavenging of an ambient RF energy source that is converted in DC using generally a rectenna (microwave rectifier mainly composed of a Schottky diode and a RC low-pass filter serially connected with an antenna through a matching network). The major challenge is to provide high-efficiency design with an ultra-compact footprint and wide band behavior. Those requirements are more challenging for designs operating at high-frequencies (beyond 10 GHz) as required by the new emergent applications.

The studies performed are focused on satellite health monitoring applications (Ku-Ka band), by harvesting electromagnetic power available on the external body of broadcasting satellites. The designs are challenging related to the unavailability of high frequency accurate Schottky diode models and to the non-optimal load of the rectifier element (10kΩ). We validated the possibility to harvest more than 2mW of DC power using 18.6 dBi gain antenna [RVSI13445, RVSI14378].

Near-field Wireless Power Transfer (WPT) techniques have been investigated in collaboration with Continental Automotive SAS France for designing multi-functional inductive wireless power systems for automotive applications. The main challenge was to provide accurate and fast enough simulation models by integrating both electromagnetic and circuital simulation in a unique co-simulation methodology [RVSI09335]. These models are now used in routine chart flow by Continental.

These researches are performed in partnership with CNES, Thales Alenia Space and Continental Automotive. Since October 2013, A. Takacs leads the new created working group WG 4.1 “Space Applications” within the COST action IC1301 WiPE (Wireless Power Transmission for Sustainable Electronics).

2.3.4 Wireless Communication Board for Active Sensor Networks

Active Wireless Sensors use a transmitter unit (integrated with the transducer) to transmit the information to the reader. Products are already commercially available using micro-transducers, analog and RF integrated circuits and transmission protocols as Zigbee, Wifi, Dash… A lot of research projects are performed to increase the performances of these systems but the majority of them are focused on existing technologies. These systems are limited today in numbers of real nodes able to be deployed and on their autonomy. Moreover, protocols like ZigBee, for example, address the case of communicating sensors from time to time; in that case the protocol is (more or less) low power. The case of massively wireless communicating sensors in real time with need for synchronization like in the industrial tests and the measurements applications, is not at all taken into account by that protocols and circuits.

We are focused on the system and network development to be able to pass from some wireless communicating sensors to a real wireless sensors network. We proposed a new approach from system and protocol point of view, co-developing software and hardware technologies in order to obtain reconfigurable physical layer upon the constraints applications and a reconfigurable MAC layer including new services like clock synchronization and localization, and later, beam forming algorithms.

We developed an energy efficient (150mW for high data rate up to 500 Mbps which means an energy/bit of 0.3nJ/bit) wireless communicating node with precise synchronization (<1ns, previous state of art established by MIT). The reconfigurable physical layer is based on 60GHz IR-UWB concept and the transceivers have been design in 65nm CMOS technology. The physical layer was coded in the Wireless Sensor Network (WSN) simulator and the main parameters of IR-UWB radio interface can be configured for each communicating node of the WSN. Flexible substrate heterogeneous integration potentialities for the complete wireless communicating nodes were studied and first results are very promising (losses < 1.1dB at 60GHz for flip-chip interconnections) [RVSI12476-RVSI11463-RVSI11511].

We participated to the European Flagship project “Guardian Angels of a Smarter Life”, that was pre-selected in 2011. We also coordinated a French Flagship project NANOINNOV-NANOCOM (2009/2011) on “Networks of reconfigurable communicating Nano-objects”. Internal collaborations with LAAS-ESE team that is focused on Energy Management are also in progress to develop integrated wireless sensor platform (Project CHIST-ERA-SMARTER 2013/2016).

2.3.5 Wireless Chipless Passive RF Sensors

For several applications (long life time, poor accessibility) autonomy is the main limiting factor for wireless sensor. To overcome this problem passive (without communication unit), battery less sensors, are studied for many years (RFID sensors, SAW sensors). But the main drawback of this kind of sensors is their low interrogation distance (lower than 10m).

In 2005, we started researches on millimeter-wave electromagnetic transducers with radar interrogation to overcome the limitations of classical passive sensors. These sensors are based on the variation of a given electromagnetic wave descriptor by the quantity to measure. The main advantages of this kind of passive sensors are unlimited energy autonomy, a full compatibility with harsh environment and higher interrogation distance. A millimeter-wave carrier frequency (few tens of GHz) has been chosen because it allows the sensor/antenna sizes reduction, the design of directional antennas, and provides higher bandwidth and better immunity to multi-paths. Electromagnetic transducers are mainly composed of a variable RF impedance or RF resonator connected to an antenna. Several concepts are possible to realize a sensor but we have chosen coupling principles that provides very high sensitivity.

Membrane displacement has been used for the development of pressure [RVSI11457], temperature [RVSI12468], stress [RVSI13195] and radiation [MAI13532] transducers. Temperature transducer principle using thermal dilatation of metallic [MAI11788] or dielectric [RVSI12839] fluids in micro-channel has been also validated. All of these transducers display state of the art (or above) sensitivity and several of them were the first published in the world (pressure in 2007, fluidic temperature in 2011, radiation in 2013).

FMCW (Frequency Modulated Continuous Wave) Radar has been chosen for the wireless interrogation. This kind of Radar is simpler than UWB (Ultra Wide Band) Radar and is more compatible with high interrogation distance. FMCW radar is used to measure the RCS (Radar Cross Section) variation of the target that is done generally by the transducer connected to an antenna [MAI12810, CII13494]. This technique has been successfully applied to the wireless interrogation of the different transducers described previously and has been validated for interrogation distance up to 20m with 20mW input signal and 14dBi antennas. These results have been obtained without complicated signal treatment showing that interrogation distance of several ten of meters may be achievable with efficient noise filtering. The main drawbacks of this technique based on echo level are the low accuracy (around 10% of the full scale) and the sensitivity to parasitic signal attenuation that involves the use of reference sensor. These drawbacks can be overcome with FCMW radar able to track the frequency for which the RCS is maximal. Specific delay lines have been also used to create low frequency bar code for sensors identification [MAI10395]. In this case, the beat frequency difference between the antenna echo and the transducer echo will provide the identification. We evaluated to 30 the number of different sensors that can be identified in a given direction by the same radar.

2.4 Optoelectronic Systems

2.4.1 Microwave Generation Using Optics

Optical devices have some specific features, which may enhance largely the system performance when well-chosen optical technologies are introduced in a microwave system. As an example, microwave signals can be easily distributed through fiber optics, which are smaller and lighter than coaxial cables, and feature other advantages such as wide bandwidth, low losses and interference immunity. Probably more interesting for applications, optical resonators overcome largely microwave resonators in terms of quality factor, even when the frequency difference between microwave and optics is taken into account. Our goal is therefore to take benefit of these advantages to design low phase noise microwave and millimeter wave signal sources based on optical devices. Our approach relies mainly on the use of ultra-high Q optical resonators, and also on our ability to model and reduce the noise contributors in these microwave optical systems.

The noise is modeled thanks to the noise measurement of all the system active devices, such as lasers and photodiodes, and using these measured data in a CAD software. The modeling approach has been developed during H. Brahimi PhD and firstly used to model a microwave frequency discriminator based on an optical delay line [MAI09497]. It has been more recently improved with a precise modeling of fast photodiodes. Firstly, the 1/f noise of a laser illuminated InGaAs photodiode has been measured for the first time, thanks to a proper cancelation of the laser noise [MAI13317]. Secondly the ability of the photodiode to realize the conversion of the laser amplitude noise into RF phase noise has been studied and modeled thanks to a nonlinear delay element included in the photodiode model [MAI14334].

Concerning the investigations on ultra-high Q optical resonators, we have successfully designed and precisely measured optical fiber ring resonators with Q factors in excess of 10^9, or even 10^{10} [MAI13564], thanks to a completely new frequency domain analysis. This approach is first based on locking the laser on one mode of the resonator, thanks to an electrical feedback loop (Pound Drever Hall technique), and then uses an RF modulation of the optical carrier to characterize the optical side-modes. It has also successfully been used to characterize the Q factor of whispering gallery modes (WGM) in 3D disk resonators realized at CNR-IFAC (Florence, IT) with polished monocrystalline materials [RVSI12354].

In a second step, these resonators have been included in various optoelectronic oscillators (OEO). The resonator based OEO is a complex system in which two control loops are involved: a low frequency loop, which stabilize the laser on the resonator, and a high frequency loop which maintains the microwave oscillation. However, even if it is more complex, the resonator approach is much more compact and efficient than the older technique based on fiber optics delay lines (Figure 4).

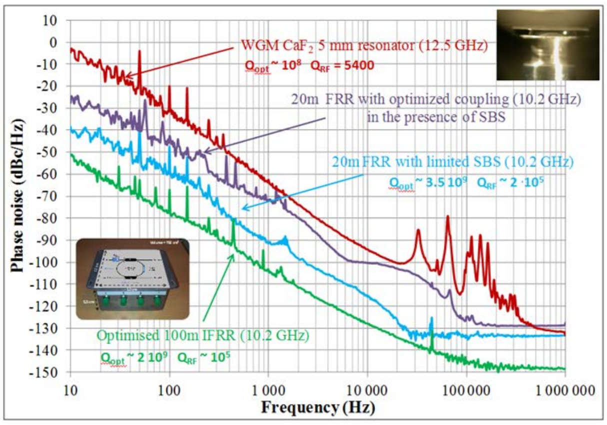


Figure 4: Phase Noise of Optoelectronic Oscillators (OEOs) Realized with Fiber Ring or WGM Disk (CaF2) Resonators

An OEO based on 3D disks WGM resonators has thus been realized and measured [RVSI12354]. However, the best phase noise results have been obtained on OEOs based on ultra-high Q fiber ring resonators (FRR). The noise in these systems has been studied thanks to our original CAD approach [RVSI13322]. This approach can predict the nonlinear noise conversions in the OEO, and particularly the conversion of the laser noise (AM and FM) into RF phase noise. However, even if some of the OEO behaviors could be successfully explained with this approach, such as the effect of a shift of the laser lock from the resonance center, it has become clear that other types of noise have to be taken into account to describe the OEO phase noise. Particularly, the high optical power level inside the resonator (due to the ultra-high Q) is responsible for optical noise and nonlinear phenomena, which have a strong effect on the OEO performance [RVSI12712, RVSI12050]. Thanks to the understanding of these phenomena, a new system has been designed featuring a phase noise level of -128 dBc/Hz at 10 kHz offset from a 10.2 GHz frequency, together with a very low spurious free phase noise floor of -148 dBc/Hz [MAI12411]. Taking into account the relatively short length of optical fiber involved in this OEO (100 m fiber ring resonator), this performance corresponds to the state of the art.

Apart from oscillators, the microwave optical approach has been used to realize the high quality filtering of microwave signals on an optical carrier thanks to coupled FRR [RVSI12355] and the generation of millimeter wave signals, up to 80 GHz. The techniques proposed to generate millimeter waves with optics were based either on the use of the modulators nonlinearity [RVSI11699] or on a cascade of stimulated Brillouin scattering effect up to the seven order in a fiber ring resonator [MAI12342].

The work in the microwave optics field has been performed in the frame of different contracts: ANR “ORA”, ANR-ASTRID “MINOTOR” (DGA), CNES, European Defense Agency “ARAMOS”, Thales and Region Midi Pyrénées.

2.4.2 Optical Interferometry Systems

In what’s called the Internet of Things, we investigate sensorics through the physical limits and performances of real-time remote embedded optoelectronic sensors (accuracy, signal to noise ratio, bandwidth, robustness in harsh environments, long term measurements…) from solid targets to fluidics. Our research is paving the way to functional diversification of sensing devices by migrating from the system board-level into a particular package-level (SiP) or chip-level (SoC) system solution, according to the More than Moore concept (analog and mixed signal design technologies for sensors, new methods for co-design of SIP and biotechnology).

We are mostly investigating new interferometric-based measuring systems. First, we are designing **fiber optic sensors (FOS)** based on as an extrinsic fiber Fabry-Perot interferometer used as a metrological tool for remote long-term displacement measurements with nanometric accuracy, for applications requiring sub-wavelength detection and when the measurand evolves very slowly. We have designed a 3 km long FOS with a patented dual modulation scheme to the laser current to induce a virtual reference displacement signal for continuous quasi-static measurements with directional determination. Real-time algorithms permit automatic quadrature phase error correction, which can occur during large displacements, compensation of source intensity variations and noise reduction. Moreover, an innovative sensor probe configuration relaxes the alignment tolerance to ~±1° [RVSI12774]. During calibration procedures carried out without any temperature control, the FOS exhibits a resolution of 70 pm and a precision of 2 nm over a frequency range of 10^{-3}-500 Hz, together with a displacement dynamic of at least 10^5 (10 nm – >1 mm). After testing this FOS for monitoring the crystallization of opal films [RVSI12294], the main targeted application is Earth strain detection in geophysics. Based on our FOS, 3 novel instruments have been designed, deployed to an underground facility in Vaucluse and are remotely operating continuously since March 2012. The instruments sensitivity permits to detect Earth tides (130 nm over 12 hr periods) as well as earthquake events worldwide. Our seismometer has demonstrated similar frequency bandwidth and background noise compared to the Streckeisen STS2 Broadband while offering the advantage of not being sensitive to electromagnetic interferences. Our borehole tilt-meter compared to the electrolytic LILY from Jewell, Inc, exhibits better precision and less system drift while concurrently being insensitive to environmental conditions. For our long baseline hydrostatic leveling sensor, compared to the capacitive device from FOGALE, noise levels are similar at the very low frequency range (~10^{-6} – 10^{-5} Hz) while towards the higher frequency region (~ >10^{-2} Hz), our instrument is at least 100 times better in noise performance. The detection limit of our sensor is ~10^{-11} rad for a 150 m baseline together with a long-term drift of < 40 nrad/month, including possible hydrostatic loading/unloading effects (Figure 5).

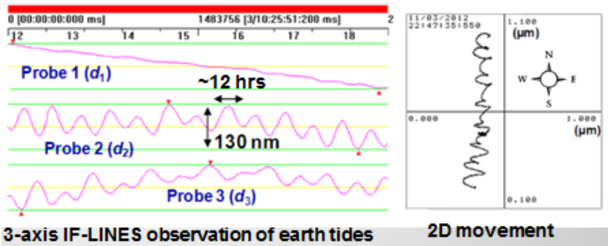


Figure 5:Detection of Earth Tides: Amplitude is Varying of 130 nm Every 12hrs

We are also exploiting the **optical feedback interferometry (OFI)** as such devices prove their interest in terms of sensitivity and resolution. OFI allows the laser diode to be used as a stand-alone micro-interferometer, i.e., by incorporating the light source and the interferometer in the active cavity of the laser itself without external optical components. However, they still offer nowadays a very limited versatility in their range of applicability. Even minor changes on the system specifications (bandwidth, range of measurements, accuracy,…) imply usually a complete redesign of the device [5]. Our strategy is then to provide relaxed constraints in the design of our embedded systems for a variety of requirements with the specificity of avoiding external optical components contrary to the usually

[5] S. Donati, Developing self-mixing interferometry for instrumentation and measurements. Laser & Photonics Reviews, pp 393–417, 2012.

proposed solutions[6]. To this end, performances of our sensing devices are first improved by modeling the physical behavior of OFI signals and by using a modular approach prone to hardware-software partitioning of our robust real-time signal processing algorithms with a specifically designed electronics. In particular, new theoretical approaches are needed for understanding the dynamics of OFI in complex and hostile environments like multiple scattering from heterogeneous diffusive medium or rough targets vibrating at the nanometric scale with fading due to the speckle effect. New associated designs are then required in OFI for critical applications such like: mechatronics (real-time vibration analysis for non-destructive testing, quality control), fluidics (sustainable energy, biomedical sensing) and detonics.

We have proposed a model to achieve sub-nanometric accuracy for displacement measurements [RVSI14019] before developing a new Phase Unwrapping Methods (PUM) generally limited to a 20 nm precision due to misinterpreted signal phase around OFI signal discontinuities [RVSI13507]. Using coupled delayed differential equations, we ensure that a truly bijective function between OFI signals and phase can be defined, thereby allowing to reach sub-nanometer precisions. As the coupling target-laser feedback factor C is continuously changing the OFI signal shapes, it is also a major cause of accuracy loss [XRVS245]. We proposed a global optimization performed on only a fraction of the collected sample to follow the evolution of C. Real-time measurement of C has been developed to perform autofocus on the target with adaptive optics [RVSI13200]. By performing data fusion (phase and gain) with a solid-state accelerometer (SSA) to correct the influence of parasitic movement of the OFI sensor itself, we have patented and designed the very first embedded OFI vibrometer [XRVS240]. Even when subject to extraneous movements, our vibrometer provides accurate measurements (40 nm) limited by the accuracy of the SSA itself. Including a real-time patented solution based on Hilbert Transform to remove the influence of the speckle effect, we can reconstruct measurements in the time domain - even in case of strong fading of the amplitude of the OFI signal - with all sorts of non-cooperative targets from very rough (sandpaper) to dark (back side of a mouse carpet). Lastly, we have coupled the vibrometer with optical fibers for studying dynamics of material subject to an explosion (pressure 100 GPa, rising time 0.5 µs, stored energy 70kJ, load voltage 85kV). We measured during the first 5 µs a displacement of a target presenting a velocity of 2000 km/h, with a 2 GHz photodiode.

OFI flowmetry is achieved with the laser directly used as a probe in a complex heterogeneous medium (like the skin). A photon is not reflected by a single particle in the flow but suffers from multiple reflections before being re-injected into the laser cavity. The obtained signal includes a whole spectrum of frequencies (spread Doppler frequency shift). Moreover as the amount of power back-scattered into the laser cavity by blood cells is low, it is necessary to extract from the OFI model the parameters that increase its signal-to-noise ratio. Our goal is first to investigate turbulent flows in microfluidics devices notably for helping noninvasive early detection of melanomatous skin cancer with rapid population screening and office diagnosis. Dermoscopy, MRI and ultrasound are of poor sensitivity for small and early malignancy. Optical Coherence Tomography has no contrast derived from cellular features for the early detection of melanoma and confocal scanning light microscopy is not portable. We have improved the spatial resolution of our OFI velocimeter with a two-lenses set-up to increase the local power density. Temporal resolution has been increased by dedicated signal processing with a frequency-meter coupled to auto-correlation (patented), instead of time-consuming usual FFT. Our OFI velocimeter is able to achieve flow measurement in a microscale channel with dimensions down to 20µm and for a velocity range from 2µl/min to more than100µL/min (due to the mechanical constraint on the channel). Real-time reconstruction of velocity profiles in micro-channels (down to 20µm) is demonstrated in different configurations (fluid viscosity, scatterers density, micro-channel section type…) [RVSI13003]. Our results have been compared advantageously with more mature technique such as dual-slit requiring at least 40s for one measured point and presenting several inaccurate measurements. Moreover, detecting very low concentration of particles like aerosols carried by fluid medium is a challenge notably for sustainable energy like windmill. Mechanical and ultrasonic anemometers do suffer from the perturbation in the airflow due to the windmill itself. LiDAR allows remote measurements but is expensive. We have then designed an OFI anemometer for measuring wind particles velocity, based on a general noise model (laser, photodetector, amplification circuit and acquisition). It detects a single particle of small diameter in the Mie diffusion regime where the ratio of emitted power to the back-scattered power can reach 10^9. Considering the high velocity of the scatterers and its ephemeral interaction with the laser beam, the high Doppler frequency is determined with a real-time embedded DFT algorithm and a threshold based algorithm, allowing detection of the Doppler signals out from the noise without averaging either in time or frequency domain. Developed with a French start-up, actual performances are more than 1 particle detection per second in any weather condition, for wind velocity up to 30 m/s implying signal acquisition and processing with frequency up to 100MHz at distances up to 7 m. Correlation of this anemometer measurement with classical anemometer is better than 99%.

By considering the relaxation dynamics of a long external cavity when several solutions to the steady-state equations can be obtained and a change in the laser-to-target distance can lead to a bifurcation in the set of solutions inducing a discontinuity in the modelled power of a laser diode, we demonstrated that high-frequency damped oscillations appear with a high-bandwidth acquisition electronics (100 MHz) instead of usual discontinuities. These transient phenomena in a single fringe contain information about the target reflectivity and absolute distance to the target paving the way to a brand new generation of OFI sensors [RVSI12738] (Figure 6).

[6] A Magnani, A. Pesatori & M. Norgia, Self-mixing vibrometer with real-time digital signal elaboration, Applied Optics, pp 5318–5325, 2012.

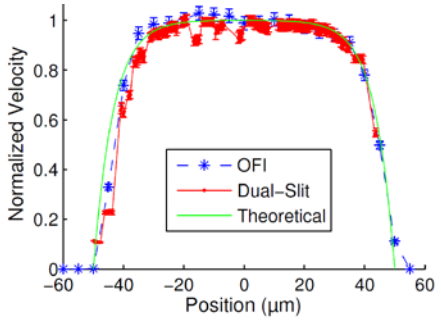


Figure 6: Velocity Profile in a µ-channel Theoretical (in green); Measurements with the Dual-slit Technique (in red, 40s by point) and with the OFI Sensor (in blue, real-time).

2.5 Photonic integration into systems

The research activity in photonics aims to make significant advances in two of the main challenges for the next generation of photonic systems, namely the development of multifunctional integrated photonic devices, and the integration of photonic components into systems. To address these two wide-ranging goals the work can be sub-divided into three strands. The first range of activities explores the development of engineered sub-wavelength materials their associated technological processing and modeling. A second and complementary research avenue focuses on the development of multifunctional integrated III-V-semiconductor optoelectronic sources[7]. Finally, the last but not least part of the activity aims to demonstrate the potential of micro-technologies and sub-wavelength optical elements for practical integration of optics in complex embedded systems.

2.5.1 Generic Approaches and Nanostructures

Generic electromagnetism-based device modeling: Our previous work on the tunability and the control of the emission wavelength in distributed feed-back (DFB) laser using photonic crystal defect waveguides has been extended to a more refined optimization of the photonic crystal (PhC) lattice. Finer control of the emission wavelength together with extremely high robustness towards optical feedback has been demonstrated on optically pumped PhC membrane lasers. These novel concepts have led to the current ANR grant "MIDAS" where the main objective is to integrate, on a single substrate, arrays of precisely tuned DFB lasers for multiplexed gas spectroscopy.

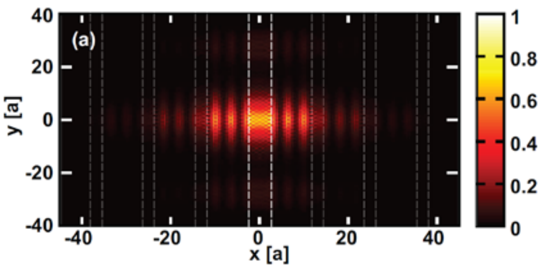


Figure 7: Stable Resonant field in a Microcavity made of 2 Mesoscopic Self-collimating Planar Mirrors.

We also extended our studies on laser cavity designs to structures that have no equivalent in usual integrated optics in the framework of the ANR GLAD and ANR CLAC programmes. In the ANR GLAD project we studied the effects of order and disorder in PhCs with the aim to demonstrate laser emission based on the diffusion in medium with high disorder. The key idea was to take advantage of nanotechnology to design, parameterize and strictly control strongly disordered active media. This study led to the demonstration of random laser action in diffusive medium and opened the way to new studies on the impact of nanopatterning of active medium. The ANR CLAC programme aimed to exploit a refractive effect in PhC, called self-collimation, which allows the propagation over arbitrarily long distances of narrow beams without diffraction or distortion. The main objective was to design a laser cavity based solely on this unusual guiding phenomenon to overcome the conventional trade-off between high-volume (high-power) and high-brightness lasers. In collaboration with E Centeno (LASMEA, Clermont-Ferrand) we have demonstrated a new kind of self-collimation in mesoscopic PhCs and have developed a model to easily study light beam propagation in these complex, multi-scale structures [RVSI12023]. This has opened a new field of research to investigate the wide potential of these mesoscopic self-collimating PhCs. In a collaboration with V. Petruzzelli team (Politecnico di Bari, Italy), we explore the design of novel integrated waveguides, tapers and cavities entirely based on mesoscopic self-collimating PhCs [RVSI14084].

Epitaxy: we have focused on molecular beam epitaxy of the emerging bismide alloys. We have grown GaAsBi thin layers and quantum wells (QW), which are elastically strained for Bi contents up to 4 % and 7 % respectively with photoluminescence emission at room temperature. In particular, an emission peak at 1.23µm has been achieved for the 7% Bi QW which is the state of the art [RVSI13554]. The effects of rapid thermal annealing have been investigated, showing that Bi diffuses easily from the well into the GaAs barriers.

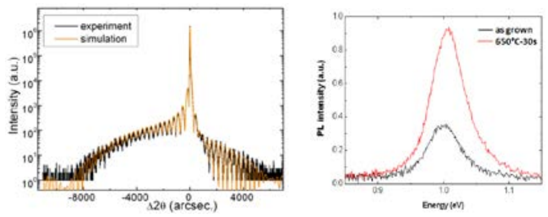


Figure 8: 7% Bi Ga(As,Bi)-GaAs Quantum Well: Measured and Simulated X-ray Diffractograms; Room temperature Photoluminesence Spectrum Before and After Optimal Rapid Thermal Annealing.

Within the framework of our collaboration with the LPCNO, the time-resolved and spin properties of these alloys have also been investigated, leading to publications [RVSI13010, RVSI13281] and emerging collaborations with European partners of the COST MP0805. In parallel, we have exploited the skills and techniques which were developed in the GHISO FP5 project (ended in 2001) to grow (111)B oriented multi-quantum well structures, to demonstrate with the LPCNO, a drastic increase of the electron spin relaxation time for (111)B GaAlAs multi-quantum-well structures [RVSI12390, RVSI11499]. This has allowed our partner to

[7] M. Smit, An introduction to InP-based generic integration technology, Semicond. Sci. Technol., 29, pp 083001, 2014

demonstrate for the first time the electrical control of the electron spin diffusion length in a semiconductor nanostructure [RVSI13388]. We are now exploring the potential benefits of using (111)B elastic strained GaInAs QWs rather than lattice-matched AlGaAs QWs. Finally, we have demonstrated regrowth on nanopatterned surfaces and developed efficient alternative methods to clean processed GaAs surfaces. Striking recent results are the room temperature emission of a GaInAs QW grown only at 15nm from the regrowth interface and localization of InAs quantum dots along nanopatterned ribbons [RVSI13554]. Moreover this regrowth expertise has been applied to demonstrate free-engineering shaped oxide apertures (see Figure 9).

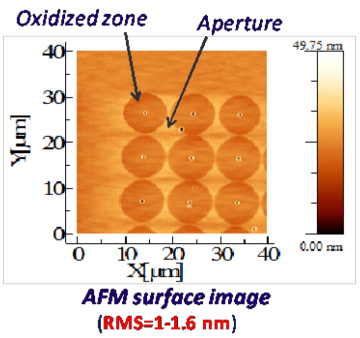


Figure 9: Atomic Force Microscopy Image of the Surface of a Regrown AlGaAs/GaAs Sample after Partial Oxidation Patterning

Technological basic building blocks: the technology of selective oxidation is one of the most versatile method for electrical and optical confinement in an ever increasing number of photonic devices. We have achieved several technological breakthroughs by demonstrating the fine control of the process on several III-V semiconductors and different photonics structures (VCSELs, high contrast gratings, low-loss waveguides for non-linear optics). Another important breakthrough was the demonstration of the use of this oxidation technology on GaSb-based platform, either by oxidation of lattice-matched AlAsSb alloys [8] or by oxidation of metamorphically-grown AlGaAs layers [RVSI11157]. Additionally, we have proposed and successfully applied a new method to perform the oxidation that keeps the surface of the sample intact and planar (i.e. does not require the etching of a mesa as in the conventional lateral oxidation which would definitely define the shape of the oxide area) which, in turns, opens up the path to more versatile structuration of the refractive index and electrical properties in not only in two dimensions but even in three dimensions [RVSI12042, RVSI14069]. These different demonstrations have contributed to place our group as an internationally recognized leader of the III-V oxidation technology.

2.5.2 III-V Nanophotonic Devices

Integrated III-V devices for high-performance operation: improving carrier injection uniformity in broad-area surface-emitting lasers is one of the main challenges for the fabrication of high-power high-efficiency electrically-pumped VCSELs. At the end of the FunFACS STREP FP6 European project, we demonstrated the interest of surface transverse patterning for power enhancement in these devices thanks to localized surface etchings combined with ITO transparent electrodes. These results were successfully compared to those given by a comprehensive electrical modeling tool developed for carrier uniformity optimization [RVSI10079]. The control of the VCSEL output is also a key element to improve VCSEL integration in optical systems. To that extent, we have demonstrated with the N2IS team, a novel method to create self-written focusing polymer microtips on VCSELs in collaboration with IS2M, Mulhouse and ICD-LNIO, Troyes in the framework of the NIR-Optics ANR project [RVSI10404, RVSI11569]. These studies are now being pursued within the MICA team for biomedical and sensing applications and are therefore detailed elsewhere (MNBT thematic research area).

Realizing that, like for doped-dielectric lasers, the emission properties, characteristics or performance of semiconductor lasers could be extended by the addition of nonlinear effects, the team's above-described strengths and capabilities in design, growth and processing are being drawn together to investigate novel methods to integrate and induce useful nonlinearities in semiconductor laser diodes. In a first instance, the specific target will be the generation of optical frequency combs using an all semiconductor technology. If successful, the demonstrated devices may find applications in metrology, telecommunication synchronization, high-purity RF synthesizers, astronomical calibration, advanced spectroscopy…. The considered approach is unusual in that it aims at using intra-cavity Kerr-effects in a micro-ring configuration [9]to generate this frequency comb rather than the saturable-absorber-induced mode-locked operation as exploited in more conventional devices [10]and may thereby overcome the dispersion and gain bandwidth limitations associated with the latter devices. The basic (waveguide) design tools and rules as well as the technological process sequence have been established and have led to a successful first fabrication run of passive devices[4]. The test and application of the devices in the striving microwave photonics area is planned.

Sub-wavelength structuration in optoelectronic devices: integration of subwavelength structures in active photonic devices was developed along two main axes. The first one concerns the development of intracavity PhC elements to enhance modal selection in edge emitting lasers. A full mix and match process of ridge lasers with intracavity mirrors was developed in the framework of the CRISPI project and successfully applied to GaAs and GaSb laser diodes fabrication. Laser diodes emitting from the edge at a wavelength of 2.3µm with high side-mode-suppression ratio have been demonstrated and successfully used for gas trace detection [RVSI12086]. In the following ANR P2N MIDAS project, we are now investigating the demonstration of all photonic crystal DFB laser diodes for gas detection, with a strong effort on high-aspect-ratio deep-etching of high Al content GaSb materials.

[8] O. Blum et al., Wet thermal oxidation of AlAsSb lattice matched to InP for optoelectronic applications, Applied physics letters, 68, pp3129-3131, 1996

[9] T.J. Kippenberg et al, Microresonator-based optical frequency combs, Science, 332, pp 555-559, 2011

[10] C.T. A. Brown et al, Compact laser-diode-based femtosecond sources, New J. Physics, 6, pp 175, 2004

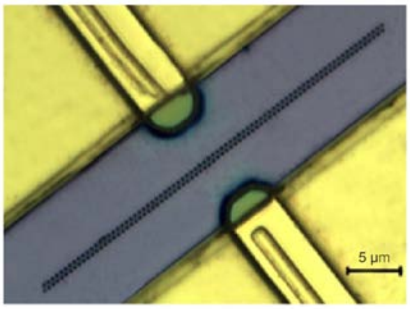


Figure 10: PhC Intracavity Mirror on a GaSb Ridge Laser Designed and Fabricated during the CRISPI Project.

A second strand of research was devoted to mid-infrared VCSELs exploiting high-contrast (photonic crystal) mirror structures. We have proposed and developed the AlOx/GaAs combination as a new material system to make high-contrast grating (HCG) mirrors. In the mid-infrared range, the replacement of conventional Bragg mirrors by HCG mirror opens different advantages in terms of fabrication and performance[11]. During the ANR MARSUPILAMI project, in collaboration with IES Montpellier and Supélec Metz, we have developed and fabricated a new kind of VCSEL by implementing on the mid-infrared GaSb-based structure [12] (Figure 10), advanced functionalities of HCG mirror combined to lateral electrical and optical confinement. We have then demonstrated for the first time, the fabrication of an electrically pumped mid-infrared VCSEL embedding a sub-wavelength diffractive structure and an oxide-based lateral confinement element [RVSI13372].

2.5.3 Non-conventional Optics for Optical Systems

Optical filters and their applications: Conventional spectral filters are based on Fabry-Perot structures and they now have reached their intrinsic limits in terms of finesse and polarization independence, especially under high incidence angle illumination. In the framework of several projects, and in collaboration with the Fresnel Institute, we have studied an innovative way of carrying this optical filtering function: the use of resonant grating filters. These elements are basically a periodically structured planar waveguide that specularly reflects and transmits light with high wavelength selectivity. After our initial studies, we first focused on the analysis of critical designs and fabrication steps [RVSI10430]. This work led to an original filter architecture, so-called crossed 1D-grating [BR1101, RVSI11226], were the usual paradigm of polarization independence of resonant gratings is overcome. We were successful in experimentally demonstrating perfect polarization independence of such filters in 2013.

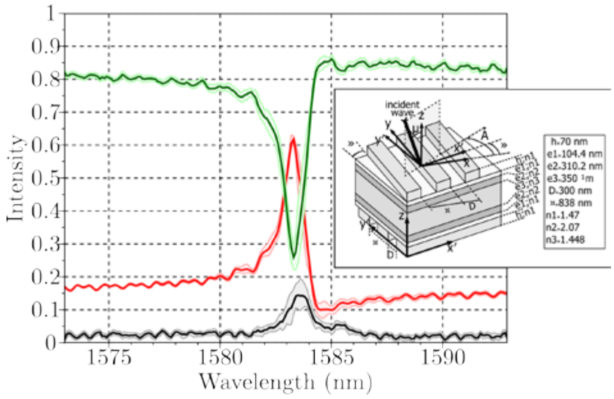


Figure 11: Schematic View of a 1D Crossed Grating Filter (inset) and Experimental Averaged over Polarization states Reflectivity (red), Transmission (green) and Losses (black). The Polarization Sensitivity is Indicated by the Grayed Areas Surrounding the Curves

Based on our experience with such filters and with III-V laser diodes, we have started to investigate the use of GMRFs for wavelength stabilization of external cavity laser diodes. The purpose is to integrate in a single element both the external mirror and the wavelength selective element, opening the way to make compact, fast switching external-cavity sources. Such demonstrations of optical stabilization had already been reported[13, 14, 15], but only few reports deal with laterally single mode lasers[16] that are the most useful for applications. To overcome the small angular tolerance of standard GMRF filters, we studied a novel class of GMRF filters, the Cavity Resonant Integrated grating Filters[17] and demonstrated their extremely high angular acceptance and angular tolerance [RVSI12220], before using them in stable cat's eye external cavity laser diodes [RVSI12677].

Technological integration for optical systems: in recent years, we have identified a few strategic developments in photonics which may lead to up-coming research sub-fields and in which the LAAS laboratory aims to play to a key role. The first innovation is the introduction of a range of novel artificial materials whose intrinsic nanoscale molecular properties can be modified on micrometer or macroscopic scales by an electrical optical, thermal or chemical activation. The second avenue deals with the emergence of innovative manufacturing methods to make large-scale and/or low-cost structures with nanometer precision. Indeed, these new methods can help address the challenges usually

[11] C.J. Chang-Hasnain, et W. Yang, High-contrast gratings for integrated optoelectronics. Advances in Optics and Photonics, 4, pp379-440, 2012.

[12] E. Tournié, et A.N. Baranov, Mid-infrared semiconductor lasers: a review. Advances in Semiconductor Lasers, 86, pp183-226, 2012.

[13] I. Avrutsky, & R. Rabady, Waveguide grating mirror for large-area semiconductor lasers, Opt. Lett., 26, pp 989-991, 2001

[14] S. Bai, & S. Y. Chou, A Spectrum-narrowed, Wavelength and Temperature Stabilized Broad Area Laser Using a Subwavelength Resonant Grating Filter Feedback, 19th Annual Meeting of the IEEE Lasers and Electro-Optics Society, pp 659 -660, 2006

[15] S. Block et al, Semiconductor laser with external resonant grating mirror, IEEE Journal of Quantum Electronics, pp 1049 – 1053, 2005

[16] A. Chang et al, Tunable External Cavity Laser With a Liquid-Crystal Subwavelength Resonant Grating Filter as Wavelength-Selective Mirror, IEEE Photonics Technology Letters, pp 1099 -1101, 2007

[17] K. Kintaka, et al, Cavity-resonator-integrated guided-mode resonance filter for aperture miniaturization, Opt. Express, pp 1444-1449, 2012

associated with the troublesome heterogeneous integration of materials and with the mixing and matching of unrelated technological processes as encountered in systems development. Two examples illustrate this approach.

The first one concerns chemical detection of gases in liquid environment. In particular, the objective is to detect methane in oceans as it is an important parameter for global warming. The conventional instruments use a semipermeable membrane, which extracts the gas from the liquid phase, and detect it by gas phase analysis. The major drawbacks of these systems are due to variable permeability of the membrane and delay associated with the phase change. The investigated approach consists in optically detecting methane that is trapped by a cage molecule (cryptophane A) in a polymer GMRF. This action took place in a broadly interdisciplinary contractual framework (RTA-MAISOE) involving chemists, marine scientists and technologists [MSN11882], [MSI12843].

The second example is part of a recent trend in ophthalmic optics based on pixelated components. This work is motivated by the emergence of new types of eyewear and communicating objects brought before the eyes, introducing new functionalities such as a color change, the display of digital images in the field of view or the addition of more advanced features to enhance vision with augmented reality. To-date, the proposed demonstrators have been electrically-addressed and suffer from a lack of transparency, a parameter of strategic importance in (human) vision. Stemming from the work on optical gratings within the PHOTO team, innovative solutions offering greater transparency are being considered from a theoretical point of view. Their practical implementation is also being investigated with a leading industrial player in the field.

3 Academic Reputation and Appeal

3.1 Main International and National Collaborations

HOPES continued to work cooperatively with international and national partners and developed additional partnerships, in line with HOPES objectives. This section provides an overview of related activities.

3.1.1 International Collaborations

We are involved in several international formal collaborations through the participation to several coordinated actions, namely:

1) **6 COST actions**, among which we contribute to 4 management committees
    a) **BM205**: European Network for Skin Cancer Detection using Laser Imaging (T. Bosch, Management committee and chairman of WG1 Full field VCSEL array perfusion imaging)
    b) **IC1301:** Wireless Power Transmission for Sustainable Electronics- WIPE (A. Takacs, Chairman of WG4.1 space applications, Management committee)
    c) **MP0805**: Novel gain and device materials based on III-V-N compounds (C. Fontaine, Management committee and in charge of gender issues)
    d) **TD1001**: Novel and Reliable Optical Fibre Sensor Systems for Future Security and Safety Applications (OFSeSa) (H.C. Seat, Management committee)
    e) **FP1101**: Assessment, reinforcement and Monitoring of Timber Structures
    f) **LAVINYA**: Laser Vibrometry European Network: systems and applications.

2) Associated International Laboratories

Between 2009 and 2012, LAAS managed the **LEA SMARTMEMS** (Smart MEMS/NEMS for advanced communications and sensing) in collaboration with IMT Bucharest (Romania) and Forth Laboratories (Greece), whose activities focused on RF MEMS. This strong activity was continued by further studies on the graphene with the support of FP7-NANORF project (09/2012-08/2015).

HOPES contributes to the **LIA ILNACS** (Associated International Laboratory Nanostructures of compounds semiconductors) in the field of advanced photonic devices with IOFFE Physical Technical Institute of Russian Academy of Sciences (Saint Petersburg, Russia), Saint Petersburg University, LPN (Marcoussis), Institut Neel (Grenoble), LPCNO (Toulouse), IES (Montpellier).

3) Erasmus mundus Action 2 :

Networking on environmental safety and sustainability initiative for engineering, 2012-2016, T. Bosch

Engineering Technology and Research Exchanges, "Euro-Asia partnership, Chulalongkorn University, Bangkok (Thailand) , C.Fontaine

4) Focus on research topics

We will focus on some research topics that have resulted in long-term exchanges and fruitful collaborations. A large part of them have benefited from bilateral programs or the European FP7 program.

a) ***RF communications***

In 2010, a collaboration started with M. Tentzeris from GeorgiaTech Athena Group on wireless communication and sensing activities (smart antennas, passive chipless sensors, radiolocalisation). Over 30 joint International communications (10 Invited) have been accepted on these topics. Three PhD students have spent intership at LAAS since 2010 and M. Tentzeris obtained 1 year CNRS visiting position at LAAS (01/2012-12/2012). Discussions are underway in order to formalize the framework of the collaboration.

In 2013, a strong collaboration started with Pr F. Udrea (2012 Silver Medal from Royal Academy of Engineering and Head of CMOS Sensor group) from Cambridge University (UK) in order to integrate LAAS wireless sensor platform and CMOS sensors developed at Cambridge. D. Dragomirescu obtained 8 months (02/2014-09/2014) French Government Fellowship (4 positions in 2014 for all scientific fields) with Cambridge University.

An European ERANET-DOSIMEMS project is lead on wireless passive radiation sensor in collaboration with 2 Polish laboratories (Wroclaw Univ. of Technology and Nuclear Center for Research) and a French company.

Since 2009, a joint work with Modena University (Italy) has led to two co-supervised thesis with this university, on integrated frequency conversion up to the millimeter wave range, and to researchers exchanges between LAAS and Modena University.

b) ***Metrology and advanced sensorics***

Contact studies at nanoscale for RF switches have been performed through collaboration with Pr. B. Bhushan, head of "Nanoprobe Laboratory for Bio- and Nanotechnology & Biomimetics" (Ohio State University, USA) that welcome a PhD student (U. Heiba) for 6 months [03/2010-08/2010] and with Pr. Papaioannou (NKUA, Greece) that was hosted for 18 months [06/2008-12/2009].

Between 2009 and 2012, a joint work with CNR-IFAC (Florence, Italy) has led to new approaches for the characterization of WGM high Q optical resonators, and to the design of a first optoelectronic oscillator based on such a device, in the frame of the EDA "ARAMOS" project. This collaboration is starting again (2014) in the frame of the new EDA project "HIPPOMOS".

Since 2009, a strong collaboration has started with the University of Queensland (Australia) on biomedical applications of optical feedback Interferometry sensors. Several programs have supported this action: FAST (PHC), Autralian research Council Discovery Project, Erasmus mundus, COST Action. Exchange of staff, PhD and post-doc has concerned 10 people, with visiting periods from 1 to 6 months.

Since 2000, we have a long-term collaboration with the University Polytechnic of Catalunya (UPC, Spain), initially on optical sensors for mechatronics and presently also on biosensors. With 2 on-going EC projects, one visiting post-doctorate for one year (2014-2015), a joint PhD (2014-2017) and a joint project under construction, this collaboration will be still alive in the future.

c) ***Development of novel materials and devices***

In the framework of COST 805 "Novel gain materials and devices based of III-V-N", C. Fontaine played an active part in co-organizing a training school "Epitaxy and structural analysis of III-V-N semiconductor nanostructures" (Heraklion, 2012) and contributed to the emergence of two hot topics " growth of dilute bismides" and "III-V growth on patterned substrates".

Since 2010, we have developed a sustained collaboration with the UMDO group at the University of Valencia (Spain) on different topics such as precise confinement in quantum dot-based LED (PICASSO PhC project 2010-2011), or on polymer waveguided embedding active colloidal quantum dots. These works have led to two publications co-authored by LAAS and UMDO researchers ([RVSI13248] & [18]).

Since 2012, we collaborate with V. Petruzzelli of the Engineering department of Politecnico de Bari on the modelling and characterization of mesoscopic self-collimating photonic crystals. This collaboration started in the COST MP802 framework with the hosting of Marco Grande for 2 weeks at LAAS, extended by the hosting at LAAS of G.Magno, PhD student of Politecnico de Bari for 9 months, starting in 2013, and was further confirmed by the granting of an EGIDE GALILEE project in 2014, to develop a fruitful collaboration between the two groups.

3.1.2 National Collaborations

HOPES is involved in various national projects and research grants. Over the period, HOPES conducted 48 national and regional projects: 24 were funded by ANR, 18 by the Midi Pyrenees Region, 4 by the Ministry of Economic Affairs, 1 by the Fondation de Recherche pour l'Aéronautique et l'Espace (FRAE), 1 by the RTRA Sciences et Technologies pour l'Aéronautique et l'Espace. A full list is given in the appendix; note that OSE projects are reported from 2011, as OSE joined officially the LAAS in January 2011.

These works reflect the multidisciplinary character of the research area of HOPES and demonstrate a right balance between academic and industrial partnerships. Without exhausting, we had various collaborations with well-recognized contributors:

- FEMTO-ST, FOTON, FRESNEL,ICMCB, IEMN, IES, IETR, IMS, INL, LAPLACE, LASMEA, LEST, UTT, XLIM…
- CEA-DAM, CEA-LETI, CEA-Saclay, CNES, INRIA
- AIRBUS France, CONTINENTAL, DATUS, DELTA Technologie, EADS France, EPSILON Ingénierie, FREESCALE, III-V Lab, INTESPACE, MICHELIN, NOVAMEMS, SIEMENS, ST MICROELECTRONICS, THALES ALENIA SPACE, THALES RT, THALES AIRBORNE SYSTEMS, UMS, ASTRIUM, IPDiA, Time Link Microsystem, OSAT …

HOPES took advantage of several structural actions launched in Toulouse by the RTRA STAE, to reinforce local interdisciplinary links, to identify emerging scientific challenges and to strengthen the partnership between academic research and local industry. HOPES was involved in 4 Projects supported by the RTRA STAE (CASA, SYMAE, MAISOE, ATRIUM) addressing cross-cutting challenges at the frontier between advanced research and innovation in the field of environment, aeronautics and space. HOPES is actively involved in the "chantier" OPTIM as coordinator of this local network gathering LAAS with researchers from fundamental physics (LCAR), astrophysics and planetology (IRAP), theoretical and applied optics (ISAE, ONERA), space technologies (CNES) to anticipate future requirements, which will shape the next optical systems. OPTIM is now involved in the set-up of the strategic activity area PHAROS (Photonique, Aeronautique et Spatial) common to both clusters "Route des Lasers" and "Aerospace Valley".

The goal of the INRIA large wingspan project Hemera was to demonstrate ambitious up-scaling techniques for large scale distributed computing by carrying out several dimensioning experiments on the Grid'5000 infrastructure, to animate the scientific community around Grid'5000, and to enlarge the Grid'5000 community by helping newcomers to make use of Grid'5000. LAAS and INRIA were in charge of the Scientific Challenge entitled "Thinking GRID for Electromagnetic Simulation of Oversized Structures". Researchers from LAAS (RC and HOPES) and INRIA

[18] I. Suárez, A. Larrue, P. J. Rodríguez-Cantó, G. Almuneau, R. Abargues, V. S. Chirvony, and J. P. Martínez-Pastor, Optics letters 39, pp 4962-4965 (2014)

simulated a complex and oversized structure (a plane cabin). The simulation had those characteristics: frequency (3.7 GHz IEEE WLAN 802.11y-2008), Cell of 8 mm, 30869 time step, 1.6 billion of TLM cells, 360 seats, 226 Go of memory, 1320 cores on Grid'5000 (Lille, Nancy and Rennes, … clusters) and 51 hours of simulation (estimated sequential time 1 year).

3.2 Journal Editorial Boards

Some members of HOPES have been involved in journal editorial boards or participated as guest editors (listed in annex). One member is associate editor of the Revue I2M (*Instrumentation, Mesure, Métrologie*) and of the International Journal on Smart Sensing and Intelligent Systems (on-line journal).

3.3 Organization of Major Conferences and Workshops

We are involved in the steering committees, the organization committees or the technical program committees of several international conferences and workshops listed in annex. We will just mention here the most international events chaired by members of HOPES over the last period:

- **Micromechanics Europe Conference** (MME), 20-22 september 2009, Toulouse
- **MEMSWAVE - European cluster meeting on RF microsystem**, co-chair from 2009
- **IEEE joint conference North-East Workshop on Circuits and Systems- Analog Information and Signal Processing (NewCAS- TAISA)** Toulouse, June 28th-July 1st 2009
- **European VCSEL Day**, 12-13 may 2011, Toulouse

It should be noted that a member of HOPES will be the general chair of the next European Microwave Week (EuMW2015 in Paris), which combines 3 major conferences (European Microwave Conférence (EuMC), European Microwave Integrated Circuits Conference (EuMIC) and European Radar Conference (EuRAD).

Members of HOPES participate as well in the organization of several national or international events, listed in annex, within the framework of periodic scientific events (JNM, JNMO, JNOG, Horizons de l'Optique, CMOI, Télémétrie Laser…) or special workshops dedicated to specific topics or events.

3.4 Major and Long Term Visits

3.4.1 Sojourns of Researchers Abroad

Some researchers and PhDs went abroad to visit laboratories and to progress on working programs in close collaboration.

One can note several visiting periods (J. Perchoux, T. Bosch, L. Campagnolo - 11 months) at University of Queensland (Australia) in the framework of partnership concerning biomedical applications of OFI sensors.

D. Dragomirescu spent 8 months in the framework of French Government Fellowship with Cambridge University (UK), in the field of wireless sensors (collaboration with Prof. F. Udrea).

3.4.2 Researchers Hosted

Among French or foreign researcher and PHD students who were hosted at LAAS, we would highlight some distinguished visitors:

- D. Dragoman and M. Dragoman, Prof. IMT Bucharest, Romania (07/2009-09/2009)
- F. Udrea, Prof. Univ. Cambridge, UK (11/2013-12/2013)
- G. Papaioannou, Prof. NKUA, Greece (06/2008-12/2009)
- M. Tentzeris, Prof. Georgia Tech, USA (05/2010-07/2010 and 01/2012-12/2012)
- Mark Hopkinson, Prof. University of Sheffield, UK, (09/2012-01/2013) (Chaire d'excellence P. de Fermat – Région Midi-Pyrénées)
- C. Ravariu, Assoc. Prof. University Polytechnica of Bucharest, Romania (10/2012-11/2012)

3.5 Scientific Evaluation Committees

3.5.1 International

HOPES members made expertises on the request of various foreign committees. Here is a non-exhaustive list : European Commission, Natural Sciences and Engineering Research Council of Canada (NSERC), National Research Council (CNCS) Romania, Italian Ministry of Education, University and Research, Barts and The London Charity, European Centre of Bio and Nanotechnology (Lodz, Pologne) …

3.5.2 National

Most of permanent members were frequently solicited to evaluate new research projects, progress reports, application files etc., at the request of ANR, Universities, Regions, Ministries…

Here are only reported the participation at national evaluation committees:

ANR: member of the steering committee of ANR VERSO (2009-2010) and ANR Generic call concerning the challenge 7 "Information and Communication Society" (2013-2014), member of the evaluation panel of ANR INFRA (2011-2012) and co-president of the evaluation panel of ANR INFRA (2012-2013).

Comité National des Universités (CNU 63) : C. Fontaine member (2008-2013)

Comité d'expertise de l'instance nationale chargée de l'évaluation des candidatures à la Prime d'excellence Scientifique (CNU 63), 2011, 2013, Chairman, H. Aubert

3.6 Major Roles in National Animation and Evaluation Structures

3.6.1 Scientific Evaluation Committees

AERES: J. Graffeuil has been scientific delegate from Oct 2010 to Oct 2012. HOPES members have also contributed to scientific committees of LabSTICC (Brest, nov 2010), XLIM (Limoges, nov 2010 and march 2014), LEAT (Sophia, jan 2011), ICube (Strasbourg, nov 2011), Institut Pascal (Clermont-Ferrand, feb 2011), Thales-CNRS (Palaiseau, janv 2014).

3.6.2 GDRs, Animation of National Programs

GDR: HOPES members participate to meetings of different GDR (Ondes, Micro-Nanosystems, NAMIS-International Research Network on Nano and Micro Systems,…).

C. Fontaine is member of the scientific committee and assistant coordinator of the GDR PULSE, launched in 2013, which gathers more than 150 researchers involved in epitaxy.

RENATECH: O. Gauthier-Lafaye, C. Fontaine, F. Lozes were involved in the definition of the strategic objectives for the Basic Technological Research Program of the French national nanofabrication network (2009-2011).

OMNT: HOPES members are involved in the scientific watch carried out by OMNT (experts: S. Calvez, G. Almuneau, F. Coccetti)

3.7 Scientific Societies

Some HOPES members are strongly involved in IEEE scientific societies:

- IEEE Instrumentation & Measurements Technical Committee on Laser and Optical Systems French chapter (T Bosch, Chair 1997-2011)
- IEEE Microwave Theory and Techniques Society, Technical Committee of RF-Nanotechnology (F. Coccetti, co-founder and chair since 2010)
- EuMA European Microwave Association, R. Plana and F Coccetti (co-founders of topical group on RF-MST), H. Aubert (member)
- IEEE Photonics Society Scottish Chapter (S Calvez, chair 2009-2010)
- IEEE Solid States Circuits French Chapter (D. Dragomirescu chapter officer)

We are also involved in *the Société Française d'Optique* (SFO):

- Executive committee of "Optical Measurements for Industry" (T Bosch)
- Commission d'Enseignement (P Arguel chair)

3.8 Awards and Distinctions

During the last 5 years, we have been distinguished for our innovations in the field of laser sensing for a wide range of applications.

The "NASA Group Achievement Award: Mars Science Laboratory: ChemCam Instrument Development and Science Team" was awarded in 2013 to Marc Lescure "for exceptional achievement defining ChemCam's scientific goals and requirements, developing the instrument and investigation, and operating ChemCam successfully on Mars". His contribution was to design the laser autofocus of the ChemCam instrument. The set-up was tested at Caltech before being integrated on the NASA rover Curiosity.

Mechatronics Awards, set up by THESAME, ARTEMA and CETIM, focus on "Innovation and Mechatronics". During 12th European Mechatronics Meeting, our project Caldiro (about an embedded laser vibrometer) has been rewarded in the Research Category (2010). This project has been supported by the *programme ANR emergence* (2011-2013) and is now supported by Toulouse Tech Transfer, the local SATT.

More generally, Thierry Bosch has received the Jean Ebbeni Award, from the club Mesures Optiques pour l'Industrie (SFO) in 2011. This award is given every 2 years to a scientist in the field of Optics for the best research activity offering a real opportunity in terms of transfer of technology.

During the 37th Congrès de Biomécanique (2012), J. Perchoux has received the best poster presentation award for a new optical feedback interferometer for measuring red blood cell velocity distributions in individual capillaries: a feasibility study in microchannels (in collaboration with S. Lorthois, IMFT, supported by ERC program).

4 Interaction with Social, Economic and Cultural Environment

4.1 Projects with Industrial Partners

Most of work is project-based research together with public and private research community.

HOPES is involved in several ANR projects including the participation of SMEs or leading industries.

There is a strong link with the industries involved in space, aeronautics, and embedded systems (cf 3.1.2). More generally, partnership is developed around the development of the next building blocks anticipating future needs in communications, sensing, metrology, quality, health,…

We are participating to the economic development of local SMEs through our participation to GIPI, a cluster mixing laboratories and SMEs (70 members). We are chairing the Innovation Committee of this cluster in close relationship with Toulouse Tech Transfer for connecting scientists and SMEs. (T. Bosch, vice-chair since 2012)

Moreover, in the JESSICA program, we are center of expertise of CAP'TRONIC for a scientific support to SMEs in the field of electronics (F. Bony, expert since 2009).

4.2 Other Major Innovation Activities

Fifteen patents were registered by HOPES over the period. One can note also the commercialization of research technological specific oxidation equipment to AET company.

Clusters

We are involved in the new DAS PHAROS shared by both clusters AESE and "Route des Lasers", especially in the launch in 2014 of the federative program "Observatory for optical and photonic technologies in systems".
We are member of the International Society on Reliability of Optoelectronics for Systems (ISROS), new consortium dedicated to the reliability and the standardization for space domain and embedded systems).

IRT Saint-Exupery

Several members of HOPES have participated to the working groups drafting the future programs of IRT

Joint Labs

Following a previous close collaboration with the world leading company in optics (ESSILOR), a new long-term research partnership has been established in 2013 on Components and Digital Optical Systems. This collaboration is mainly in connection with the activities of HOPES (teams PHOTO and OSE are already involved) and will be expanded in the future with the RAP team of ROBOTICS. Currently, six ESSILOR engineers are located in the laboratory and two PhD have already begun.

Start-Ups

We highlight the 2 start-ups created by HOPES researchers during the evaluation period:

- Start-up **3DiS Technologies** society, on tridimensional integration, by a former PhD student of HOPES. 3DiS Technologies was awarded within the emergence competition of OSEO (june 2013)
- Start-up **Epsiline**, created in 2009, scientifically supported by 2 Senior Researchers from HOPES. Two joint patents have been applied in 2013. They are designing a laser anemometer for windmill based on optical feedback interferometry. Grand Prix de l'Innovation Midi-Pyrénées 2010

Three on-going maturation processes are being supported by Toulouse Tech Tranfer (TTT – SATT Midi-Pyrénées) for designing prototypes in the fields of geophysics (hydrostatic levelling sensor), mecatronics (embedded vibrometer) and biomedical (skin cancer).

4.3 Scientific Popularization

Some examples are given hereafter:

- 50-years laser on 2010: participation to CNOP national committee, coordination and organization of events for CNRS-INSIS
- Novela 2010, « La Harpe Laser » demonstration
- « La harpe laser à climats musicaux: un projet pluridisciplinaire de médiation scientifique par l'art », *Colloque sur l'Enseignement des Technologies et des Sciences de l'Information et des Systèmes* CETSIS 2011 [MAI11421].
- « Laser between science and science fiction », conference, University Paul Sabatier, 24/4/2014, T. Bosch
- Educational Open Data for Optics (HAL-SFO, P. Arguel responsible since 2009).
- "Nous concevons des puces RFID sans électronique", interview kwantik, 13/10/2010, H. Aubert
- Open doors days (Fête de la Science).

5 Involvement in Training through Research

5.1 Leading Roles in Doctoral Schools

GEET is the main doctoral school associated to the scientific field covered by HOPES. G. Graffeuil was director of GEET doctoral school up to 2010, and several members of HOPES are members of the executive committee or the PhD commission of GEET.

5.2 Research Seminars in Training Programs

5.2.1 "Seasonal" Schools

Lectures on optical sensors, Silpakorn University, 12/2012, T. Bosch

International Summer School on RF-MST, chairman, since 2009, F. Coccetti

NAMIS International School Nov 2009, H. Camon chairman

COST805 International school on "Epitaxy and structural analysis of III-N-V semiconductor nanostructures", Heraklion, Crete, 29 April - 1 May 2012, C Fontaine co-organizer.

5.2.2 Advanced University Courses

Specialized course on Microwave and Millimeter wave circuit integration at Modena University (Italy) (T. Parra, 2010-2011)

European Microwave Lecturer, F. Coccetti, 2013-today

International Master on Electronic systems for embedded and communicating applications (J. Perchoux, ENSEEIHT - INPT). This educational program is focused on research and development for embedded systems integration, from analog and/or digital circuit design to complex heterogeneous system conception.

5.3 PhD and Internship/Master Programs

64 PhD students have been supervised over the evaluation period. The number of current PhDs is 32 for 26 permanent staff, which gives a ratio 1.2 PhD/permanent.

Five international theses were co-advised:

- A. Bakar, University of Queensland (Australia), 2009-2012, T. Bosch co-director
- A. Belarni, University USTHB,(Algeria), 2006-2014, P. Pons co-director
- R. Kliese, University of Queensland (Australia), 2010-2013, T. Bosch co-director
- E. Ramirez Miquet, Havana University (Cuba), 2013-2016, J. Perchoux co-director
- A. Magnani, University of Modena (Italy),2011-2014, T. Parra co-director.

5.4 Teaching and Education Materials

Europhoton: training course in AIME platform (*Atelier Interuniversitaire de Micro-nano-Electronique*) at Toulouse, for pre-doctoral and doctoral students, accredited to the EURO-DOTS (European Doctoral Training Support in Micro/Nano-electronics, 257051) program of the EC Framework 7 (since 2013, P. Arguel).

HOPES is deeply involved in a federative and educative project called **NIMPH (Nanosatellite to Investigate Microwave Photonic Hardware)**, which involves master students of UPS and ISAE, and which aims at integrating a nano-satellite payload. The goal of NIMPH is to test under real space conditions two complete RF optical links, and more specifically the radiation-induced degradation of erbium doped fiber amplifiers. The EDFA noise figure will be measured in the satellite, and the noise and gain data will be transmitted to the earth during the satellite lifetime. This project is supported by CNES, Thales Alenia Space and Toulouse University IdEx. It will be continued and, hopefully, will go up to the monitoring by the students of the satellite data stream. This is a first step towards devices and systems reliability studies for space applications in real space environment.

HOPES participate to FP7-Marie Curie–EDUMEMS (07/2011-06/2016) project focused on MEMS design. The main objective is to give advance training on MEMS to Ukrainian researchers. HOPES is involved in wireless passive RF sensors.

5.5 PhD/HdR Committees

HOPES members took part in more than 150 PhD and HdR committees (among which 17 HdR committees and 13 PhD committees abroad).

5.6 Faculty Selection Committees

Several HOPES members regularly contributed to PR and MCF recruitments at various universities: Bordeaux, Montpellier, Rennes, etc.

Some HOPES members are in charge of the selection committees due to their participation to local 61-63 sections Scientific College.

VII - Nano Engineering and Integration (*NanoIngénierie and Intégration* — N2I)

Leader: C. Rossi

Research Teams: NanoEngineering and Systems Integration

Keywords: Integration, Nanoengineering, microfluidics, lab-on-chip, MEMS, BioMEMS, pyroMEMS, nanofluidics, reactive nanomaterial, atomic scale modeling, smart sensor integration, wearable and embedded System, smart sensing

Personnel Status (as of June 30, 2014):

Team	N2IS
Leader	FOURNIOLS JY, LANDA G (adj.)
Permanent Researchers	ACCO P (MdC) (01 2011), BANCAUD A (CR-HDR), BOIZARD JL (MdC), BOUKABACHE A (MdC), BRULIN D (MdC) (09 2012), BRUT M (MdC) (10 2011), ESCRIBA C (MdC), CAMPO E (PR), CAMPS T (PR), CAZARRE A (PR) – Dir. EDOC GEET, DJAFARI ROUHANI M (PR Emérite), ESTEVE A (CR-HDR), ESTEVE D (DR Emérite), FOURNIOLS JY (PR), HEMERYCK A (CR) (10 2011), JOSEPH P (CR), GUE AM (DR)-Dir. Adj. LAAS, LANDA G (DR) – Pres. CNU 28, ROSSI C (DR) – Anim Thème, SOTO ROMERO G (Associated researcher - MdC) CHAN M (CR) (left 09 2012), MARTY A (DR) (left 04 2012)
PhD Students (Arrival date)	AL ATTAR S (2008 – 2012), AL BLUWI I (2009-2012), ALLOUCH A (2008-2011), BAHRAMI M (2010-2013), BELISARIO A (10/2012), BETTAHAR F (10 2012), BLARD F (2008-2011), BOSSUYT R (2008-2012), BOTERO GALEANO D (2009-2012), BOUKABACHE H (2009-2013), BOURENNANE W (2009-2013), BRUT M (2005-2009), CALAIS T (10 2013), CARGOU S (20010-2013), CHARLON Y (10 2010), CRATTELET J (2007-2010), DUROU H (2007-2010), FOUET M (10 2012), FULCRAND R (2006-2009), GLAVIER L (02 2014), GUILTAT M (10 2013), HAJJOUL H (2007-2010), HAJJINE B (02 2013), HE Q (2008-2012), JEMAI N (2006-2010), LACROIX J (10 2011), LANTHONY C (2006-2014), LASTAPIS M (2008-2011), LEFILLASTRE P (2006-2010), LU J (2011-2013), LUBIN J (2008-2012), MANCZAK R (11 2012), MARTY B (2006-2009), MASTAIL C (2006-2009), MATHON J (2009-2012), MATMAT M (2006-2010), MOUNKAILA M (11 2012), NAILLON A (10 2013), NASREDDINE N (2007-2012), PETRANTONI M (2007-2010), PEZOUS H (2006-2009), PIAU A (10 2013), PICOT V (2009-2012), PINON S (2009-2012), RAMOND A (2008-2011), RANCHON H (2008-2013), RECOULES L (11 2011), REIG B (2008-2012), RENVEZ G (2006-2009), ROUSSEAU % (2006-2009), ROUX J (11 2013), SOULIMANE S (2007-2010), TATON G (2010-2013), TRAPAIDZE A (2010-2014), VALADE A (11 2013), VIERO Y (2008-2011), ZAHI Y (2006-2009), ZEDEK S (11 2011), ZHOU H (2006-2009).
Post-docs; Engineers	ARDILA RODRIGUEZ G (2008-2009), BRUT M (2009-2009), CHAUVET F (2011-2012), DUCERE JM (2006-2011)(12 2013), GENOT A, HAJJOUL H (2010-2011), HEMERYCK A (2008-2011), JUGIEU D (2008-2009), KAKLAMANI G (2013-2014), MADER A (2010-2011), MATMAT M (2010-2011), MEANCE S (2012-2014), NASREDDINE N (2012-2014), PINON S (11 2013), ROUX C, TATON G, PICOT V (2012-2013), RAMADOSS V (2012-2013), RICART T (2009-2010), TARBAGUE H (2013-2014), ZAHI I (2009-2011), AQACHMAR Z (2011-2012), BERBER A (2010-2011), CODREANU C (2009-2013), DUBOSC F (2011-2013), DURAND X (2009-2012), GRONDIN Y (2007-2011), KSOURI S (2008-2011), ZATOUT Y (2011-2011), TATON G (02 2014)
Visiting Researchers (Affiliation, Country, Period)	Prof. Y CHABAL , Univ. of Texas in Dallas (06-2012, 07-2013) Dr. C FURGER, S DERICK, C. GIRONDE, LED (09 2013) Vincent PICOT with TTT and Cyril RENAULT SENTENAC in connection with LED

1 Presentation

In June 2014, NanoEngineering and Integration (N2I) staff gathers 19 permanent researchers: 7 CNRS (section 8), 10 EC[1] (section 63 and 28), 2 Emeritus members (1 professor and 1 director of research). In addition to the 19 N2I researchers, there are roughly 18 PhD students, 7 postdoctoral fellows, one associate professor who joined us in Sept. 2013 and 3 visiting engineers (two of them are from LED start-up).

Our staff brings together **theorists** skilled in physics, material chemistry and **experimentalists** skilled in biophysics, materials science, fluidics**, technologists** at the micro and nano-levels jointly with **circuits/systems researchers.**

N2I originates from a research group born in 95's which has greatly evolved following and anticipating the main technological transitions in micro and nano-systems while maintaining the same research philosophy "***develop both theoretical and technological tools for micro and nano systems to address the future need of the society*****".**

1.1 Objectives and Scientific Positioning

We all share the same commitment which is **to foster collaborative and interdisciplinary research in Science and Engineering to address the challenges associated with current and future nanoengineered systems responding to the modern society needs**.

In this context, our research spans a broad set of activities aiming **at developing theoretical, experimental and technological tools for the manipulation, manufacturing, understanding and modeling of complex multi-scale systems of different nature: molecule, solid state material, fluid, DNA, cells, sensors and systems**.

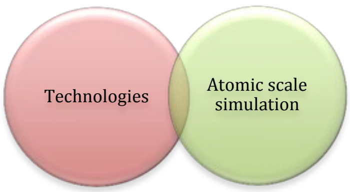
[1] *Enseignant-Chercheur*

Originally, a common framework of our research aims to link **fundamental understanding to smart system demonstrators deployment** with strong connections to local and national societal and economic environments and formation.

In addition to multi-domain research, our strengths and original positioning in the French and foreign scientific communities are twofold:

(1) We are **multidisciplinary** and we are **multi-scale, with the ability to design and build systems at all size scales and integrate micro/nano structures into multi-scale systems**.

(2) Another nationally recognized strength and high originality of N2I research approach **is the ability to develop atomic scale modeling and simulation methods to investigate and rationalize technological processes and device issues.**



Particularly, in the evaluation period, we tackled societal challenges in **health/biology**, **aging population**, **water quality**, **security** and **industrial renew**.

1.2 Scientific Organization and Life

Concretely, our research activities are organized into **3 key disciplinary areas** involving in each area strong collaborative researches.

- Theory and modelling (5 researchers)
- Nanoengineering of solids, liquids, and their interfaces (4 researchers)
- Smart Systems Integration (10 researchers)

Each of these **key scientific areas** gathers a small group of researchers working in close collaboration and sharing the same theoretical and experimental research tools.

In the evaluation period, our research projects fall into six sub-topics transversally to the scientific areas and which are mutually-reinforced by the complementary skills of N2I researchers. The first sub-topic aims to propose **novel atomic scale modeling and simulation** methods to investigate and rationalize technological processes and device issues. Four topics are focused on **experimental researches in materials science, biology and technology**. The last sub-topic, devoted to smart sensor integration for Structural and Human Health Monitoring, bridges the gap between basic experimental *research* and industrial applications based on demonstrators with real-world specifications.

Table 1 summarizes the different research topics and marks with ✓ the different scientific contributions.
We also read in Table 1 that five over the six N2I research sub-topics support both LAAS axes: Alive and Adream.

Table 1: N2I matrix: 2009-2014 Research topics *vs* N2I Scientific areas. *Subscript corresponds to the LAAS axis connections*

N2I 2009-2014 *Research Topics* / ***Disc. Areas***	**Theory and modeling**	**Nano-Engineering of solids, liquids and interfaces**	**Smart Systems Integration**
Atomic scale modeling and simulation ALIVE	✓	✓	
Nano-engineering of flows ALIVE		✓	✓
Nano-Engineered Reactive Materials	✓	✓	✓
DNA nanotechnology: sensing for life sciences and assembling for technologies ALIVE	✓	✓	
MEMS and BioMEMS ALIVE	✓	✓	✓
Structural health monitoring and human health monitoring ADREAM			✓

Each research sub-topic is motivated and detailed in the following sub-sections.

1.2.1 Atomic Scale Modeling and Simulation

"Computer models mirroring real life have become crucial for most advances made in chemistry today" ***Press release for the Nobel Prize in chemistry 2013***.

Our modeling activity aims at bringing novel methodological bricks for achieving predictive modeling via multi-models approaches for the simulation of complex systems such as interfaces, chemical processes at surfaces, self-assembly, biomolecular interactions at large. Particular attention is dedicated to accompany real experiments in which fundamental issues are to be solved. Two mainstream contributions have been considered in the last period:

- Static Mode method to account for biomolecular conformational changes under external stimuli. Applications have concerned DNA nanotechnologies but an axis on structural oncology is driving most of the current forces with ambition on how to drug a protein through in silico screening of oncomutants.
- DFT-KMC coupled approach for the simulation of reactive nanomaterials and oxidation processes (Si, SiGe, Al/CuO nanolaminates, Al/Ni bimetallic), from molecular interactions to process scale simulations. On-going effort is to account for local exothermic reaction in non-conventional KMC.

These researches are strongly connected to DNA nanotechnology and reactive materials nanoengineering.

1.2.2 Nanoengineering of Flows

According to Prof G Whitesides, *Lab on a Chip* ***11***, *191 (2011)*, nanofluidics is one of the key directions in labs-on-chip research: it should enable developing new or enhanced functions, such as molecule concentration for biosensing or energy conversion. However its development is still quite confidential because of technological and scientific challenges. In this context, we tackle **nanoengineering of flows** at three levels ranging from technology and flow understanding to the development of functional devices:

- Technologies for nanofluidics: we develop silicon and polymer-based fabrication technology for nanofluidics. We demonstrated for example the fabrication of nanochannels at wafer scale with a simple method, based on phase shift lithography.
- Nanoscale flow understanding and control: we characterize simple flows inside fabricated nanochannels that constitute model nanoporous media. We have for instance quantified capillary filling in 20-100 nm deep channels (see highlight). We are also developing flow metrology, based on the distribution of nanoparticles velocity within µm-sized channels.
- Functional devices: microchannels for the handling of micro- and nano-objects: we use our know-how on fluid flow to manipulate objects within channels. We are for example using self-organized arrays of microbubbles for photonics; and we develop devices able to sort sub-µm particles, in the context of environmental sensors.

There is a close connection between nanoengineering of flow, DNA nanotechnology and BioMEMS. This topic has also strong scientific connections and collaborations with MNBT and HOPES themes.

1.2.3 Nano-engineered Reactive Materials and Devices

"In much the same way that silicon in the 1970s led to the modern information technology industry, the development of advanced materials will fuel many of the emerging industries that will address challenges in energy, national security, healthcare, and other areas." ***Materials Genome Initiative for Global Competitiveness, US NATIONAL SCIENCE AND TECHNOLOGY COUNCIL, 2011***

Next breakthroughs in materials will not necessarily concern the discovery of a new class of materials but rather the exploration of advanced nanoengineering tools combining "top-down" and "bottom-up" technologies to build nanostructured materials, 2D layered materials and multifunctional nanocomposites designed to respond to targeted applications. Our contribution is at three levels ranging from technology, modeling and understanding to the development of functional pyrotechnical devices with applications in Primers, Miniaturized pyrotechnical devices, Fuzing, Safety and Arming Elements as described herefater.

Nanoengineering of materials: in particular, in the evaluation period we addressed two specific technical and scientific challenges:

The development of magnetron sputtering based process to produce new highly reactive nanolaminates made of tens stacked Al and CuO nanolayers. Controlling copper oxide structure and interface formation are among the most important technological hurdles to design and engineer tailored and safe reactive nanolaminates.

The development of DNA directed-assembly of energetic nanocomposites to produce tunable heat, pressure and gas. The idea to design and build materials and devices using DNA synthetic strands is really a new form of thinking and a new technology era possibility.

Reactive interface formation characterization: Understanding the process of interface formation based exclusively on experimental methods is always confronted to the limitations of chemical and structural analysis. We developed the understanding of the early stages of the deposition chemistry of CuO onto Al (as in a real PVD experiment) using first principles calculations of the DFT coupled with a Monte Carlo approach.

Demonstration of functional devices: We have developed a new polymeric electro-thermal initiator for non-contact ignition of propellant with state of the art performances.

These developments are strongly connected to modeling and MEMS research activities. This topic had connection with GE theme.

1.2.4 DNA Nanotechnology: Sensing for Life Sciences and Assembling for Technologies

DNA attracts considerable attention in life sciences and in nanotechnologies. The development of technologies, which improve or extend the performances DNA sequencing or DNA microarray, is indeed expected to have considerable impact for personalized diagnostics, as defined by the definition of tailored drug regimen based on patient specific molecular information. Further DNA is unique material for physics and nanofabrication, which can be engineered at the atomic level to perform biophysical researches and/or accomplish technological processes with exquisite precision. Convinced by the potential of this molecule at the nexus of technology and biology, we develop new fluidic systems dedicated to the analysis of DNA *in vivo* and *in vitro* as well as for DNA-based biosensing. We have been focusing on three main objectives:

- Develop aptamer-based sensors targeting the thrombin molecule, which is the key protein in homeostasis regulating both pro and anticoagulant activities. Aptamers, which are short single strand DNA molecules with a specific folding that allow for the specific binding to proteins, were chosen due to their generic performances as sensing elements.
- Conceive micro- and nano-fluidic devices for DNA manipulation and analysis. Our quest is to perform genomic analysis at the entire chromosome level, whereas conventional molecular biology techniques have been devised to characterize short fragments.
- Study genomic DNA structure and dynamics in living yeast with novel tools based on optics and microfluidics. Our thrust is to provide a physical description of the genome structural properties.

These developments are strongly connected to the research developed in modeling and nanoengineering of flows. This topic had strong scientific connections with MNBT and HOPES themes.

1.2.5 MEMS and BioMEMS

Since two decades, MEMS have been identified as one of the most promising technologies for the 21st Century with the potential to revolutionize both industry and society *(L'expansion, 2002).* Over the evaluation period, N2I has performed collaborative research in design (based on COMSOL MULTIPHYSICS software), innovative new process technologies development as well as fluid engineering and packaging. Our overall objective is to enable new MEMS systems, propose new manufacturing processes and explore new applications by exploiting our technological know-how acquired through the last two decades especially on:

- Microfluidic technology based on multi-layered SU8 or dry film photoresist microstructuration and Si and Glass/PDMS structuration.
- The engineering of electro-thermal actuating micro elements on suspended membrane to actuate, sense, heat.
- The engineering of pyroMEMS.

Our contribution is application driven and has led to the development and demonstration of:

- New concepts of integrated microfluidic devices for bio-chemical sensing applications. Some key innovations lie in the exploration of RF and magnetic field within microfluidic devices to sense and actuate, respectively.
- Innovative integrated safe/arm/fuse for defense and space applications. One main addressed technological issue has been focused on the management of multifunctional and multimaterial integration.
- New type of (stress/thermal) sensors for aeronautic applications and food industry.

These developments are strongly connected to the research developed in the previous detailed research topics. This topic had also connections with MNBT and HOPES themes.

1.2.6 Smart Sensing for Structural Health Monitoring and Human Health Monitoring

The proliferation of commercial components (COTS) and manufacturing processes along with the combination of low energy computing and wireless communication technology are the foundations in the 00s of interconnected multifunctional smart systems, called Internet of Things enhancing our quality of life *(the economist 2005)*.

One way to address the understanding and modeling of complex systems is to develop a distributed instrumentation based on advanced technologies of smart multifunctional sensors, combining low energy computing, versatile architecture and wireless communication with the objective to diagnose weaknesses of the observed system. We focus for many years on the development of methods and technologies for the analysis, identification and localization of **vibration signatures and displacements in heterogeneous material or structure for Human or Structural Health Monitoring (HHM & SHM).** Importantly, our contribution is application driven and has led to the development and demonstration **above or inside the structures** in 3 fields of application, in close link with industries:

- SHM to provide aircraft composite structures safety and reliability based on the implementation of smart networks of piezo sensors glued **above the composite structure** able to analyze both echoes of guided waves and electromechanical impedance variation. This approach has been transferred to AIRBUS and RATIER companies.
- SHM for civil engineering with the development of an innovative **in-situ monitoring** solution based on a composite thin multilayer and multi sensor structure (temperature and deformation) a low profile.
- HHM dedicated to frailty of the elderly. Our work focuses on learning of walking behavior (smart shoe insole), the drop detection (patch worn on his back between the shoulder blades), changes in physical activity or behavior. These works has allowed us to be driven in the realization of the ADREAM apartment-lab for technical development and "*Maison intelligente de Blagnac*", dedicated to trials in real use conditions and teaching; we demonstrate that the miniaturization as a flexible patch allows better transduction phenomena. The methods are based on learning of living behavior and sudden modifications. Many demonstrations (see *demo table*) have been done in close collaboration with institutions: smart shoe insole, a patch worn on his back between the shoulder blades. A striking result is HOMECARE, a complete monitoring system for dependent old people, experimented in real site (retirement home).

These developments are strongly fed by the research developed in MEMS technologies.

1.2.7 Summary

Our research within each sub-topic is mainly supported by LAAS technological platforms, in particular the MicroNanoFab facility for MEMS & bioMEMS manufacturing. Advanced material and biological sciences are performed through long-term scientific collaborations or by the development of specific tools. The LAAS CAD platform and our connection to supercomputer national centers (CALMIP, GENCI) allow for intensive calculation campaigns. There are also several scientific interactions and collaborations with other LAAS themes**:** MNBT, GE and HOPES (see shared PhD thesis section). Finally, most if our research contributions feed both LAAS strategic axes, ALIVE and ADREAM, making our scientific positioning totally in agreement with lab's strategy.

Figure 1 summarizes the N2I research topics in connection to the fields of interest.

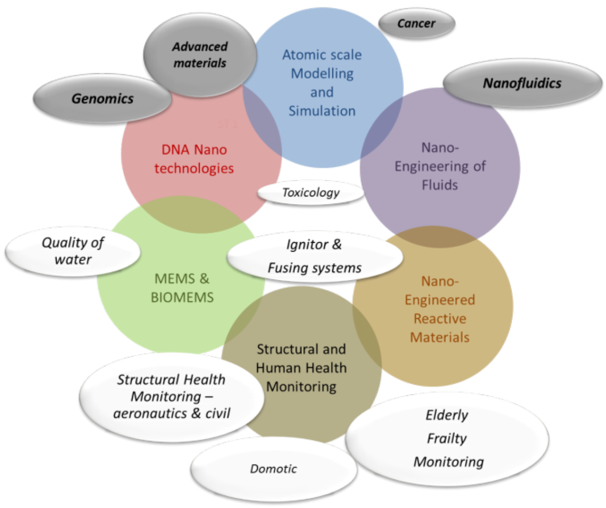


Figure 1: Schematic of the applications and their connections with each research sub-topic. Grey shapes correspond to basic research and white ones to applied research.

White shapes correspond to the collaboration with industrial partners and grey circles correspond to basic research workprograms (ANR, FP7, NSF funding).

1.2.8 Activity Profile

N2I scientific organization has been built to foster interdisciplinary and collaborative researches as well as to achieve a good equilibrium between:

- **The development of fundamental understandings in basic and applied research** including advanced materials, nano-bio and nano-technology, nanofluidics and nanosystems.
- **Providing innovation and support for industrial development** by the deployment of smart system demonstrators in various fields of applications.
- **Promote nanoengineering and technology through education**. We annually train more than 20 masters and ~18 PhD students. Three master degrees are headed by N2I staff.

Figure 2 is a tentative of N2I activity profile.

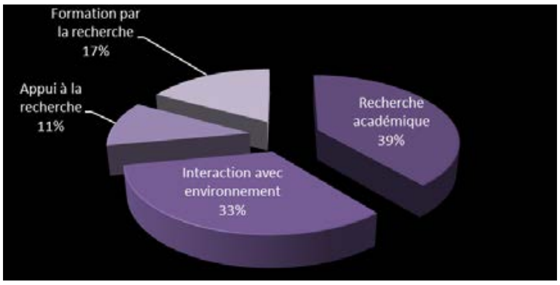


Figure 2: N2I activity profile.

1.2.9 Scientific Life and Coordination

The theme is led by a senior scientist elected in 2012 among the staff. The role of theme leader is:

- To enhance scientific exchanges though weekly seminar and annually scientific events.
- To share scientific information through bi-monthly councils and ensure a clear link between the lab's management team and the N2IS team leader.
- To clearly defend and promote the theme scientific prospective during arbitration with the lab's management or in any other instances.

In the evaluation period, N2I researchers were regularly motivated to promote their research results to the foreign scientific communities through seminars in foreign universities (in Europe, Asia and USA) as well as to invite foreign researchers for internal scientific seminars.
Invited seminars have been given in many foreign University : John Hopkins Un. (Maryland), Stanford Un. (California), Un. of Southern California (California), Un. of Dallas (Texas), Un. Maryland, Un. of Lausanne (Switzerland), Un. Pierre et Marie Curie (France), Shaanxi Applied Physic-Chemistry Research Institute in Xi'an (China)…

An average of ~1 external seminar every 2 months has been organized. Among them there are: Edward Brody (USA), Masumi Yamada (Japan), Jean-Baptiste Salmon (Rhodia France), Pascal Etienne (Univ. Mont), Jean-Christophe Baret (Germany), Alkis Hatzopoulos (Greece), Yves Chabal (USA), Minami Yoda (USA)….

Below is the short list of synergetic activities organized on the impulsion of the theme leader.

- One weekly internal N2I theme seminars. Each Thursday at 1pm, one N2I PhD Student gives a short talk on his/her contribution.
- One bi-monthly N2I scientific meeting. This is triggered as a function of the scientific actuality and as possible, one scientific discussion is made about one scientific topic.
- One annual scientific seminar. In April of each year, one-day external scientific seminar is organized where PhD students, post-doc fellows and permanent staff give scientific talks.
- One annual theme internal research report is written and then diffused to our collaborators.
- One annual prospective brainstorming is organized.
- One theme web site has been created and an intranet permits to share internal documents and theme current information (PhD thesis topics, submitted or funded projects, main results, submitted scientific articles…).

In addition, we are very careful to foster scientific exchanges with other LAAS themes and promote synergies with the foreign scientific community. N2I staff has been implicated in many inter-theme projects (3 in the period) and have participated to 6 PhD thesis co-management.

1.3 Salient Facts

In this section, first we propose to outline N2I major highlights in term of national/international scientific impacts and outstanding scientific contributions that could lead to major technological breakthroughs.

Then, a list of the **major selected scientific articles** is proposed outlining our attachment to produce high quality articles.

To finish, a list of **major** workshops in international conferences chaired by N2I's researchers is given as a testament of our scientific notoriety.

1.3.1 Scientific Impact and Outstanding Contributions

- **N2I has enabled a technological breakthrough and a significant evolution in the context of the ageing population challenge.**

During, more than ten years we have been proposed and experimented human monitoring systems, the topic is a major focus of socioeconomic development which connects the national health system and the communication electronics industry (telemonitoring, telemedicine, teleassistance, remote sensing of the frail elderly...). The regional environment is favorable to have a competitive offer: N2I gathers useful skills. One N2I researcher, E. Campo, has been mandated by lab's management team to be responsible for the animation: many industrial transfer operations are under preparation. A striking result is HOMECARE: a complete monitoring system for dependent old people, experimented in real site (retirement home). This is a complete technological monitoring offer for institutions, a technological breakthrough in the concept and for the realization of miniaturized worn patch, connected with a tag installed in the home or with an embedded phone used to collect data and making the link with the tag. And this is a conceptual advance for the validation of a supervisory approach based on habits and behaviors modeling.

- **N2I has pioneered the integration of nanoenergetic material into MEMS to realize high energy actuation sources leading to several well identified industrial impacts (especially for defense industries).**

This technological area called in 2010 by N2I "nanoenergetic-on-chip" has the potential of developing new multifunctional combustion or pyrotechnical systems with enhanced capabilities at low cost and safer (i.e. without manipulating dangerous products). Our team is the only one in France and is world-wide recognized for its contributions, on the sputtering Al/CuO reactive nanolaminates and association of reactive materials with MEMS. Nanothermites are expected as the next-generation material in replacement of explosive materials in arm and fire systems. Their application is currently the subject of extensive research especially as nontoxic primers for conventional ammunition, additive for solid rocket propellant. Nanothermites could therefore afford the perspective to fabricate smaller weapon systems or higher lethality weapon. Moreover, compared to conventional explosives, one asset of nanoenergetic materials as we develop them, is the possible adjustment of the energy density, power release and pressure generation by a suitable choice of fuels, oxidizers, material geometries and interfaces. Our positioning and scientific roadmap are both internationally recognized since the C. Rossi's team is regularly requested to give talks or expertise in the field as well as we are solicited to organize international workshops.

- **N2I is nationally recognized as major contributor in the control of biomolecule movement and elongation in nanofluidic devices for large genomic analysis. Impact is obvious for cancer screening for example.**

We acquired a high expertise and developed a set of experimental tools and methods to manipulate, separate, elongate, analyses the dynamics of single biomolecules (as DNA or chromosomes) and single cells. This has been possible by the combining of micro/nanofluidics technologies (technological topics launched in our theme in the early beginning of 00's) and nanopatterning of obstacles (~ 40 to 250 nm) for example or with more conventional electrophoretic or hydrodynamics actuation. In parallel, we also set up and fabricate micromirrors for three-dimensional single-particle tracking in living cells particularly useful for high-throughput 3D live cell imaging for large genomic analysis (CNRS patent).

- **N2I has acquired an internationally recognized expertise in coupling DFT calculations with homemade Kinetic Monte Carlo Codes enabling simulations of technological processes at the atomic scale, thanks to more than 25 years of researches in atomic scale modeling.**

DFT/kMC expertise dates back to the 95's and remains original in France since we are the only team able to support micro technological process development with fundamental understanding and atomic scale prediction. The expertise covers especially fundamental understanding of oxidation chemical processes at semiconductor surfaces (Silicon, SiGe, high-k materials growth) as well as mesoscale understanding of oxide layer formation such as "densification" of ALD grown high-k materials. This team has also established a new methodology, the "Static Modes", for describing the flexibility of macromolecules. We have demonstrated its universal predictive capability in a number of biomolecular objects, peptides, proteins, DNA (modified, simple or double strand). N2I researchers have acquired multi-scale methodological expertise for embracing biomolecular issues that includes the use of conventional software (Molecular Dynamics and DFT-based packages) as well as homemade codes (FLEXIBLE, APTACAD).

1.3.2 Journal Covers and High Impact Articles

- Lab-on-Chip / Nature News "Cells go fractal" (2009)
- Nature Material (Nanopatterning Si(111) surfaces as a selective surface-chemistry route) (2010) **RVSI10060**
- Back cover: Adv Funct Mater, *Vol. 22, 2 (2012)* - **VSI11256**
- Selection AIP/APS Virtual Journal, *Appl Phys Lett, Vol.100 (2012)* - **RVSI12266**
- CNRS International Magazine n° 24 (2012)
- Genome Research - communiqué de presse INSIS / INP / INSB + rapport prospective du CNRS + UPS magazine (2013)
- Invited paper in "International Innovation, Research Media Ld" (2013)
- Journal Cover, APL 104 – Vol. 14 (2014) - **RVSI14116**

1.3.3 International Workshops Chaired by N2I Researchers

Several international workshops hosted either in France or in North America have been chaired by N2I senior scientists, such as:

- 41st AVS-ICMCTF San diego, USA: "Energetic Materials and Microstructures for Nanomanufacturing" – 75 attendees.
- MRS-2012 Boston, USA: "Synthesis, Properties and Application of Reactive Materials" – 250 attendees.
- EMRS-2012 Strasbourg, France: "DNA Directed Programmable Self-assembly of Nanomaterials for Energy and Other Applications" – 50 attendees
- EMRS-2009 Strasbourg, France: "Nano-scale Energetic Materials: Fabrication, Characterization and Molecular Modeling" – 75 attendees
- CECAM-2014 Toulouse Workshop Simulation of biomolecular interactions with inorganic and organic surfaces as a challenge for future nanotechnologies – 50 attendees.

2 Scientific Production

Here, for each research topic presented in Section 1.2, one or two major achievements are further presented illustrating some major published results.

A list of selected published scientific articles is then reported in a second item. The highlighted author name corresponds to N2I staff.

2.1 Selected Major Scientific Results

2.1.1 Atomic Scale Modeling and Simulation

Copper Oxide and Oxygen deposition on Aluminum (111): a review of basic atomic scale mechanisms

C. Lanthony, JM. Ducéré, M. Djafari Rouhani, A. Hemeryck, A. Estève, C. Rossi

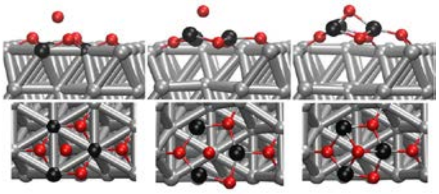


Figure 3: DFT modeling illustrating the extraction mechanism in three steps, side views on three top images, top views at the bottom.

Abstract: The chemical mechanisms occurring during early stages of molecular CuO deposition onto the Al(111) surface are investigated using Density Functional Theory calculations (DFT). The atomistic mechanisms are fully examined, leading to the systematic determination of their reaction enthalpies and associated activation energies. We demonstrated theoretically that CuO undergoes dissociative chemisorption on Al(111) surface and that Cu and O species tend to separate from each other.

O_2 deposition: We evidenced for the first time a barrierless mechanism for describing the oxidation of Al(111) in which oxygen atoms located on the outer surface extract aluminum atoms of the surface layers through local cooperation of other pre-adsorbed oxygen atoms. We showed the details of this complex chemical process that kinetically competes with the non-destructive formation of an oxygen monolayer onto the Al surface, thus elucidating the initial aluminum oxidation regime.

Cu deposition: Cu atoms are shown to promote copper islands on the surface accompanied by massive insertion of Cu into the subsurface. If oxygen atoms also tend to stabilize as surface islands, on the contrary to Cu behavior, no insertion was observed.

Rather, these islands are oxide nucleation sites through which aluminum atoms are extracted from the surface, leading to mixing of oxygen and aluminum atoms in specific atomic arrangements of the γ-alumina type. Finally, Cu and O co-deposition mechanisms are investigated. Copper exhibits a dual role: it promotes oxygen-aluminum interaction while exhibiting a tendency to be rejected from the oxide front, preventing full mixing of Al, Cu and O species.

Main articles & communications:

RVSI12422 : J. Chem. Phys., 137, 094707 (2012)
RVSI11344 : Thin Solid Film, 520, 4768 (2012)
RVSI12118 : ACS Appl. Mater. Interfaces, 5(2014)
International Innovation, Research Media Ld, Septembre 2013
4 international invited talks: **CII11046, CII12160, CII13099, CII13696**

Bringing aptamers into technologies: impact of spacer terminations

M. Brut, A. Trapaidze, A. Estève, A. Bancaud, D. Estève, G. Landa, M. Djafari Rouhani

Abstract: We propose a low cost modeling approach to screen the impact of aptamer structural modifications on their biomechanical stability. This responds to the current immature control of aptamer properties when integrated into bio-hybrid devices.

We predict that common spacers (PEG, polythymine) disrupt aptamer rigidity, whereas alkyl chains have minimal incidence on its mechanical properties. We also observe that mutations in the active site are equally perturbative as PEG or polythymine.

We suggest that the rational design of aptamer-based biosensing devices calls for a precise modeling of surface grafting and envision that our tool is readily adapted to face this challenge

Main article & communications:

RVSI12266 : Appl. Phys. Lett., 100, 163702 (2012)
3 international invited talks: **CII11075, CII12062, CII12158**

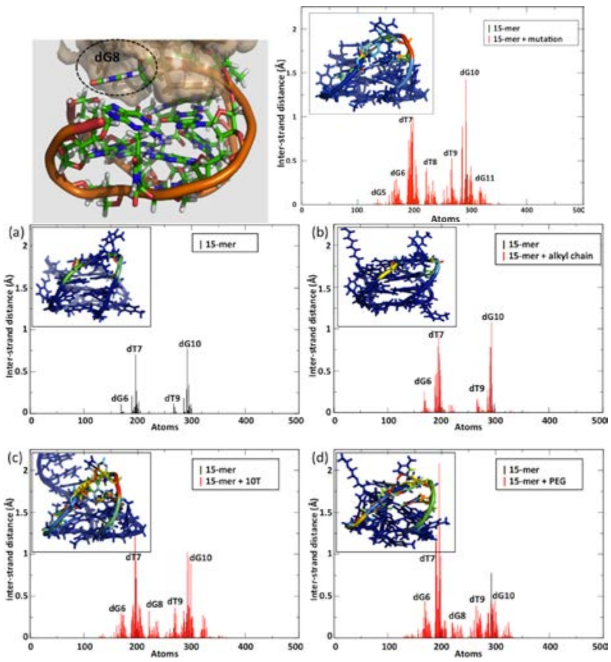


Figure 4: Schematics of dG7-dG10 distance variations induced by systematic excitation (on each of the 500 atoms) for the mutated G8T TBA.

2.1.2 Nanoengineering of Flows

Fabricated nanochannels: model nanoporous media

F. Chauvet, L. Djeghlaf, S. Geoffroy, A. Hamoumi, V.-N. Phan, N.-T. Nguyen, C. Yang, M. Prat, AM. Gué and P. Joseph

Abstract: Control and understanding of flows inside fabricated nanochannels is rich of potential applications such as biomolecule analysis or energy conversion, but nanoscale physics of fluids still remains to be clarified. We report an experimental and modeling investigation of capillary filling in nanoslits (depth 20-400 nm). Filling kinetics is shown to be slightly slower than predicted by hydrodynamics. Role of gas through trapped bubbles during nanoslits capillary filling is analyzed thanks to experiments realized with water, ethanol and silicone oil in silicon-glass nanochannels. Bubbles are trapped only when slit depth is below a liquid-dependent threshold. This is interpreted as possible contact line pinning strength varying with wettability. Influence of bubbles presence on the capillary filling kinetics is modeled, as well as gas pressurization ahead the meniscus.

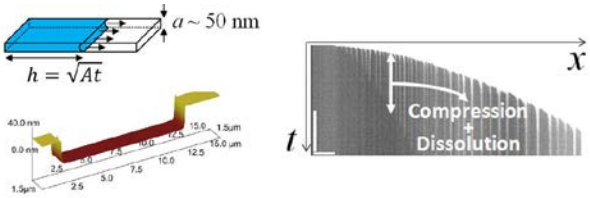


Figure 5: Capillary Filling of Nanoslits: design, AFM image showing channel topography, and filling kinetics illustrating bubble formation and dissolution.

This study opens the path to using fabricated nanochannels to gain insight into flows in real nanoporous media, for applications to oil recovery, transfers in concrete or nuclear waste storage.

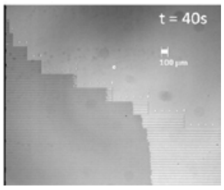


Figure 6. Photo of Capillary Filling of 45nm thick channels.

Main articles & communications:

RVSI12245 : Soft Matter 8, 10738-10749 (2012)
RVSI10442 : Heat Transfer Engineering 32(7-8), 1-12 (2011)
RVSI11253 : Langmuir Vol.27 (11) 2011
3 international invited talks : **CII10349, CII12332, CII13238**
4 conference proceedings

2.1.3 Nano-engineered Reactive Materials and Devices

Interfacial chemistry in Al/CuO reactive nanolaminates

J. Kwon, J.M. Ducéré, P. Alphonse, M. Bahrami, M. Petrantoni, J.F. Veyan, C. Tenailleau, A. Estève, C. Rossi, Y. J. Chabal

Abstract: Interface layers between reactive nanolaminates or nanoenergetic materials are believed to play a crucial role in the properties of nanoenergetic systems since they control reaction kinetics and stability at low temperature. So far, the formation of these interfacial layers is not well-understood for lack of *in-situ* characterization, leading to a poor control of important properties.

We have combined *in-situ* infrared spectroscopy and *ex-situ* X-ray photoelectron spectroscopy, differential scanning calorimetry, and high resolution transmission electron microscopy, in conjunction with atomic scale deposition method and first-principles calculations to identify the stable configurations that can occur at the interface. We find that (i) an interface layer formed during physical deposition of aluminum is composed of a mixture of Cu, O and Al through Al penetration into CuO, and constitutes a poor diffusion barrier; and in contrast (ii) atomic layer deposition (ALD) of Al_2O_3 using trimethylaluminum (TMA) produces a conformal coating that effectively prevents Al diffusion even for ultra-thin layer thicknesses (~0.5 nm), resulting in better stability at low temperature and reduced reactivity.

This work reveals that it is the nature of the monolayer interface between CuO and Al_2O_3/Al rather than the thickness of the Al_2O_3 layer that controls the kinetics of Al diffusion, underscoring the importance of the chemical bonding at the interface in these energetic materials.

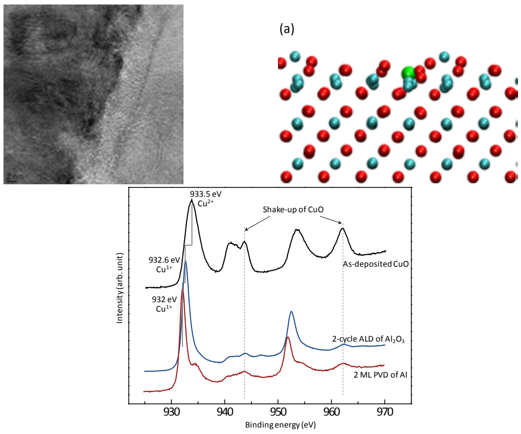


Figure 7: HR-TEM images of the interface between sputter-deposited Al and CuO. DFT modelling illustrating the penetration of Al atom into the CuO Subsurface and amorphization of the layer. FTIR diagram supporting same conclusions.

Main articles & communications:

RVSI12118 : Appl. Mater. Interfaces, 5, 605–613 (2013)
RVSI10278 : J. Appl. Phys. 108 (1), 084323 (2010)
6 international invited talks: **CII11046, CII11200, CII11647, CII12161, CII13099, CII13696**
2 Invited articles: **RVSII10085, RVSII14111**
3 invited seminars in US universities (John Hopkins Un., Un. South. Cal, Un. Maryland)
1 invited article in International Innovation: Research Media Ld (2013)

2.1.4 DNA Nanotechnology: Sensing for Life Sciences and Assembling for Technologies

Genome Architecture and Dynamics Studied in Living Yeast

H. Hajjoul, J. Mathon, C. Normand, J.M. Victor, O. Gadal, K. Bystricky, A. Bancaud

Abstract: Chromosome dynamics are recognized to be intimately linked to genomic transactions, yet the physical principles governing spatial fluctuations of chromatin are still a matter of debate. Using high-throughput single-particle tracking, we recorded the movements of nine fluorescently labeled chromosome loci located on chromosomes iii, iv, xii, and xiv of *Saccharomyces Cerevisiae* over an extended temporal range spanning more than four orders of magnitude (10–2–103 sec). Spatial fluctuations appear to be characterized by an anomalous diffusive behavior, which is homogeneous in the time domain, for all sites analyzed. We show that this response is consistent with the rouse polymer model, and we confirm the relevance of the model with Brownian dynamics simulations and the analysis of the statistical properties of the trajectories. Moreover, the analysis of the amplitude of fluctuations by the rouse model shows that yeast chromatin is highly flexible, its persistence length being qualitatively estimated to <30 nm. Finally, we show that the rouse model is also relevant to

analyze chromosome motion in mutant cells depleted of proteins that bind to or assemble chromatin, and suggest that it provides a consistent framework to study chromatin dynamics. We discuss the implications of our findings for yeast genome architecture and for target search mechanisms in the nucleus.

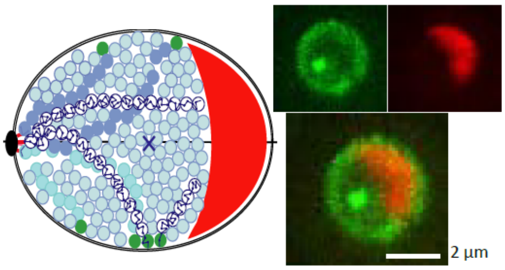


Figure 8: Live cell imaging of living yeast allows for the detection of the nucleolus, one chromosome locus, and the nuclear periphery, which appear as a red region, a green spot, and a green rim in the right panel, respectively. The analysis of spatial fluctuations defines an architectural model of the yeast based on polymer physics, as represented in the left panel.

Main articles & communication:

RVSI13284 : Genome Research (2013) 23: 1829-1838.
RVSI13278 : S. Huet (2013) International Review of Cell and Molecular Biology;
RVSI13283: Albert, Mathon (2013) Journal of Cell Biology
1 international invited talks: **CII13237**
2 books contributions: **OPI09401, OPI10244**

High Energy Al/Cuo Nanocomposites Obtained by DNA-directed Assembly

A. Esteve, A. Bancaud, F. Severac, C. Rossi

Abstract: Nature possesses an extraordinary capacity to assemble complex nanostructures that have active and specialized functions. Our ability to precisely position distinct components providing rich functions on the nanometre scale remains a key goal in nanotechnology and materials science. Bioinspired fabrication method has raised considerable interest in the nanotechnology community for it provides a unique way to engineer high-performance and multifunctional materials or systems, thus opening new area in material and electrical engineering. Among promising bioinspired fabrication method, DNA technologies has emerged as one of the most powerful 'bottom-up' approach with a unique possibility to build hierarchical architectures of various nanoobjects, including molecules, nanoparticles, nanoelectronic components…, keeping the fabrication protocol nearly identical. We exploit DNA technology to engineer new advanced energy-generating materials capable to produce tunable heat, gas and chemical species. A DNA-based assembly protocol of Al and CuO nanoparticles to form a micron size particle of Al/CuO nanothermite has been developed. Two strategies were followed to bind oligonucleotides on Al and CuO nanoparticles: thiol-modified oligonucleotides were attached to CuO nanoparticles and biotin-(neutr)avidin system was employed to coat Al nanoparticles. In the first case, the strong affinity of thiol groups for copper oxide allows to directly graft thiol modified oligonucleotides to CuO nanoparticles. In the second case, neutravidin is adsorbed on the thin alumina shell covering the aluminum NanoParticles, and biotin modified oligonucleotides are grafted on these protein modified NPs. Micron sized self-assembled Al/CuO nanothermites were obtained through DNA hybridization as illustrated in Figure 9 and Figure 10. We have characterized the resulting Al/CuO nanothermites giving a total heat of reaction of 1800 J/g which is among the best ever achieved. We also demonstrated the possibility to tune the onset temperature by changing the size of aluminum NanoParticles while keeping the same assembly protocol.

Figure 9. Schematics of the different steps for the DNA-directed assembly of Al/CuO thermite nanothermites. Al and CuO nanopowders are first suspended and stabilized in aqueous solution, then functionalized with single DNA strands, and eventually assembled through hybridization of complementary DNA strands.

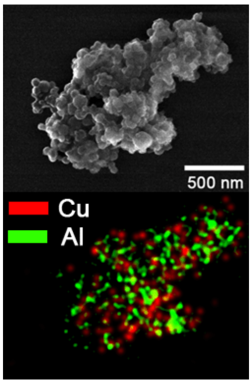


Figure 10. Scanning electron micrograph of one individual Al/CuO aggregate of ~2µm.

Main articles & communications :

RVSI11256: Severac, F. et al. Adv Funct Mater 22 (2012).
3 related international invited talks: **CII10994, CII12161, CII14110**
1 full article in « Technique de l'Ingénieur » - 2012
Several reports in *le monde, science et vie, CNRS site, La revue de l'université Paul Sabatier, les technique de l'ingénieur, le petit illustré de chimie….*

2.1.5 MEMS and BioMEMS

On Chip Magnetic Actuator for Batch-Mode Dynamic Manipulation of Magnetic Particles in Compact Lab-On-Chip

R. Fulcrand, A. Bancaud, C. Escriba, Q. He, S. Charlot, A. Boukabache, AM. Gué

Abstract: Based on the use of the photosensitive polymer (SU8), it has been developed a compact technology allowing to obtain bioMEMS whose action is based on the magnetic fields created by integrated micro-coils. This type of system has been used to perform spatial fluidic manipulations of magnetic

micro-particles whose the functionalized surface contains biological molecules. The magneto-fluidic characterizations have been conducted and they inbdicated that microbead batches can be manipulated in continuous flow along controlled spatial pathways. Because micro-electromagnets are individually activated by sequential current actuations, our microfluidic system is reconfigurable. The technology therefore has a unique potential to design and monitor complex architectures of actuators with excellent spatial precision. The time to transport microbead batches from one site to the next is short compared to the time of, e.g., enzymatic reactions, or purifications. Thus, unlike any other approach, micro-coils arrays allow to simultaneously process multiple batches of particles by synchronizing the injection of beads in the channel and the actuation of micro-coils.

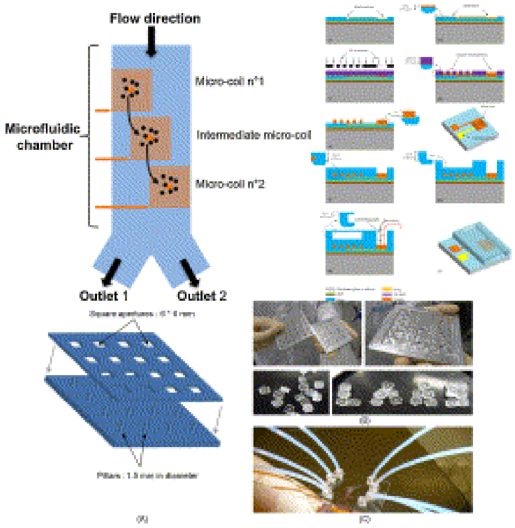


Figure 11: Schematic view of the magnetic lab-on-chip, its manufacturing process and photos of the final assembly

Main articles & communications:

RVSI11573: Sensors & Actuators B: Chemical, Vol.160, N°1 (2011)

2.1.6 Structural and Human Health Monitoring

New Real-Time Structural Health Monitoring Microsystem for Aircraft Propeller Blades

C. Escriba, JY. Fourniols, M. Lataspis, JL.Boizard, G.Auriol, S.Andrieu

Abstract: This system allows blade monitoring to be conducted using computing algorithms. Using a top-down modeling method, this recorder can be adapted to any kind of blade. In this article, recorder was devised for a Transall plane blade. This device was used to record data in order to subsequently compute a real-time blade monitoring algorithm. Our demonstrator works based upon the following processing procedure: it first stores one second of data in its memory. After analyzing blade eigenfrequencies, it detects whether an impact has occurred. It then computes a spectral energy analysis to compare various eigenfrequency levels. Finally, it indicates the location of the impact.

Main articles & communications:

RVSI11540 : IEEE Aerospace and Electronic Systems Magazine, Vol.27, N°2, pp.29-41 (2012)
RVSI12506 : Sensors, 12, 13617-13635
RVSI11536 : Journal of Energy and Power Engineering, Vol.6, N°7, 1042-1049 (2012)

A Wireless Wearable Smart Sensor for Health Monitoring of Alzheimer's

Y. Charlon, E. Campo, W. Bourennane, D. Brulin, D. Estève

Abstract: A smart monitoring system based on low cost and infrared (IR) presence sensors and a wireless wearable electronic tag has been designed and developed to help and monitor frail people activity. Based on the use of MEMS devices like accelerometer, the body sensor has been developed to integrate the functions of fall detection, localization, identification in order to describe activity motions of Alzheimer's patients. This set of devices constitutes a network connected to a personal computer (PC) which contains acquisition and analysis algorithms to detect abnormal situations and trigger alarms in case of deviation from normal daily lifestyle. Experiments have been made in hospital during several months with medical staff.

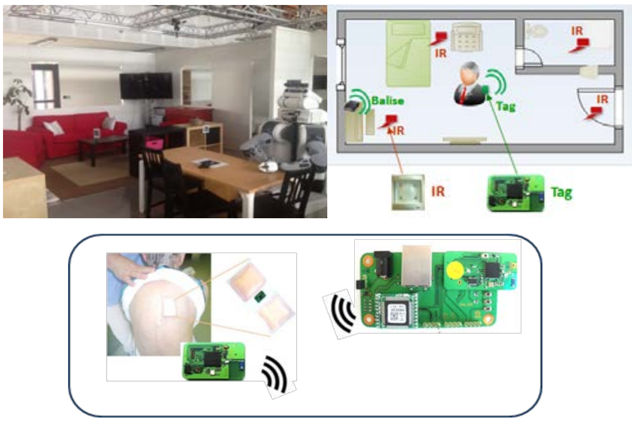


Figure 12: Schematic view of the embedded wireless tag and beacon designed to monitor health parameters

Main articles & communications:

RVSI13377 : Expert Systems With Applications, Vol40, N°18 (2013)
RVSI13378 : Sensors, 13, 11728-11749
RVSI13028 : IRBM, Vol.34, 1, 63-63, mars 2013
RVSI13162 : IRBM, Vol.34, 2, °292-100, Avril 2013
Entreprises Midi-Pyrénées, N°36, pp.42-44, juin-juillet 2013

2.2 Selected Scientific Publications

All the N2I scientists have published their results in international journals. In the evaluation period, the number of peer-review scientific articles issued in international journal is 135, corresponding to a rate of 30 per year. When divided by the number of Research Full Time Equivalent[2], it gives a mean number of 2 per RFTE and per year. We also contribute to 8 books. Interestingly, we have deposited or co-signed 6 patents in the period. Finally, we gave 27 invited talks in international conferences.

[2] EC count for 0.5 and CNRS researchers count for 1.

RICL Scientific articles issued in international journals	135 *~2 per* Research Full-Time Equivalent and **per year**
OP: Books contribution	8
CII: International invited conferences	27
Patents	6

A selection of 35 scientific references is given below to illustrate our scientific contribution during the evaluation period.

2.2.1 High IF or High Citations or Significant Impact

RSI08372: Hemeryck, A. et al., Fundamental steps towards interface amorphization during silicon oxidation, **Physical Review B**, Vol.B79 (2009)

RVSI09403: Bancaud, A. et al., Molecular crowding affects diffusion and binding of nuclear proteins in heterochromatin and reveals the fractal organization of chromatin. **Embo** J 28 (2009).

MAI08485: Chan, M. et al., Individual Movement Trajectories in Smart Homes. **Ifmbe Proc** 23, 1014-1018 (2009).

RVSI09404: Hajjoul, H. et al., Lab-on-Chip for fast 3D particle tracking in living cells. **Lab Chip** 9 (2009).

RVSI09826: Lavelle, C. et al. Right-Handed Nucleosome: Myth or Reality? **Cell** 139 (2009).

RVSI09040: Suhard, S. et al. When Energetic Materials, PDMS-Based Elastomers, and Microelectronic Processes Work Together: Fabrication of a Disposable Microactuator. **Chem Mater** 21(2009).

RVSI09047: Zhang, K. et al. Integrating Al with NiO nano honeycomb to realize an energetic material on silicon substrate. **Appl Phys a-Mater** 94 (2009).

RVSI10504: Audry, M. C. et al., Amplification of electro-osmotic flows by wall slippage: direct measurements on OTS-surfaces. **Faraday Discuss** 146 (2010).

RVSI101004 : Brut, M. et al. Atomic-scale determination of DNA conformational response to strained furanose a static mode approach. **Tetrahedron** 66 (2010).

MAI10264 : Campo, E. et al., Behaviour monitoring of the elderly by trajectories analysis. **Ieee Eng Med Bio**, 2230-2233 (2010).

RVSI10060: Michalak, D. J. et al. Nanopatterning Si(111) surfaces as a selective surface-chemistry route. **Nat Mater** 9 (2010).

RVSI10805: Zhou, H. W. et al., Simulation model and droplet ejection performance of a thermal-bubble microejector. **Sensor Actuat B-Chem** 145 (2010).

RVSI11073: Brut, M. et al. Atomic Scale Determination of Enzyme Flexibility and Active Site Stability through Static Modes: Case of Dihydrofolate Reductase. **J Phys Chem B** 115 (2011).

RVSI11573: Fulcrand, R. et al. On chip magnetic actuator for batch-mode dynamic manipulation of magnetic particles in compact lab-on-chip. **Sensor Actuat B-Chem** 160 (2011).

RVSI11252 : Hajjoul, H. et al., Optimized micromirrors for three-dimensional single-particle tracking in living cells. **Appl Phys Lett** 98 (2011).

RVSI11253: He, Q. H. et al., Directed Assembly of Nanoparticles along Predictable Large-Scale Patterns Using Micromolded Hydrogels. **Langmuir** 27 (2011).

RVSI11443 : Lavelle, C. et al. Chromatin Topological Transitions. **Prog Theor Phys Supp**, 30-39 (2011).

RVSI11206 : Renvez, G. et al. The electrostatic probe: a tool for the investigation of the A beta(1-16) peptide deformations using the static modes. **Phys Chem Chem Phys** 13 (2011).

RVSI11614: Viero, Y. et al., Hydrodynamic Manipulation of DNA in Nanopost Arrays: Unhooking Dynamics and Size Separation. **Small** 7 (2011).

RVSI11315: Zahi, I. et al., Micro PEM fuel cell current collector design and optimization with CFD 3D modeling. Int J **Hydrogen Energ** 36 (2011).

RVSI11615: Bancaud, A. et al., Fractal model for nuclear organization: current evidence and biological implications. **Nucleic Acids Res** 40 (2012).

RVSI12266: Brut, M. et al. Bringing aptamers into technologies: Impact of spacer terminations. **Appl Phys Lett** 100 (2012).

RVSI12422 : Lanthony, C. et al. On the early stage of aluminum oxidation: An extraction mechanism via oxygen cooperation. **J Chem Phys** 137 (2012).

RVSI11256 : Severac, F. et al., High-Energy Al/CuO Nanocomposites Obtained by DNA-Directed Assembly. **Adv Funct Mater** 22 (2012).

RVSI11616: Viero, Y. et al. Efficient prototyping of large-scale pdms and silicon nanofluidic devices using pdms-based phase-shift lithography. **Microfluid Nanofluid** 12 (2012).

RVSI13277: He, Q. H. et al. Conformational Manipulation of DNA in Nanochannels Using Hydrodynamics. **Macromolecules** 46 (2013).

RVSI12118: Kwon, J. et al. Interfacial Chemistry in Al/CuO Reactive Nanomaterial and Its Role in Exothermic Reaction. **Acs Appl Mater Inter** 5 (2013).

RVSI11403 : Chan, M., et al., Smart wearable systems: Current status and future challenges. Artificial Intelligence in Medicine, 2012. **56**(3): p. 137-156.

Viero, Y., et al., Single molecule study of DNA collision with elliptical nanoposts conveyed by hydrodynamics. Electrophoresis, 2013. **34** (24): p. 3300-3304

2.2.2 Review Papers

RVSI09620: Chan, M., Campo, E., Esteve, D. & Fourniols, J. Y. Smart homes - Current features and future perspectives. **Maturitas** 64 (2009).

RVSI11403: Chan, M., Esteve, D., Fourniols, J. Y., Escriba, C. & Campo, E. Smart wearable systems: Current status and future challenges. **Artif Intell Med** (2012).

RVSII14111: Rossi, C., Two decades of research on nanoenergetic materials, **Propellants, Explosives Pyrotechnics**, *39* (2014).

2.2.3 Books, Edition of Special issues, Invited Papers

OAN10876 : JY. Fourniols, C. Escriba, Systèmes électroniques analogiques. Amplification, filtrage et optronique, **Presse Universitaires du Mirail** (Sept, 2010)

RVSII10085 : C. Rossi, A. Esteve, P. Vashishta, Nano scale energetic material, **Journal of Physics and Chemistry of Solids** 71 (2010)

RVSII14111: Rossi, C., Two decades of research on nanoenergetic materials, **Propellants, Explosives Pyrotechnics**, *39* (2014).

2.3 Tools and Demonstrators

Numerous tools and demonstrators have been produced and demonstrated. A list and some illustrations are given hereafter.

2.3.1 Tools and Software Packages

- **FLEXIBLE**: Biomolecular flexibility
- **APTACAD**: Aptamer twizers design
- **COCOA**: Al/CuO PVD simulation package
- **PEM CAD**: Collector design and optimization
- **SACER**: simulateur de réseaux de capteurs

2.3.2 Demonstrators

µIFI: *Micro allumeurs sécurisés et redondés pour fonction terminales de lanceurs spatiaux*

APTE: *Micro allumeurs sécurisés pour propulseurs militaires*

BEA: *Bracelet électronique*

FIL: Système multicapteurs de localisation de personne

FOOTEST: *Semelle intelligente*

HOMECARE: A complete monitoring system for dependent old people experimented in real site (retirement home).

3 Academic Reputation and Appeal

3.1 Main International and National Collaborations

In the evaluation period, N2I researchers have conducted 48 national and international projects. Approximately 20% of the support comes directly from industry and much of the reminder comes from the various funding schemes : 10 ANR, 2 PIA[3], 2 Plan Cancer & RITC[4] , 10 projects funded by Regional funds or others : DGA (Direction Générale de l'Armement), CNES (Centre National Etudes Spatiales), CEA (Commissariat à Energie Atomique). Two third has been leaded by N2I staff.

It has to be noted that N2I has an ERC (*Equipe Recherche Commune*) with the CEA-Saclay on the topic of simulation.

Finally, in the evaluation period, three N2I researchers participated actively in regional FERMAT federation along two axes: "microfluidics" and "materials and applications".

3.1.1 International Collaborations Including Europe

N2I researchers collaborate with universities and labs all around the world (see Figure 13) through conventional partnerships (International labs, Partner University Funds, Erasmus, Ulysses programs) or within long-term non-officially established collaborations.

N2I researchers were active during the 7th European Framework Program and proposed 4 main projects unsuccessfully.

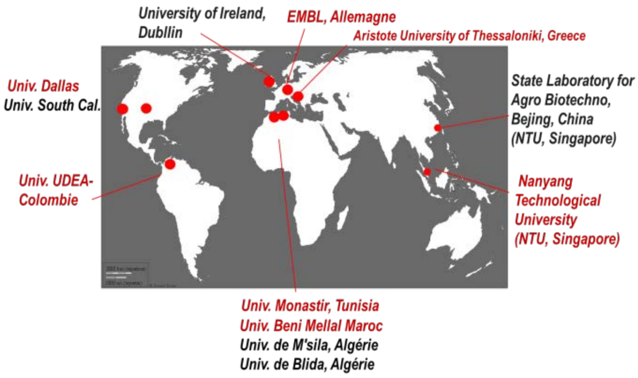


Figure 13: Mapping of N2I international collaborations Red: long-term collaborations - Blue : punctual collaborations

3.1.2 National Collaborations

N2I researchers develop their research in collaboration with a network of French laboratories (see Figure 14) within academic projects or through unfunded long-term partnerships.

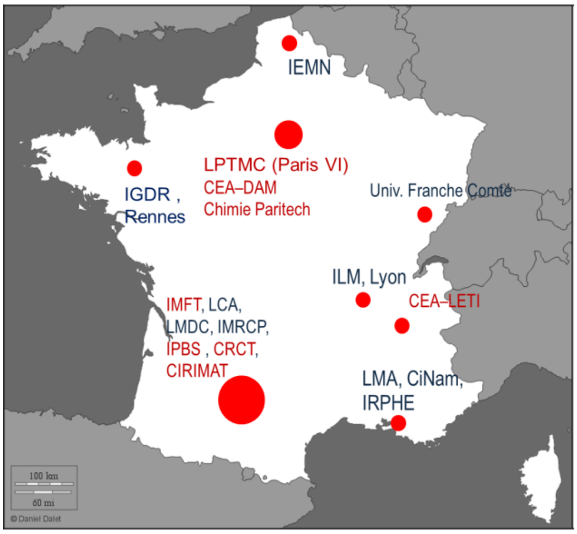


Figure 14: Mapping of N2I national collaborations Red : long-term collaborations - Blue : punctual collaborations (on project)

[3] *Plan Investissement Avenir*
[4] *Recherche et Innovation Thérapeutique en Cancérologie*

3.2 Journal Editorial Boards

N2I researchers participate to editorial boards upon request. In the evaluation period, only one senior researcher is on the board of two journals: *Techniques de l'ingénieur: Nanotechnologies* and *Wiley, Propellants, Explosives, Pyrotechnics, since 2011,*

3.3 Organization of Major Conferences and Workshops

Some N2I Researchers are actively involved in the organization of international workshops / symposium in their scientific areas.

3.3.1 Chair/Co-Chair/Lead Symposium

In the evaluation period, four researchers were solicited regularly to chair workshops or symposiums in international conferences such as MRS (Material Research Society) conferences, IEEE conferences, AVS and ACS conferences. We count 5 Chair/Co-Chair/lead Symposium in international conferences.

3.3.2 Members of Organization Committee

In addition, many N2I researchers are for several years members of international conferences organization committee such as µFLU, p-Health, IADIS on Computer Science and Information Systems, IEEE-EMB HEALTHINF, IEEE Healthcom, IEEE CAMAD, IEEE Intern. Conf. On Signal Circuits and Systems.

3.4 Technical Program Committees

Two N2I researchers were members of International Conferences Program Committees: PowerMEMS (3 consecutive years) and Eurosensors (5 consecutive years).

3.5 Steering Committees

Several N2I researchers actively participated to national and international Steering Committees such as µFLU (since 2010) and STIC santé GDR, MicroNanoFluidique GDR.

3.6 Major and Long Term Visits

3.6.1 Sojourns of Researchers Abroad

Four current N2I researchers have done a long-term sojourn in foreign Universities. One associated professor spent 2 years in the University of Stanford under the supervision of Prof. Mickael Levitt, Nobel Prize 2013. One CNRS researcher spent one year in the University of southern California with Prof. Priya Vashista. Two CNRS researchers spent annually 1 month at the University of Dallas with the frame of the Associated Labo between CNRS (INSIS institute) and the University of Dallas.

3.6.2 Researchers Hosted

Four categories of hosted researchers is proposed:

2 Senior Visiting professors, hosted within the frame of a collaboration around a scientific topics. They are foreign permanent senior researchers or professor.

6 Engineers. They are hosted to drive one maturation project or for prototyping action.

21 **Post-docs, being hosted to support a project and 50 PhDs**. Most of foreign PhD students and Post-docs are coming from Europe and North Africa.

3.7 Scientific Evaluation Committees

The N2I researchers have been regularly invited to participate to different National evaluation panels (ANR, Universities calls), European evaluation panels (FP7-NMP, ICT) as well as to be part of international boards (Austrian Science Foundation, DARPA-MTO, ICHEC Irish Center for High-End Computing…).

3.8 Major Roles in National Animation and Evaluation Structures

Several N2I researchers acted as members or presidents of researcher Selection Committees from CNRS or Universities.

Two of our CNRS are actual Presidents: one is president of CNRS National Committee (CoCNRS 54) and the other one is president of the University Council (CNU 28). One N2I CNRS researcher has been elected as members of CoNRS 08.

Several professors had a chair in local committees as : Conseil National des Universités 28ème section, Commission Permanente du Conseil National des Universités (all sections), Instance Nationale Spécifique d'Avancement de Grades (Interdisciplinar council), Toulouse University scientific college EEA, Commission INSA.

One CNRS researcher is part of the Commission des Droits de l'Homme de la Société Française de Physique

3.8.1 Scientific Networks & GDRs, …

Many N2I researchers are actively involved in various scientific networks and national research groups (such as GDR, OMNT working group (one OMNT working group was leaded by a N2I researcher in 2009-2010).

One CNRS researcher of N2I is at the origin of the GDR Microfluidic and we are actively involved in the current Microfluidic & MicroNanoSystems GDR. Also, N2I researchers actively participate to SoC-SiP and ANR GDR. And one CNRS researcher is part of the ANR GDR's bureau.

Importantly, N2I is at the origin of COST- EC FP7 COST – DNA. Currently, one CNRS researcher participates to the management committee and is a workgroup leader *"Biomechanisms and molecular modelling"*.

3.9 Scientific Societies

Four of the N2I scientists are members of scientific societies: American Chemical Society, European Materials Research Society, International Society for Gerontechnology, IEEE (Institute of Electrical and Electronics Engineers).

3.10 Awards and Distinctions

Several awards were granted to N2I scientists and students during the evaluation period:

- Price for the best talk, MRS – Boston, nov. 2012

- Numerous prices for best talks in national colloques
- 1° Prix Syntec partenariat Grand Groupe PME
- INP best thesis
- 4 GEET doctoral school best thesis
- 3AF prize in 2014

4 Interaction with Social, Economic and Cultural Environment

4.1 Projects with Industrial Partners

N2I research has strong connections to local and national societal and economic environments. The different industrial partnerships can be classified into three main categories: ***Longterm Partnership*** (durable collaboration around one scientific topic), ***Project Collaborations*** (collaboration around one scientific project) and ***Industrial Transfer*** detailed in Section 4.2: *Major Innovations Activities*.

- *Long-term Partnerships*. We have long-term industrial collaborations on three research topics :
  - Nanothermites and pyroMEMS such as safe arm and fire systems with 2 different companies: ROXEL and DASSAULT-AVIATION.
  - MEMS based Monitoring for domotic (confort and safety) application with companies such as SIGFOX, EDF and Orange
  - Structural Health Monitoring aeronautic with EADS-IW, RATIER, AIRBUS.

This type of relationship fits both with industrial objectives and academic ambitions: the scientist is fed by applicative needs and industrial constraints to enrich his (her) positioning and drive his (her) scientific prospective and on the other side the industrial partner takes profit of the researcher expertise and MEMS technologies to enrich his (her) product and know-how.
Numerous long-term industrial relationships are a real chances for N2I theme since it also provides recurrent funding permitting to have long-term visibility and push forward innovative research in a few emerging field.

- *Project collaborations*: here the partnership is built temporary to respond to a specific call or to answer a specific industrial request. It is often based on the initiative of industrial partners looking for specific expertise to national or regional Calls. During the evaluation period we had the opportunity to collaborate with companies such as Bioneff, Telegrafik, Studelec, Pierre Fabre, Soben racing, Sefee, TCSD. In the evaluation period, we have contracted ~ 50 industrial partnerships entering in this category. These are direct or through ANR or regional fundings. 10% of these projects are 1 year project and 90% is 3-years projects.

4.2 Other Major Innovation Activities

In the evaluation period, we started four industrial transfers, two of them through TTT scheme.

TTT transfer**: MicroLAS with picoMetrics aims** the valorization of different microfluidic methods and technologies developed by N2I researchers (CNRS patents WO/2014/020271 / PCT/FR2013/051821) and permitting the manipulation and separation of biological molecules and cells in solution with the potentiality of large-scale analysis compared to the well-known sequencing method. **MicroLAS** will be a fully integrated Micro-fluidic Biochips for DNA analysis. The main addressed application is genomics research but it can also find industrial applications for toxicology tests since the damage after biological or chemical threat can be deduced from an analyzing of the DNA fragment size and sequence.

***TTT transfer* with Adveez**. This starting project aims at prototyping and diffusing softwares for elderly fall detection. 2 patents in which N2I researchers are authors are being deposited.

NanoLUCS with LED (start-up). This transfer project is leaded by 3 LED engineers and aims at developing a novel micro-fluidic bacterial biosensor for water toxicity based on the using of bioluminescence detection.

µIFI with Dassault-Aviation. One N2I researcher is implied in a pyroMEMS technological transfer for space application. The full pyrotechnical system development is taken in charge by an engineer from Dassault-Aviation; N2I provides pyroMEMS chips to be integrated and assembled in the Dassault product. We obtain the 3AF prize in 2014 on this technology.

4.3 Scientific Popularization

Scientific popularization is considered favorably by N2I scientists. In the evaluation period, we frequently communicated on the topics mentioned in salient fact section and different journals were addressed : *le monde*, *science et vie*, *Chocs Avancées*, *La Micro-nanoélectronique*, *Le journal du CNRS*, *Les techniques de l'ingénieur*, *Le petit illustré de chimie*….

We also participated to specific manifestations such as *La NOVELA* (organized by la marie de Toulouse), les *Journées Annuelles de la Société Française de Gériatrie et Gérontologie*….

Upon sollicitation, researchers participated in round table and took part of public debates such as the *Colloque international de l'Université du Mirail*, le *Salon Futurapolis*, etc.

Importantly, N2I researchers participated regularly to the annual organization of the "Fête de la Science". We always proposed 3 demonstrations and actively participated to the public welcome.

Two scientists also wrote a 4-pages article in two international journals, **International Innovation** and **Pan European Networks.**

5 Involvement in Training through Research

As already mentioned, N2I researchers share one important mission which is to promote micro-nanotechnology through education. We annually train more than 20 masters and ~18 PhD students. It gives a total of 50 PhD students for the evaluation period, corresponding to 2.7 students / N2I permanent. 80 % have found positions in companies in France directly after the PhD or after a post-doctoral position in

France or abroad. The rest found academic positions: one is ass. prof. at Franche Comté Univ, one is ass. prof. at Grenoble Univ., two are ass. prof at Toulouse Univ. and one became CNRS researcher.

Three master degrees are headed by N2I staff.

5.1 Leading Roles in Doctoral Schools

Three of N2I researchers are strongly engaged in Masters and Doctoral Schools management. One is the head of GEET Doctoral School (*Electrique, Electronique, Télécommunications*). Two researchers (one CNRS and one professor) supervise two Master of Research : *Micro and Nano technologies* (MNT) and *Ingénierie de la Matière : Modélisation des Processus Physiques* (IM2P2).

5.2 PhD and Internship/Master Programs

5.2.1 Thesis Supervised

During the evaluation period, the number of defended PhD thesis is 35 (corresponding to 3 defended PhD per permanent researcher).

5.2.2 Co-supervised Thesis

The co-supervised theses represent 30% of the overall PhD theses. We can distinguish three categories:

Intra-LAAS and Inter-theme: in the period, 2 PhD thesis were shared between GE and N2I.

Inter-lab: there are 2 Co supervised PhD thesis between LAAS and IPBS, 1 co supervised PhD thesis LAAS and IMFT, 2 Co-supervised PhD thesis LAAS and CIRIMAT, 1 Co-supervised PhD thesis LAAS and LATTIS, 1 co-supervised PhD thesis LAAS and INSERM

International co-tutelles: N2I built two university *co-tutelles*: there was one PhD thesis between LAAS and LBME in Germany and one is ongoing between Univ. of Toulouse – LAAS-CNRS and the Univ. of Texas in Dallas. It is important to outline that a Chateaubriand fellowship has been granted in 2014 to support this LAAS/UTD PhD thesis.

5.3 PhD/HdR Committees (outside the University of Toulouse)

A ratio of 50 % of the N2I permanent researchers (9 over 19) have the Habilitation to conduct their Research (HDR) and therefore are requested regularly to be examiner for PhD or HDR thesis defense committees. Over the evaluation period, the N2I researchers participated **as examiner** to 27 PhD thesis, 5 HDR and 5 foreign PhD thesis committees.

5.4 Faculty Selection Committees

Several N2I researchers acted as members or presidents of Faculty Selection Committees from national and international Universities.

VIII - Micro Nano Bio Technologies (MNBT)

Leader: Liviu NICU

Research Teams: High Frequency and Fluidic Microsystems (MH2F), Microsystems for Analysis (MICA), Materials and Processes for Nanoelectronics (MPN), Nano Bio Systems (NBS)

Keywords: Nanoelectronics, nanomaterials integration, biosensing, chemosensing, living cells analysis

Personnel Status (as of June 30, 2014):

Team — MPN	Materials and Processes for Nanoelectronics
Leader	Fuccio CRISTIANO (CR)
Permanent Researchers	Eléna BEDEL-Pereira (CR), Guilhem LARRIEU (CR) (arrived Sep. 2010), Francois OLIVIE (Prof.)(left Jan. 2014), Sébastien PLISSARD (CR) (arrived Dec. 2013), Emmanuel SCHEID (CR)
PhD Students (Arrival date)	F. SEVERAC (2005-2009), M. BAZIZI (2006-2010), J. BOUCHER (2008-2012), M. COLLET (2009-2013), Z. ESSA (2010-2013), Y. GUERFI (2011-2014), N. KLEIN (2011-2014), A. CASANOVA (2013-2016), B. DURAND (2013-2016)
Post-docs; Engineers	P.F. FAZZINI (2007-2010), A.M. BELTRAN (2010-2012), V. MORTET (2011-2013), C. NYAMHERE (2011-2013), Y. QIU (2013), G.T. ORTIZ-HERNANDEZ (2013)
Visiting Researchers	E. Talbot (2009)
Team - MICA	Microsystems for Analysis
Leader	Philippe MENINI (MCF-HDR)
Permanent Researchers	Véronique BARDINAL (DR arrived 9/2/2012), Ludivine FADEL (MCF) (left ->1/11/2012), Jérôme LAUNAY (MCF), Philippe MENINI (MCF-HDR), Gérard SARRABAYROUSE (DR) (retired in 06/2013), Isabelle SEGUY (CR), Pierre TEMPLE-BOYER (DR), Francois OLIVIE (Prof.)(arrived Jan. 2014)
PhD Students (Arrival date)	P. YAMEOGO (2007 – 2010), C. CHRISTOPHE (2007 – 2010), P. YOBOUE (2007-2010), H. HALLIL (2007 – 2010), F. SEKLI (2007 – 2011), A. CAZALE (2009 – 2012), L. DJEGHLAF (2009-2013), M. PALOSSE (2010-2013), N. DUFOUR (2010-2013), A.T TSOPELA (2011-2014), S. ABADA (2012-2015), A. LALE (2012-2015), B. DURAND (2013 – 2016)
Post-docs; Engineers	F. SEVERAC (2009 – 2010), E. VANHOVE (2010-2012), C. CHRISTOPHE (2010), F. SEKLI-BELAID (2013-2015), A. CHAPELLE (2013-2014)
Visiting Researchers (Affiliation, Country, Period)	C.H. SHIM (AlphaMos, South-Corea, 2009-2012), F. SEVERAC - M. L. POURCIEL - C. CHRISTOPHE - R. YUNE - A. CAZALE (Nanomade, France, 2011)
Team — MH2F	High Frequency and Fluidic Microsystems
Leader	Katia GRENIER (CR HDR)
Permanent Researchers	David DUBUC (MC 2009-2013; Prof. 2013-2014)
PhD Students (Arrival date)	Tong CHEN (2009-2012), Thomas CHRETIENNOT (2010-2013), François ARTIS (2011-2014), Marie DEBURGHGRAEVE (2013-2016), Amar TAMRA (2013-2016), Wenli CHEN (2013-2016)
Post-docs; Engineers	Pierre MEINERI (2010-2011), Hélène BATUT (2011), Hélène CAYRON (2012), Laura CHAUVET (2012), Jean-Pierre MARTIN (2014-2015)
Visiting Researchers	—
Team - NBS	NanoBioSystems
Leader	C. Thibault (McF)
Permanent Researchers	C. Bergaud (DR), A. Cerf (CR), E. Dague (CR), E. Descamps (CR), T. Leichle (CR), L. Nicu (DR), C. Vieu (PR), D. Saya (CR, left 1/09/2012 for LIMMS, Tokyo), JP Peyrade (PR, retired since 1/09/2010), B. Legrand (arrived 1/12/2013)
PhD Students (Arrival date)	L. Aoun (01/10/2011), A. Bhaswara (01/10/2012), V. Castagnola (01/10/2011), L. Chopinet (01/10/2010), A. Coutable (01/10/2010), A. Delaguarde (01/10/2012), B. Demain (01/10/2012), D. Dezet (01/10/2011), C. Formosa (01/11/2011), S. Habtoun (01/10/2012), Y. He (01/10/2012), R. Marchand (01/10/2012), M. Schiavone (01/02/2012), A. Simaite (01/10/2012), P. Teerapanich (01/10/2011), C. Tinguely (17/03/2006), T. Alva (01/10/2006), S. Salmon (01/10/2008), S. Guillon (01/10/2008), F. Seichepine (01/10/2008), A. Labernadie (01/10/2008), DTM LE (15/01/2009), A. Beduer (01/10/2009), A. Egea (01/10/2009), F. Larramendie (01/10/2009), N. Belaid (01/10/2009), E. Jauver (01/10/2009), J. Bareille (01/10/2010), H. Cayron (01/10/2013), A. Lecomte (01/10/2013), V. Lachaize (01/10/2013)
Post-docs; Engineers	J. Chalmeau, C. Séverac, L. Tanguy, C. Martin, P. Flavien, C. Quintero, C. Bartual, B. Salma, S. Houmadi, S. Gautier
Visiting Researchers	TREVISIOL Emmanuelle (CNRS, FR, 01/01/2010-30/12/2014)

1 Presentation

1.1 Objectives and Scientific Positioning

Scientists separate per disciplines. We tend to separate the social sciences from the natural sciences, chemistry from physics, and biology from psychology. As often seen, the life sciences are rarely included in the same academic department as the physical sciences and it is not uncommon for these fields to be taught in separate faculties. And even within the broad categories of life sciences or physical sciences, microbiologists are likely to be in separate departments from immunologists, while physicists may rarely interact with their chemist colleagues.

While the distinctions between disciplines are traditional, they are fast becoming less applicable as science crosses the boundaries that once existed. Are efforts to understand how biomolecules are grafting onto chemically-functionalized surfaces a facet of chemistry or biology? Are attempts to interrogate neurons with field-effect transistors a concern of physical science or of biology? Are studies related to robotics-dedicated artificial muscles made of polymers an issue related exclusively to physics, chemistry or biology? It is becoming increasingly irrelevant whether a particular research topic fits neatly into one discipline or another; in fact, many of the most interesting scientific questions and pressing societal issues are requiring the collective expertise from various and multiple fields. **These areas of overlap are the foundations and the focus of the MNBT theme**, where part of the events being studied cannot unambiguously be described as solely contained within the life or physical sciences. *While the thread which runs across the four teams of MNBT theme is linked to understanding and exploiting the physics of semiconductors to shape innovative micro(nano)devices and systems, the rationale at the intersection of the four teams' backgrounds is the translation of biological information in a measurable physical signal*. As a direct consequence, the MNBT research activity is fully circumvented by the ALIVE strategic axis of the laboratory.

Groups or departments sharing similar goals were already existing or have been set-out since MNBT was founded (January 2012):

- in France: at IEMN (MicroNanoSystems Axis), IEF (MEMS, Nanobiotechnologies Department), FEMTO-ST (MicroNanoSciences and Systems Department) and other labs (LTM, LPN, SATIE, IMS),
- in Europe: at EPFL (Switzerland), within the CIC microGUNE Center (Spain), at IMTEK (Germany),
- in Asia: at the Academia Sinica (Taiwan) or LIMMS-CNRS (Tokyo),
- in the USA: Stanford (Geballe Lab. For Advanced Materials), PennState University (Center for Nanomedecine and Materials), University of Illinois (Micro/Nanotechnologies Laboratory)…

When the theme was created, its activity was described as the concatenation of the activity of 4 separate teams. However, as the years went, the scientific animation within MNBT produced clear synergetic effects. The result is that now we have identified common scientific mainstreams shared by two (or more) teams within the theme and we build our future scientific roadmap accordingly.

1.2 Organization and Life

MNBT relies on four research teams, as presented in the first part of the report, each of them running its own scientific strategy and associated budget. Each team leader holds administrative and scientific meetings on a regular basis, involving the permanent and non-permanent staff.

The activity profile of each team is briefly indicated hereafter:

- MPN activities are mainly related to advance of knowledge in the nanoelectronics domain;
- MICA focusses on the integration of heterogeneous materials to develop microsystems for fluid analysis;
- NBS mainstream is dealing with enabling nanotechnologies for biology and medecine-related applications;
- MH2F deals with electromagnetic interaction with complex materials at the micro and nanoscales, for health and life sciences notably.

On top of the daily life of each team, the theme adds Scientific Councils on a bimestrial basis, dedicated to sharing organizational information as well as, when necessary, prioritizing multi-teams requests related to equipment purchase, soon-to-be available permanent positions profiles etc. The theme holds, as an endogenous initiative, Internal Strategic Seminars on hot topics (e.g. *Implantable nanodevices* or *Nanowires for biology*) aiming at state-of-the-art overview in a precise area and subsequent analysis of whether or not is relevant for the theme to commit efforts in such directions. Last but not least, benefiting from an annual budget exclusively dedicated to scientific animation, the theme invites external speakers to hold scientific seminars on a specific topic (e.g. Prof. Susan Trolier-McKinstry – PSU, Prof. Nicholas Melosh – Stanford, Prof. P. Juneau – UQAM etc.).

1.2.1 Activity Profile

Table 1 hereafter depicts the activity profile for the theme and gives also the profiles for the teams involved.

Table 1: Activity Profile

%	Academic research	Interaction with environment	Research Support	Training
MNBT	**56**	**15**	**13**	**15**
MPN	**56**	**16**	**11**	**17**
MICA	**53**	**17**	**15**	**15**
NBS	**59**	**16**	**13**	**12**
MH2F	**48**	**5**	**18**	**25**

1.2.2 Scientific Coordination

The theme is led by a senior scientist elected for a period of five years among the personal of the four teams encompassed by the theme. Besides what has been already described, his(her) roles are mainly:

- To set a permanent and clear link between the lab's top management and the four teams' leaders;
- To foster scientific activities inside the theme (across two or more teams) as well as outside the theme (inside or outside the lab);
- To promote the scientific activities and results of the theme during various meetings with a specific focus on two or more teams backgrounds.

1.3 Salient Facts

Several salient facts stemming have been selected and grouped hereafter in three specific categories: *Scientific Outputs* (when related to notable scientific results issued in highly ranked international reviews), *Workshops/Conferences* (when related to international events hosted by/chaired by MNBT teams' members) and *Industrial Hits* (when linked to industry-related achievements).

1.3.1 Scientific Outputs:

MNBT researchers, together with an IPBS Toulouse team, co-authored a paper issued in PNAS [RVSI10755] showing that podosome biophysical properties are amenable to Atomic Force Microscopy. The experimental method allowed the study of podosomes in living macrophages at nanoscale resolution (Figure 1) and the analysis of their intimate dynamics which opened new ways towards understanding of their mechanical properties under physiological and pathological contexts.

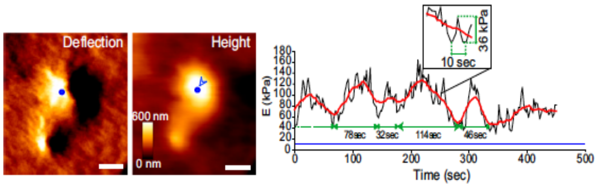


Figure 1: Podosome stiffness dynamics measured by timelapse AFM.Young's modulus variations over time of a podosome in a living human macrophage.(Scale bars, 0.5 µm.) Right: Curve of stiffness over time. Black curve corresponds to raw values, with small oscillations of stiffness (type I, Inset). Larger variations, type II, were identified on the smoothed curve (red curve)

The same team made the July 2009 Small cover [RVSI09901] demonstrating individual lymphocytes addressing on an arrayed Surface Plasmon Resonance prism following subsequent electrochemical functionalization with antibodies using silicon-made microcantilevers (Figure 2).

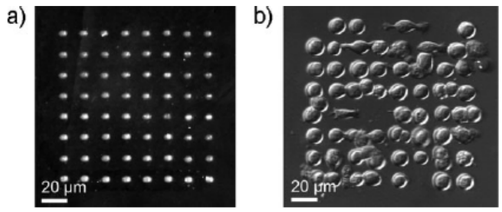


Figure 2: Microscope images of 64 spots (8x8) arrayed with a 20-µm pitch. a) Fluorescence image of arrayed rabbit IgG spots. b) Image of arrayed anti-IAb antibodies recorded after B-type lymphocyte incubation.

In a joint work with CNR-IMM Catania and CEMES Toulouse, MNBT researchers investigated and revealed damage evolution and dopant distribution during nanosecond laser thermal annealing of ion implanted silicon. The study, issued in Nano Letters[1], concluded on a possible modification of the defect formation energy induced by the compressive stress developed in the nonmelted regions during laser annealing (Figure 3).

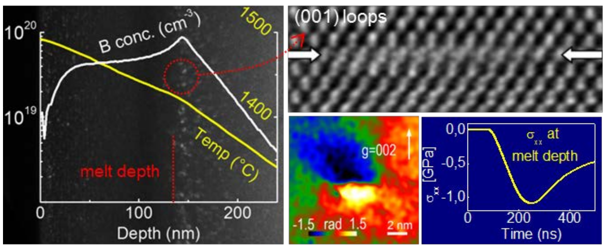


Figure 3: Left: SIMS boron profile (white curve) and corresponding cross-section TEM image after melt-laser annealing. Yellow curve: calculated depth variation of the peak temperature reached during laser annealing. Top right and bottom center: HRTEM image and corresponding geometric phase analysis of a (001) dislocation loop. Bottom right: stress variation as a function of annealing time calculated at a depth of 100 nm for a laser annealing at a temperature just below the melting threshold.

[1] Y. Qiu, F. Cristiano, K. Huet et al., « Extended defects formation in nanosecond laser-annealed ion implanted silicon », Nano Letters 14, pp.1769-1775, 2014.

MNBT researchers, together with a CRCT team, co-authored an invited review paper in IEEE T-MTT [RVSI13496] on microwave-based dielectric spectroscopy of cells (Figure 4). This paper addresses key breakthroughs of the technique for non-invasive cellular investigations. The discrimination of living and dead cells kept in their traditional and rich in ions and nutrients liquid medium without any labeling method is part of these features.

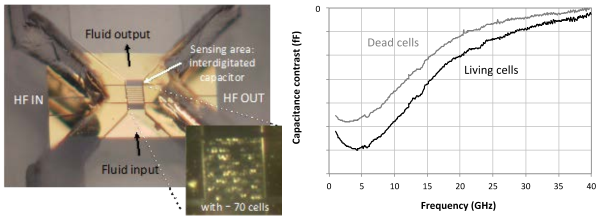


Figure 4: Left: Microscope image of a microwave and microfluidic sensor loaded with living cells. Right: Broadband capacitive contrasts up to 40 GHz of living (black curve) and dead (grey curve) B-cells lymphoma measured in their culture medium.

1.3.2 Workshops/Conferences:

Senior scientists from MNBT chaired international workshops or conferences hosted either ***in Toulouse*** (9th NanoBioEurope Workshop, 2013 – 200 attendees; 38th International Micro & Nano Engineering Conference, 2012 – more than 600 attendees; 2nd International Workshop on NEMS, 2011 – 200 attendees; VCSELs Day Europe, 2011 – 70 attendees) or ***elsewhere*** (E-MRS Symposium K, 2013 – 100 attendees, IEEE International Microwave Symposium since 2012 - more than 2500 technical program attendees, 600 exhibitors and 9000 participants; IEEE BioWireleSS 2013 - 75 attendees; IEEE ESSCIRC - 350 attendees).

1.3.3 Industrial Hits:

A long-term, well-established collaboration between MNBT researchers and Innopsys (SME based in Carbonne, France) has been concretized in February 2014 by the LAAS-Innopsys Joint Lab which aims at delivering new processes, new tools and applications of soft-lithography. A 30 m² working space has been set-up at LAAS to welcome up to 5 engineers from Innopsys during the Joint Lab period of life (5 years, on a renewable basis).

2 Scientific Production

As mentioned in Section 1.1, the MNBT scientific production will be thoroughly addressed but before digging into details, a brief analysis of the overall scientific production of the theme (more than 170 articles published in international journals) reveals an average of 2 articles/Research Full-Time Equivalent personal/year and the disciplinary footprint (percentage of articles/domain) depicted in Figure 5.

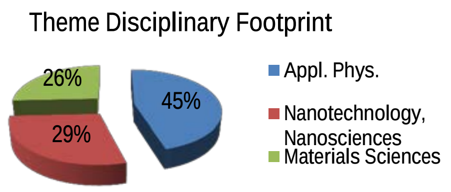


Figure 5: Quantitative analysis of the MNBT scientific output per main disciplines over the evaluation period.

The methods, scientific activities, productions and results for each team of the MNBT theme are detailed hereafter.

2.1 Materials and Processes for Nanoelectronics

2.1.1 Objectives and Positioning

Due to the increased difficulties to maintain the MOS miniaturization pace[2](as well as to the approaching of its physical limits), the general context of the MOS-related research domain has strongly evolved over the last years.

On the one hand, the continuous increase of short channel effects, including increasing parasitic resistances and capacitances, has put forward the reduction of power consumption as the main issue to be solved in future device generations. Research studies towards this objective have therefore become crucially important to implement the technology solutions that will ensure the development of future MOS devices until the end of the roadmap[3]. These range from the continuous improvement of the channel carrier mobility (by strain engineering methods or the integration of alternative high-mobility materials), to the continuous optimization of advanced doping and annealing schemes, up to the disruptive development of innovative 3D MOS architectures, such as multi-gate devices (FinFET, tri-gate approaches) for the improvement of the electrostatic control of the channel. Along this way, the "ultimate" evolution of such 3D architectures is provided by the gate-all-around (GAA) transistors fabricated on semiconductor nanowires (NWs) that represent the ideal case for the electrostatic control of charge.

On the other hand, the years 2000s have seen the emergence of the s-called "More-than-Moore" domain4, consisting in the addition of novel functionalities to electronic devices based on (or derived from) Silicon MOS technology. The "More-than-Moore" domain covers a wide spectrum of product categories (RF, high-voltage/power, SiP, passives, sensors, actuators, microfluidic, biochip, etc.) and has become more and more strategically important in the European research scenario[5]. Moreover, developments in the "More-than-Moore" domain (as well as in the Beyond CMOS domain) are foreseen in ITRS as part of an "extended-CMOS" vision, i.e. MOS technology is considered as an "extended platform" for the integration of future multifunctional electronics, as schematically shown in Figure 6. As a consequence, despite "*More-than-Moore*" extra-functionalities do not necessarily scale with Moore's law, research in this domain has to be strictly "connected" to research in advanced MOS devices[6].

In the context of such "extended-CMOS" technology domain, **the Materials and Processes for Nanoelectronics-related research activities (MPN team)** cover the fields of Materials Science and Nanoelectronics and involves researchers that were already working in this domain within the former LAAS-M2D[7] group.

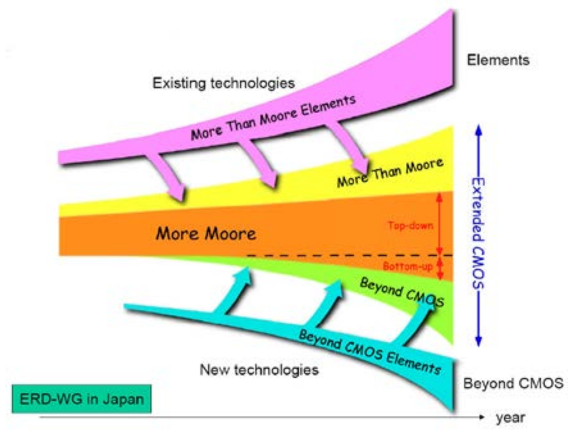


Figure 6: « Extended-CMOS » platform for the development of More Moore, More-than-Moore and Beyond CMOS devices (from ITRS 2011).

The overall scientific objectives in this area can be summarized as follows: *(i)* understand and model the physical phenomena occurring during the fabrication of nanoelectronics devices; *(ii)* fabricate innovative nanoelectronic devices.

2.1.2 Methods and Scientific Approaches

Our strategy to achieve the objectives presented in previous section is schematically summarized in Figure 7. The knowledge acquired thanks to basic Materials Science studies is the key to the optimisation of the fabrication processes and hence to the successful fabrication of innovative devices. For these studies, we rely on advanced complementary characterization methods, including TEM/SEM for the structural analysis, SIMS for the chemical dopant profiling, Hall-effect/DLTS or PL for the electrical/optical investigations.

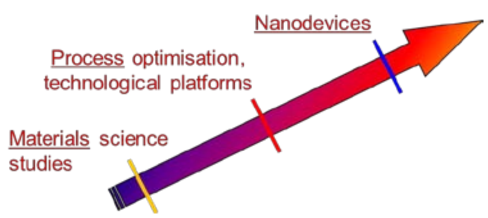


Figure 7: MPN scientific approach: from materials to nanodevices

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[2] H. Iwai, "Roadmap for 22nm and beyond", Microelectronic Eng. 86, pp. 1520-1528, 2009.
[3] 2013 International Roadmap for Semiconductor Technology, http://public.itrs.net
[4] G.Q. Zhang, M. Graef, F. van Roosmalen, "The rationale and paradigm of *More than Moore*", Electronic Components and Technology Conference, Special Issue pp. 151-157, 2006.
[5] SINANO Institute vision, June 2009
[6] Report of the FP7 Workshop on Advanced Nanoelectronics Technologies, Brussels, September 2009
[7] Microdispositifs et Microsystèmes de Détection

The path towards the next steps of our scientific approach (process optimization and realization of novel devices) is strongly supported by the specific skills of our research staff in the field of fabrication nanotechnologies and device characterization. In particular, our work in the nanodevice fabrication domain focused on the realization of Nanowire-based devices, including both the "top-down" and the "bottom-up" approaches. The first one requires considerable expertise in nano-lithography (for the fabrication of high aspect ratio nanopillars), nanoscale-controlled etching (for the transfer of the patterned structures to a Si substrate) and the fabrication of metallic contacts on the edges of the fabricated nanostructures. As for the "bottom-up" approach a great effort was instead devoted to the development of a generic alignment method (based on the dielectrophoresis technique) in order to massively localize and address a large number of nanowires. Overall, we consider that a strong expertise in all the experimental aspects involved in this scientific domain is crucial to successfully tackle the various technology challenges at the frontiers of knowledge and therefore achieve true innovation, through the development of new concepts and new ideas.

2.1.3 Highlights and Major Achievements

Over the last 5 years, the activities of the MPN team can be grouped in the following three research axes:

- Ultra-Shallow source/drain junction formation in advanced MOS: defects and dopant engineering
- Carrier mobility improvement in SiC power MOSFETs
- NW-based nanosystems

For each of them, the major achievements will be presented in the sequel.

2.1.3.1 Ultra-Shallow source/drain junction formation in advanced MOS: defects and dopant engineering

The most common method for the fabrication of source/drain regions consists in the localized doping of the substrate by **ion implantation**, followed by thermal annealing to achieve electrical activation. Today's Ultra-Shallow Junctions (USJs) are obtained using implantation energies below 1 keV, with the option of adding a pre-amorphisation step and/or additional impurity co-implants, while further improvements are expected from alternative implantation-based methods, such as molecular, cluster, cold and **plasma implants**. Similarly, thermal annealing has evolved towards shorter cycles combined with higher temperatures, with currently used RTA "spike" anneals expected to be replaced with even faster methods operating in the millisecond scale and below (Flash-RTA or **laser annealing**).

The major problem related to the use of ion implantation is the **formation of extended defects** and their interaction with dopants during annealing, which are respondible of major diffusion and activation anomalies. In addition, the growing need for a reduction of power consumption requires that the **defects' impact on leakage currents**, critically important for instance in all mobile communication devices, or in CMOS image devices, has to be investigated. Finally, **high-mobility channel materials** (Ge and III-Vs) are also to be considered as a replacement for silicon in future devices.

Within this context, our research activity, mainly carried out in the frame of two EU research projects (ATOMICS, 2006-2009 and ATEMOX, 2010-2013), has strongly contributed to the understanding of the various phenomena occurring during the fabrication of USJs, as well as to the improvement of the physical models for the predictive simulations of USJ fabrication[8].

Major achievements include the investigation of **B-implanted USJs in Germanium** and in particular the stability of these junctions during post-annealing steps [RVSI10502], showing how it is possible, in Germanium, to achieve highly-activated defect-free p^+-n junctions using the pre-amorphisation technique.

Among the several issues related to the use of **plasma ion implantation**, one of the major findings was the observation of large unconventional (001) oriented defects in BF_3 implanted structures, which were suspected to be "Large Boron Interstitial Clusters" (LBICs) [CII12452]. A "CPU time-effective" predictive model of LBICs formation, based on the moments approach was then developed, that allows for an improved agreement between SIMS and TCAD boron diffused profiles and accounts for dopant deactivation leading to better agreement with Hall effect measurements[9].

Concerning the **impact of implantation-induced defects on leakage currents**, we first carried out a systematic investigation of the defects' electrical properties by Deep Level Transient Spectroscopy (DLTS). Based on the systematic comparison between DLTS data and defect simulations, we then evidenced that the concentration of defect-related DLTS centers is closely related to the concentration of interstitials on the periphery of the structural defects rather than to the number of Si interstitial atoms they contain [RVSI13153]. Subsequently, using the knowledge obtained about the electrical activity of the dislocation loop defects, device simulations have been conducted[10] to reproduce the measured leakage currents, including their dependence on the defect parameters as e.g. position and concentration.

Finally, an extensive work on the formation of defects in ion implanted silicon during **melt-laser annealing** was carried out within the EU ATEMOX project. The outcome of this research11 is one of MNBT theme "salient facts" and is briefly summarized in section 1.3 of this report.

2.1.3.2 Carrier mobility improvement in SiC power MOSFETs

Low channel mobility in 4H-SiC power vertical MOSFETs is a critical weakness in SiC power electronics. Achieving higher channel mobility is therefore

[8] *Le journal du CNRS*, n° 243, avril 2010, p.35

[9] Z. Essa, F. Cristiano, E. Bedel-Pereira et al., « Large boron interstitial cluster modelling in BF_3 plasma implanted silicon", Phys. Stat. Sol. C 11, pp.117-120, 2014.

[10] C. Nyamhere, F. Cristiano, F. Olivie, E. Bedel-Pereira, F. Olivie, Phys. Stat. Sol. C 11, pp.146-149, 2014.

[11] Y. Qiu, F. Cristiano, K. Huet et al., « Extended defects formation in nanosecond laser-annealed ion implanted silicon », Nano Letters 14, pp.1769-1775, 2014.

extremely desirable, as it allows: *(i)* to reduce the device on-resistance, leading to smaller chip size (lower channel width) and lower fabrication costs; *(ii)* to operate devices at oxide fields lower than 4 MV/cm, leading to increased oxide stability and high temperature reliability; *(iii)* to achieve a working threshold voltage of about 5V, which is required to ensure normally-off operation and adequate noise-immunity at high temperature and noise environments. Overall, SiC-based MOSFETs with sufficiently high mobility will help to build more energy efficient power energy transmission/conversion in automotive applications and, above all, to reduce CO_2 emissions.

Within this context, the aim of our research activity, carried out within the Carnot-FhG project MobiSiC (2010-2013), was to improve the understanding of the impact of the different process fabrication steps on the performances of SiC MOSFETs (and especially the channel mobility), and identify optimized processes to increase mobility beyond currently achieved values.

For this, we established a comprehensive methodology based on the combination of physical/ electrical characterization and simulation of the electrical behavior of SiC MOSFETs. In particular, a **dedicated Hall-effect set-up was developed at LAAS** [RVSI12415] for the automated T-dependent measurement (10-500 K) of the channel carrier mobility and concentration, as well as the density of interface traps near the conduction band. We focused on the correlation between the Hall-effect measured parameters and two critical proceses in n-type MOSFETs fabrication: *(i)* donor impurity implantation into the channel before gate oxidation and *(ii)* bulk potential engineering (through Al^+ implants at different doses) to modify the acceptor concentration in the substrate.

In the case of donor impurity implants (N^+ in our case), a strong increase of the carrier mobility is achieved (up to ~80 $cm^2V^{-1}s^{-1}$) however the mobility increase is accompanied by a V_T reduction, leading to normally-on MOSFETs at the highest N^+ doses. We explained the observed behaviour in terms of the modification of the spatial electron distribution in the channel when the donor concentration is increased by the implant, leading to incomplete depletion of the n-doped surface at zero bias and hence to normally-on devices.

As for the background doping effect, we showed that when the aluminium acceptor concentration in the substrate decreases from $5x10^{17}$ down to $1x10^{15}$ cm^{-3} (without nitrogen co-implantation in the channel), a **much stronger mobility increase is observed, with values up to ~140 cm^2 V^{-1} s^{-1}** (Figure 8 left). In addition, the combination of field- and temperature-dependent Hall effect measurements (Figure 8 right) allowed us to investigate the associated scattering mechanisms. For instance, in the case of the highest mobility values, the dominance of Coulomb scattering was inferred from our analysis, with a non-negligible contribution of phonon scattering, especially at high effective field. Particularly important was also the fact that, in addition to the significant increase of the channel mobilities, these high-mobility MOSFETs also possess a positive threshold voltage (i.e. they are normally-off), making them suitable for application, and this was confirmed in a wide temperature range from 303 K to 553 K. In summary, it has to be noted that the reported mobility values are among the highest ones ever obtained <u>in normally-off devices</u>.

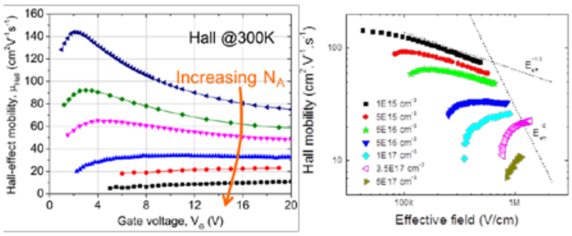

Figure 8: Hall mobilities vs. VG (left) and vs. effective field (right) for different background doping levels.

2.1.3.3 NW-based nanosystems

Today, the physical limitations of nanoscale transistor operation (in particular the increasing power consumption per chip) have led to the development of innovative MOS architectures, such as multi-gate devices (FinFET and trigate) to improve electrostatic control of the channel. The natural evolution of these architectures is the gate-all-around (GAA) transistor implemented on a semiconductor nanowire (NW). NW GAA NW FETs provide an ideal design for electrostatic control of charge inversion and allow further reductions in transistor size. However, the current flowing through them in the "on" state (current drive) remains low due to the small NWs diameter. It is therefore essential to implement these transistors on NW arrays rather than on single NWs so to combine excellent electrostatic control with increased current capability.

Vertical integration is a particularly attractive approach as its 3-D character is compatible with both top-down and bottom-up fabrication methods and allows extremely high integration densities (70% surface shrink compared to planar devices), opening the way to new integration approaches. In spite of such promising potential, a vertical approach has not yet been used to demonstrate scaled architectures.

Among the possible device architectures, the one based on dense vertical NW arrays fabricated by the **"top-down" approach** is developed by our group. In addition to providing "ultimate" MOS scaling, it is also very promising for the realisation of future "More-than-Moore" devices, including high sensitive biochemical sensors or photovoltaic cells. However, to achieve such promising results, several fundamental challenges must be addressed, that cover several domains, including **device engineering and materials science**. These challenges range from the fabrication of NW arrays, through their controlled oxidation, to the silicidation of the source/drain regions and the reduction of the interface defects at the gate dielectric/NW interface.

Concerning the fabrication of vertical Si NWs arrays, we demonstrated high aspect ratio nanopillars (7.5) with 20 nm diameter in 150 nm-thick HSQ (Hydrogen SilsesQuioxane) using 20keV energy exposure based on a detailed study of design strategies [RVSI12569].

A particular effort was devoted to understand and engineer the **oxidation of Si NWs** and, more generally, of various Si nanostructures (nanobeams, concave/ convex nanorings…). First, an in-depth understanding of the experimentally observed retarded oxidation of Si nanostructures was achieved through the modeling of the mechanical stress generated during oxidation [RVSI12187]. The acquired knowledge was then used to engineer their shape (particularly that of vertical NWs) by the self-limited oxidation effect [RVSI13389].

The characterization (and optimization) of NW contact resistance is a difficult task as, in most cases, the Si NW body resistance, R_{NW}, is higher than the contact resistance, R_C. Starting from an ultra-scaled 3-D structure based on short vertical NW arrays (see Figure 9 left), so that $R_{NW} < R_C$, we reported for the first time the fabrication of two-terminal structures implemented on vertical Si NW arrays defined by the top-down approach with an ultra-high density. Each NW termination is silicided and contacted to an external metal line. Thanks to a precise control of the NWs radius and number within an array, we demonstrated perfectly reproducible I-V characteristics when a large number of NWs is used (up to 5100 NWs in parallel, see Figure 9 right).

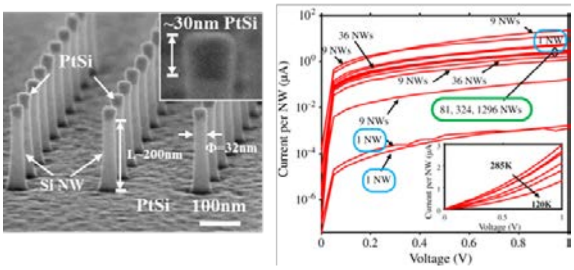

Figure 9: Left: SEM images of vertical NWs arrays with hetero structure PtSi/Si. Inset: SEM image of a PtSi contact on top of a Si NW. Right: I-V characteristics of 2 contacts' device with a varying number of NWs associated in parallel from (1 to 1296). Inset: temperature dependent I-V curves.

Our advanced and reliable set-up allowed us to unambiguously interpret the temperature dependence and the nonlinearity of the I–V characteristics. In particular, we showed that contacts dominate the overall resistance of the Si NW arrays, even in the case of extremely small NW radii. In this context, the electrostatic landscape at the vicinity of the silicide/Si contact interface is dominated by the field effect imposed by peripheral surface states and not by the Schottky barrier height [RVSI12020].

Finally, the thorough investigation and optimization of all the fabrication steps allowed us to demonstrate the integration of massively-parallel dense NW arrays with silicided S/D contacts and scaled metallic gate length (down to 14 nm) in a CMOS-compatible process (Figure 10 left). The proposed architecture offers several advantages including better immunity to short channel effects (Figure 10 right), reduction of device-to-device variability, nm gate length patterning with no need for high resolution lithography [RVSI13029] and low defect density [RVSI13599]. These benefits are important in the large-scale manufacture of low-power transistor and memory devices. This major breakthrough has been highlighted in numerous journals[12].

[12] *CNRS international magazine*, n° 30, July 2013, p.40. *IEEE Spectrum*, May 2013, Les Echos 09 Avril 2013 p 12.

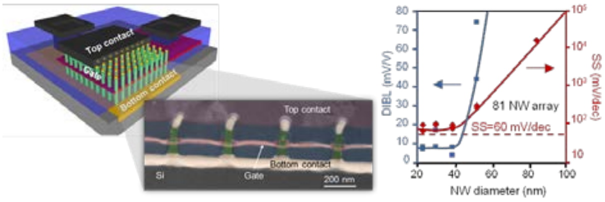

Figure 10: *Left:* Schematic description of a vertical nanowire array-based field effect transistor. *Centre*: TEM cross section micrograph in tilted view of the device. *Right*: evolution of sub-threshold swing and drain induced barrier lowering as a function of nanowire diameter showing immunity against short channel effects and threshold voltage variability.

2.2 Microsystems for Analysis

2.2.1 Objectives and Positioning

The current research activities dedicated to microsystems for analysis address a common objective that is "micro-analysis of fluids" (liquid or gas) by combining different transduction modes (electrochemical, electromagnetic and optical) as it is sketched in Figure 11.

These technologies dedicated to bio and chemical analysis are generally built on generic platforms that permit to address various needs and challenges in the fields of environment, health, biology or security. Our long experience in this field fostered numerous collaborations with other teams in the lab but also with many other national and international labs (mainly chemists, biologists or physicists).

Thanks to our know-how in technology, multiphysics modeling and metrology, our proven strength is our ability to study and integrate heterogeneous micro or nanostructured materials (Si, III-V, metal oxides, polymers, organic semi-conductors...) in novel devices and to functionalize active surfaces in order to realize new prototypes of miniaturized and high performance gas, chemical and biological sensors.

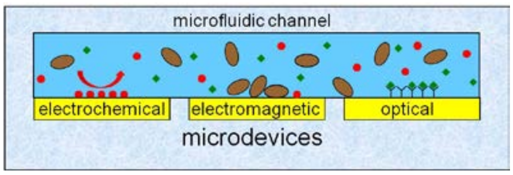

Figure 11: Schematic view of MICA Team objectives: using and combining various transduction modes for innovative and efficient microsystems dedicated to fluid analysis

As we are also interested by reproducibility, robustness and reliability, we strive to develop prototypes with relatively high TRL levels (between 3 and 6), that promotes our strong collaborations with industries.

In this report, we have chosen to present the results related to the microsystems for analysis by separated transduction fields. However, there are growing interactions between them and our long-term strategy aims at building more efficient microsystems by coupling these different devices in a multiphysics platform.

2.2.2 Methods and Scientific Approaches

Thanks to more than fifteen years of experience in micro/nanotechnology, we develop new technological processes to integrate micro/nano structures of materials into smart microsystems.

In this context, our upstream research related to physics, electronic, chemistry and optics, can be described by three interconnected parts from advanced materials to microsystems for fluid analysis:

- material studies (Si, III-V, organic semi-conductors, Metal oxides, polymers) to take advantage of nano-structures properties and of herogeneous integration in order to improve transduction sensitivity and selectivity
- single devices design and fabrication (Resistors, Capacitors, FET transistors, microelectrodes, OLED, MOEMS-VCSELs devices, photodiodes, magnetoresistances)
- demonstration of innovative sensors, multi-sensors or microsystems for fluid analysis (Chem-FET, ElecCell, MOX gas sensors, integrated optical microsystems: sources, lenses, photoreceptors)

Upstream to the microsystems design and realisation, research studies are conducted concerning materials integration processes (silicon-based, polymer-based, III-V and organic semi-conductors (S-C) compounds based technologies) as well as associated properties. Furthermore, materials and their functional properties have to be considered according to a given application and therefore to a specific microdevice. This microdevice becomes finally the best test-vehicle for studying materials and processes integration according to the chosen functionality. Thus, through the development of dedicated technological platforms, microsystems realisation is finally demonstrated according to the application of interest (thanks to LAAS facilities in particular the cleanroom -as part of Renatech network- and the CAD plateform for intensive multiscale and multiphysics modelling).

In terms of silicon, III-V and organic semi-conductor based technological research, the approach of MICA team aims to define theoretical and/or semi-empirical relations between integrated materials properties and integration process technological parameters. Accordingly, studies emphasize theory, modelling, simulation, characterization and/or use of specific microdevices. They plan to understand the main process mechanisms in order to optimize the integrated materials properties for specific applications.

In terms of devices or dedicated microsystems for fluid analysis, the approach is focused on technological integration. Starting from upstream collaborations with different scientific fields as materials and processes sciences, mechanics, optics, physics, chemistry, biology,…, main research activities concern design, fabrication, characterisation and optimisation of technological platforms dedicated to detection or transduction microdevices. This work aims on one part to the study of physical, chemical and biological phenomena at the microscale, and on the other part to the realization of analysis microsystems dealing with reliability, pre-series and industrial transfer.

We strive to implement this strategy in our developments that can be divided in four main domains:

- **Bio-electro-chemical microsensors for the liquid phase analysis,**
- **Gas sensors,**
- **Magnetic sensors based on organic/inorganic hybrid devices,**
- **Optical biosensors based on polymer micro-optics on VCSELs.**

2.2.3 Highlights and Major Achievements

Among the studies that have been carried on or undertaken since 2004, we present hereafter a summary of last major activities and achievements in each domain.

2.2.3.1 Bio-electro-chemical microsensors for the liquid phase analysis

In the frame of the liquid phase analysis, research activities have been dedicated to the integration of bio-electro-chemical microsensors using silicon-based technologies. They have concerned the theoretic study of the potentiometric and amperometric electrochemical detection/transduction principles as well as the set-up of associated technological platforms, respectively dedicated to chemical field effect transistors (ChemFET) and electrochemical microcells (ElecCell). Thus, research works have dealt with the modelling of bio-electrochemical detection principles, the integration of (bio)chemical-sensitive layers, the development of packaging techniques (from wafer to system level) for fluid handling and liquid phase analysis, as well as the realisation of measurement interfaces.

Concerning the ChemFET platform, the collaboration with the HEMODIA Company has been carried on. Two leading projects have driven these researches. First, the MICROMEDIA project has concerned the industrial development of enzymatic field effect transistors (EnFET), allowing the on-line monitoring of urea during haemodialysis treatments [RVSI10680]. Second, the ANR CSOSG SWEAT project has concerned the development of ion-sensitive field effect transistors (ISFET) for the sweat analysis (Figure 12, left). Thus, the [Na^+] concentration in sweat has been correlated with the internal temperature and, as result, the natremy was demonstrated to be a good marker for the physiological stress on-line monitoring [RVSI12525].

In parallel, in a more upstream way, the ChemFET platform has been extended to the realisation of electrochemical field effect transistors (ElecFET) (Figure 12 right).

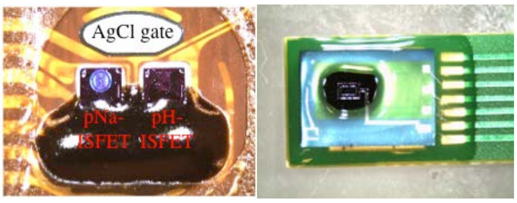

Figure 12: pNa-ISFET for sweat analysis (left) and ElecFET microdevice coupling potentiometry and amperometry at the microscale for liquid phase analysis (right).

Thus, by coupling potentiometric and amperometric detection/transduction principles at the microscale, out-of equilibrium, impulsional pH variations have been monitored. Such phenomena have been theoretically studied, evidencing interesting potentialities for the bio-electro-chemical analysis. Thus, the ElecFET platform has been successfully adapted for the detection in liquid phase of hydrogen peroxide H_2O_2, glucose and lactate ions [RVSI12243].

Concerning the ElecCell platform, basic technological researches have been focused on its optimization. Firstly, the common integration of different metals - i.e. gold and/or platinum, platinum and silver for the work, counter and reference microelectrodes, respectively - has been studied. Secondly, a low-temperature (T ≈ 100°C), Si_3N_4 passivation has been developed using plasma-enhanced chemical vapour deposition process [RVSI12439]. Finally, ElecCell integration process has been adapted from standard silicon substrates to transparent glass substrates. Thus, (Au – Pt – Ag/AgCl) and (Pt – Pt – AgCl) ElecCell microdevices have been successfully microfabricated while ensuring the "thin-film metals" electrochemical properties, controlling the microelectrodes electroactive surfaces, and enabling the coupling between electrochemical and optical analysis in liquid phase (Figure 13, left). Four projects have driven these researches. First, the MICASSO project has concerned the oxidative stress analysis in collaboration with "Pierre Fabre Dermo-Cosmetics" company. Through the integration of PEDOT-based sensitive layers, the detection of different anti-oxidant species (ascorbic acid, uric acid, dopamine,…) in liquid phase has been demonstrated and finally adapted to the skin anti-oxidant global capacity measurement [RVSI12439]. Then, The ElecCell platform has been applied to the detection of nutrients for the monitoring of marine waters, demonstrating the silicate ions SiO_4^{4-} detection feasibility (RTRA STAE MAISOE Project). Finally, researches works have been also focused on the on cells cultures monitoring, still dealing with oxidative stress analysis and up to now with dissolved oxygen O_2 and hydrogen peroxide H_2O_2 detection (Figure 13, right). Thus, in order to improve detection properties, specific attention has been brought to the integration of porous black platinium layers, evidencing the H_2O_2 detection for concentrations as low as 5 nM

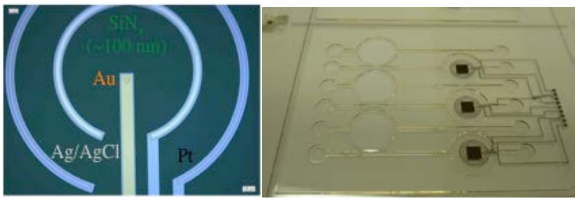

Figure 13: (Au – Pt – Ag/AgCl) ElecCell technological platform (left) and ElecCell integration on transparent glass substrate for algae cultures monitoring (right)

. Two projects were directly concerned. The first one (ANR JC DOLFIN project), has been dedicated to the analysis of algae metabolisms allowing the monitoring of respiration and photosynthesis mechanisms. The second one (ANR BLANC NANOMITO project) has been focus on the study of mitochondrial activities[13].

2.2.3.2 *Gas sensors*

In both the literature and industry, there are various examples of gas detection devices which use electrochemical sensors, resistive metal oxide based sensors, catalytic or even piezoelectric sensors. The growing interest in these microsensors for many applications is due to several reasons. Among them, we can cite low production costs helped by the development of microtechnologies. This allows for reducing the size of components and therefore produce a large number of sensors on one silicon wafer. As such, with the emergence of micro and nano technologies, we are seeing an ever increasing development of miniature, portable and "intelligent" devices integrating sensor(s), the power supply, processing electronics and other elements. These are therefore termed as "integrated electronic noses".

Producing these new devices involves micro and nano technologies as well as new techniques for integrating new sensing materials which are often nanostructures or even new micro-production or assembly methods. This allows the industry to respond to the needs of the market such as low production costs, the lowest possible energy consumption, good stability, reproducibility, reliability and increased portability for embedded systems or sensor networks.

Thanks to our know-how in micro-nanotechnology, gas sensor activities are currently focused on the development of semi-conducting microsensors, with moderate cost and low consumption in order to develop an integrated electronic nose for different applications as environment, health, transport, home automation, agro-industry and/or still defence. Their realization leans on the development of new technological processes (new materials, new structures, new designs of single and multisensor platforms), integration of various sensing materials (semiconductors, metal oxides, spinel oxides, ferrites), multiphysical simulations, electric and thermal characterizations and finally, on the signal processing with dedicated electronic circuits. Metal-oxides chemical micro-sensors are still the best candidates to meet this demand at industrial level: they are highly sensitive to many gases, fast response times, and their production cost could be very low. As it is well known, their main drawback is a lack of selectivity. Since 2009, our research work has consisted of developing a multi gas sensor array based on conductivity detection on a silicon micromachined chip with different sensitive layers to selectively detect several gases in a mixture. Most important developments have been focused on stable microhotplates for high operating temperatures (around 600°C) and on the integration process to deposit sensitive materials. A flexible method for depositing quickly and at low costs several sensitive layers (ZnO, CuO and SnO_2) on a single cell structure has been developed with industrial inkjet printer. An example of this multi sensor platform is shown in Figure 14.

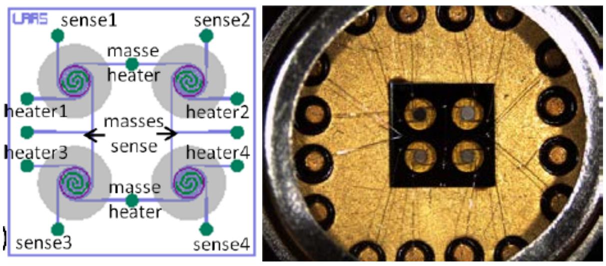

Figure 14: Schematic view of the micro sensor array and its realization.

[13] S. Ben-Amor, J. Launay, P. Temple-Boyer et al., "Enhanced detection of hydrogen peroxide with platinized microelectrode array for analyses of mitochondria activities", Electrochimica Acta 126, pp.171-178, 2014.

In parallel, we developed a decision-making system, including two main elements: the development of an optimized working dynamic profile by controlling power in heater and sensitive resistors in order to improve stability, sensitivity, and above all selectivity thanks to appropriate data multivariate analysis. Thanks to this approach, it has therefore been possible to selectively detect few conventional target gases (alone and mixed) at low concentrations (NO_2-0.2ppm, C_2H_4O-2ppm, NH_3-5ppm and CO-100ppm) which is still not possible with actual commercial MEMS gas sensors.

Few projects are in progress to use these new integrated electronic noses for different applications. A strong collaboration with chemist laboratories (LCC-CNRS, CIRIMAT) for new sensing materials allows us to meet strong demand in several fields of application with ALPHAMOS and RENAULT for instance. In this frame, a new patent concerning a new multistack structure has been deposited in 2011 and published in December 2012.

Concerning the development of wireless sensor networks, our team is involved in two different projects related to two different approaches. The first one consists in using the technology of multisensor array previously described combined with a specific working protocol and data treatment embedded in a micro controller and associated with an RF chip module. In that case, we should optimise all of the different parts (sensor technology, working principle and data acquisition and treatment) to realize a low consumption wireless gas sensor. The second project is dealing with new transduction principle using radiofrequency (RF) electrical function in order to provide powerless sensors. This new research started in 2007, in collaboration with the MINC group. Then these studies were focused on autonomous wireless sensors network. We have therefore proposed a new RF transduction for detecting gas which is based on changing the permittivity of a metal oxide (used as a resonator) by the phenomenon of dielectric relaxation in the presence of gas which therefore causes a shift in the resonant frequency at the hyperfrequency filter. In our case, we used a sensor as a variable element in a filter where the characteristic frequency is read with as high quality factor as possible in order to obtain the best level of sensitivity. The demonstrator shown in Figure 15 is based on Titanium dioxide dielectric resonator operating with whispering-gallery modes (WGM).

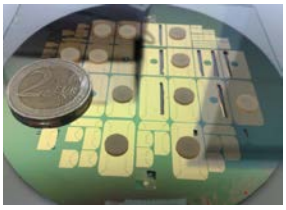

Figure 15: Photograph of the first gas sensors with electromagnetic transduction

Gas vapours adsorption modifies its dielectric permittivity and then the variation of resonant frequencies of high-Q WGM in the millimeter-wave frequency range. After a full wave electromagnetic simulation that demonstrates the transduction principle, we validated experimentally in a first hand, the strong deviation of the resonant frequencies in presence of ethanol and isopropanol vapours, and in a second hand, the possibility to detect these variations with a 3 meters-remote FMCW-Radar and antenna connected to this passive sensor.

2.2.3.3 Magnetic sensors based on organic/inorganic hybrid devices

Organic magnetic sensors belong to organic spintronics, a fusion of organic electronics and spintronics, which is a new and promising research field where organic materials are applied to mediate or control a spin-polarized signal. The field of organic spintronics particularly attracts attention because of the potentially very long spin relaxation times in organic semiconductors (OSC). One of the main attractive features of OSC is that they allow chemical tuning of their physical properties such as electronic gap, injection barrier, mobility, spin-orbit coupling and hyperfine interaction. This undoubtedly makes organics a strong competitor for developing efficient spintronic devices (those devices could be used as magnetic sensors for the detection of magnetic tags currently used in medicine). The most popular geometry for organic thin films spintronic devices is by far the vertical device (Figure 16).

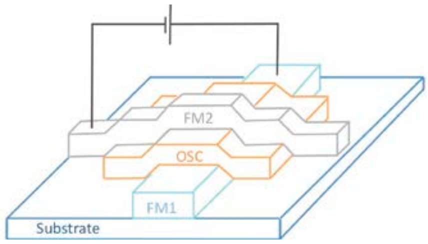

Figure 16: Schematic view of a vertical device on glass substrate (FM1, FM2 - Ferromagnetic 1,2; OSC - Organic Semiconductor)

The reason is the ease of fabrication by evaporating thin layers on top of each other. But those devices present also two drawbacks. On one hand, the achievement of anisotropic transport for OMR is rather difficult due to device size (about 100X100µm^2). On the other hand, the deposition of organic-inorganic hybrid structures based on two ferromagnetic metals and an organic layer requires the optimization of the deposition conditions for each individual layer. This is mandatory to keep the physical properties of the materials. It is indeed easy to grow a single ferromagnetic (FM) film with magnetic properties or a single OSC layer, but the deposition of the top FM film on the OSC is generally critical for the OSC integrity and complicates the vertical FM1/OSC/FM2 architecture realization. Our main objective is associated with the development of fabrication processes and devices to achieve room temperature organic magnetoresistance (OGMR). In this research project, softer electrode deposition processes have been studied to protect the organic layer. Our preliminary results have shown that we can obtain 3% OGMR at 5 K and 40 K either by using perylene or hybrid thiophene/furan π-conjugated derivatives, NiFe and Co films as FM electrodes with two innovative soft deposition techniques for the Co. This work joins together 1) a micro/nanotechnology laboratory – LAAS, 2) a chemistry laboratory - MOLTECH-Anjou, 3) a physical-chemistry and materials physics laboratory - CEMES, and 4) a physical-chemistry of nano-objects laboratory - LPCNO. These fields of research gather the necessary competences for the realization of the research project.

2.2.3.4 Polymer micro-optics on VCSELs for optical biosensors

Optical bio-sensing has experienced this last decade a strong development since optical methods are fast, highly sensitive and contactless. In view of fabricating portable optical sensors, needs for miniaturized, multifunctional and low consumption sources are therefore growing rapidly. As a result, III-V semiconductor laser diodes are more and more used in bio-sensing field. In particular, VCSELs (for Vertical-Cavity Surface-Emitting Lasers) are of major interest as they exhibit a parallel operation, a circular Gaussian beam, low power consumption and internal detection capabilities and LAAS has a long experience on the design and fabrication of such near-infra red devices. To collimate the emitted light or to focus it in the fluidic channel, we have developed innovative and collective methods for integrating polymer micro-lenses on the surface of VCSEL arrays [RVSI11381].

2.2.3.4.1 Focusing lenses self-written on VCSELs by Near-Infra-Red (NIR) photo-polymerization

We have demonstrated a self-writing process for integrating microtips on VCSELs in the frame of NIROPTICS ANR project (in collaboration with IS2M, Mulhouse and ICD LNIO, Troyes). Our single-step and room temperature technique is based on the use of novel NIR photopolymers [RVSI10044]. These materials have been optimized to make possible a precise control of initial thickness prior to photo-fabrication [RVSI11569] for a collective fabrication at a wafer-scale [RVSI13106]. Thanks to these improvements, a complete photo-chemical study has been led on different kinds of VCSEL sources (Figure 17, top). The focusing abilities of these tipped-VCSELs have been also evaluated both experimentally and theoretically in collaboration with Pr. Debernardi at IEIIT-CNR Italy, showing that our method can be exploited for the fabrication of compact optical micro-probes for scanning probe microscopy and for near-field optical microscopy (Figure 17, bottom) [RVSI12398].

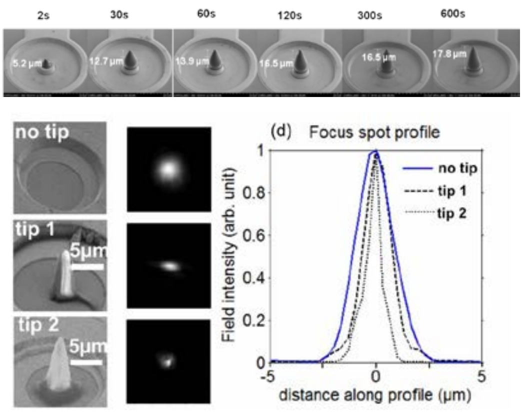

Figure 17: Top: SEM (Scanning Electronic Microscopy) images of self-written tips on VCSELs for different exposure doses. Bottom left: SEM images of a bare VCSEL and of two self-written microtips on similar VCSELs and corresponding focus spot images. Bottom right: Horizontal field profiles spot widths as low as 400nm can be achieved in presence of the tip.

The application of this technique for coupling a VCSEL and an optical fiber is currently under study in the frame of NIRConnect Inter-Carnot project (MICA-LAAS) and of LEAF Equipex project devoted to laser writing.

2.2.3.4.2 Polymer MOEMS integrated on VCSEL arrays for dynamic focusing

To allow for a real-time analysis in a microfluidic channel, VCSEL beam has not only to be focused at a sufficient working distance but also dynamically shifted over the channel width (typically 100µm).To fulfil these goals, we have designed and fabricated a new kind of polymer MOEMS. It is based on an electro-thermal actuator (SU-8 membrane) equipped with a polymer refractive microlens deposited on its top surface by local dispensing. The interest of our approach is to make possible a collective integration on VCSEL arrays thanks to a small footprint (Figure 18, top). We have demonstrated that this tunable microlens can be shifted under actuation over a vertical range as high as 8µm (Figure 18, bottom) [RVSI12133]. A comprehensive 3D model has been developed using COMSOL Multiphysics to simulate the actuator and was found to reproduce well experimental measurements. A first integration on multimode VCSELs has been also achieved [CII13456]. A dynamic focusing was demonstrated at a working distance compatible with VCSEL association to a microfluidic channel (300µm) and with a scanning range exceeding several tens of microns [CII13336]. Finally, reliability of SU-8 microstructures for microoptics was also recently investigated under wet and hot conditions in the frame of FIAB-SU8 regional project (in collaboration with CIRIMAT, EADS Astrium and FIALAB) This study has demonstrated a good stability of optical and mechanical properties for the considered sizes.

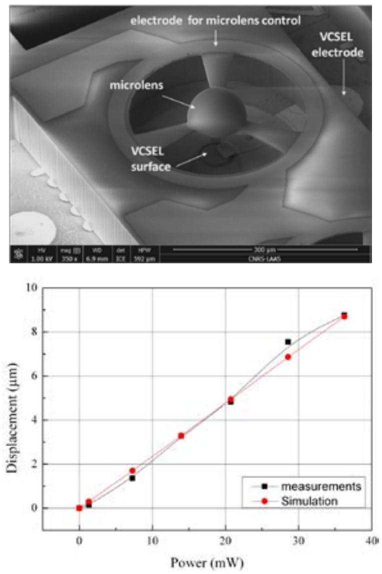

Figure 18: Top: SEM (Scanning Electron Microscope) image of the full polymer MOEMS integrated on a VCSEL device bottom: Vertical displacement of the microlens versus applied power: comparison of measurements (black squares) and simulations (red circles)

2.3 NanoBioSystems

2.3.1 Objectives and Positioning

By shading a different light onto the biological and the physical world, scientific research has the capacity to radically impact our world. The quantum theory issued at the very beginning of the last century from the physicists community opened up ways towards “vital” inventions like the transistor, the lasers, and speeded up our technological progress. A few decades later on, by unraveling the intimate of the DNA molecular structure, biologists started the genomics revolution.

Should we expect same kind of groundbreaking innovations from a Biology/Physics-related disciplines alliance? Our group is more than ever committed to give a positive answer to this question. This pattern resolutely fits into one of the future mainstreams of our laboratory (Interacting with the Living strategic orientation ALIVE) as well as into the general strategy of our governing institution (the INSIS CNRS Institute).

Since 2009, the scientific road-map in the nanobiosystems area was made of new exciting challenges rather than incremental approaches on existing basis. Our road-map was mainly motivated by the mature level of some of our key developments which are now sold (or about to be sold) to private companies. This strongly motivates our will to focus on new topics while empowering our confidence in the future.

Our strategy of research is divided into three different mainstreams using our expertise in micro and nanotechnology:

- Exploring living cells and their interaction with the environment;
- Integration of advanced materials for nano-devices;
- Biosensing.

It is worth noting that MNBT members are sensitive to dissemination of interdisciplinary knowledge and ethics on nanobiotechnologies and nanomedicine. A significant part of our team work is dealing with the organization of international conferences, lectures and workshops.

The different scientific mainstreams are detailed hereafter.

2.3.2 Methods and Scientific Approaches

During the last decade, our research was mostly dedicated to the development of innovative micro/nanotechnologies to produce micro/nanodevices. Our experience in these technologies led us rapidly to confidently focus our efforts almost exclusively on biotechnology-related applications.

Exploring living cells and their interaction with the environment is one of our research axes. We study cells, using different technologies for their immobilization and their analysis. By the use of soft lithography, atomic force microscopy and fluorescent imagery we can follow, in almost real time, the interaction of cells with drugs or their direct environment.
Since the creation of the NBS team, we started to form strong collaborations with biologist and physicians, allowing us to answer scientifically relevant questions for biology. We investigated new methods by the use of modified substrates or AFM tips (e.g.: micro/nano patterning, chemical modifications, etc.) to characterize the cells' behavior under various stresses.

Integration of advanced materials for nano-devices represents our second research axis. It is directed towards a better understanding of the behavior of nanomaterials and soft materials, and their integration in functional micro- and nanosystems for applications in chemistry, biology and life sciences. We try to better understand and monitor physical phenomena at a reduced scale and adapt them to use in devices for specific applications.

Following many years of experience with chemists and biologists, we now strive to use new materials like spin-crossover complexes or carbon nanotubes to dramatically change the response of our devices. We also work with biomaterials to increase the performance/living time of our devices in physiological conditions.

Biosensing is our earliest research axis (historically our first attempt to biological applications) and is being directed towards the conception of innovative solutions for the detection of biomolecules and cells. Depending of the targeted object, we build and optimize new devices from the micro- to the nanoscale.
These objectives lead us to develop technological solutions from the development of fluidic platforms, biomechanical sensors and their functionalization to label-free biosensors.

2.3.3 Highlights and Major Achievements

From 2009 to now, we have carried out various projects, some of them being presented hereafter along with a summary of some of the major relevant activities and achievements in each axis.

2.3.3.1 Exploring living cells and their interaction with the environment

Tissue engineering is a vast domain of research. For this reason, we focus on our strength of competences, like substrate engineering and AFM characterization. The three achievements presented hereafter are representative of these competences, developed in the past five years, related to substrate modifications and AFM studies.

We are actively investigating the cell mechanics of macrophages in collaboration with the IPBS. We have shown that by micro-contact printing (µCP) of some proteins of the extra cellular matrix, we can control the adhesive pattern of these immune cells by confining podosomes in well-controlled positions (Figure 19).

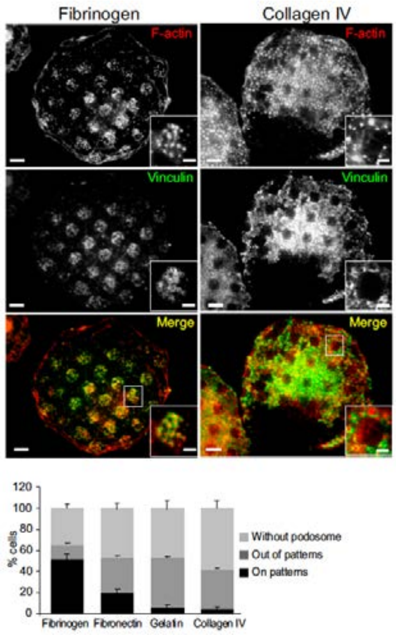

Figure 19: Extracellular matrix (ECM) dictates podosomes formation and organization. Podosome organization in human macrophage 2 h after plating on fibrinogen and collagen IV patterns. F-actin (red) and vinculin (green). (Scale bars, 5 µm; Insets, 2 µm). Means of at least three independent experiments (n ≥ 100 cells and at least three donors per condition) for each substrate are represented.

In collaboration with an INSERM unit (Purpan hospital), we have also investigated methods for controlling the growth and the differentiation of neural stem cells (Figure 20) with the perspective of generating a brain implant

[RVSI12091] for stroke therapies. We have been able to show that the brain insertion of a bio-implant made of a micro/nanostructured polymer plated with human neural stem cells, in heavily deficient rats after an induced stroke, displayed a strong therapeutic effect. The role of the micro/nano engineered implant turned out to be crucial, since animals implanted with 10 times more stem cells but without the polymeric nano-template exhibited strictly no recovery effects, demonstrating the potentialization of stem cells by nanoengineering.

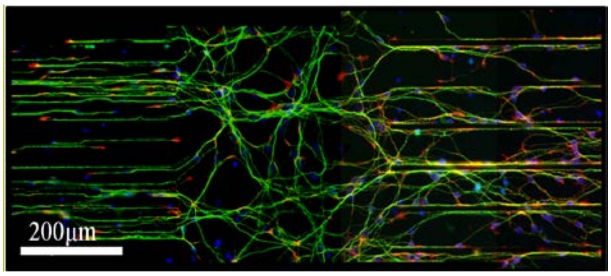

Figure 20: Neural tract engineering using different topographical surface patterns for designing functional neuronal networks with a controlled architecture.

We also explored an innovative molecule (CX1) and elucidated its mechanism of action. As far as P. aeruginosa is concerned our biological goal has been to understand the nanoscale effects of antibiotics (ticarcillin and or tobramycin) on the roughness and the mechanical properties of the bacteria interface. P. aeruginosa is a threatening bacteria as it can acquire mechanisms of resistance to all the known antibiotics. We thus decided to analyze the nanoscale effects of antibiotics, used in clinic (ticarcillin and or tobramycin), on the interface of this bacteria. We have demonstrated that a resistant strain is not affected neither in term of morphology nor the nanomechanical properties. The innovative molecule CX1 is, on the contrary, able to disorganize the cell wall of both sensitive and resistant strains. We have shown, using functionalized AFM tips, that unexpectedly long molecules can be unfolded from the surface of the resistant strain treated by CX1. Finally, we have elucidated the mechanism of action of this new molecule, by using artificial phospholipidic bilayers (Figure 21). CX1 creates holes in the membrane that can be compared to the surface morphology of treated cells [RVSI12787].

2.3.3.2 *Integration of advanced materials for nano-devices*

Since more than five years, we developed strong collaborations aiming at the integration of three types of materials. The first that will be discussed is a specific family of spin-crossover materials used in many different applications, here in the field of the high-resolution thermometry. Secondly, we present some of our technologies based on carbon nanotubes (CNTs) and finally, we review results related to synthetic membrane bilayers.

Temperature plays a fundamental role to study chemical and biological processes. Fluorescent thermometry appears as a simple, noninvasive and cost-effective method for providing good spatial, temporal and thermal resolution in both solid and liquid phases, even in distant or inaccessible environments.

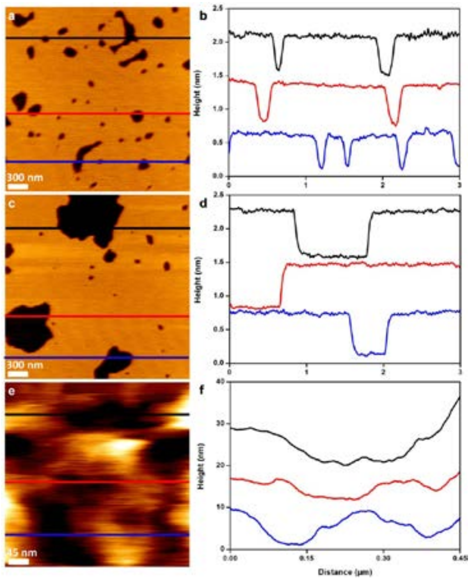

Figure 21: Antibiotic effect on supported bilayers. (a), height images (z-range = 1.5 nm) of POPE:POPG (2:1) supported bilayers at t = 0 minutes after treatment by CX1 (0.01 mg/mL), and (c), 1 hour after treatment. (e), height images (z-range = 600 nm) of PaR3 treated by CX1 (32 µg/mL). (b), (d) and (f), cross sections taken along the colored lines on the images.

Here we propose a novel approach for fluorescent thermometry and thermal imaging purposes using spin crossover nanoparticles [RVSI10001] of Fe(II)-triazole (temperature sensor) and an appropriate fluorophore (signal transducer). The primary advantage of this system is that the nanoparticles are modified easily, which enables fine control of the thermometric properties, while the optical properties (i.e. the signal detection) remain virtually unchanged. This system could thus be adapted in a straightforward manner to various problems where the use of fluorescent thermometry would be beneficial (**Erreur ! Source du renvoi introuvable.**).

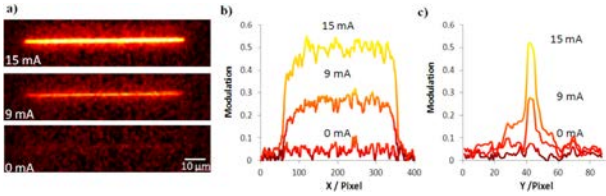

Figure 22: Thermal imaging through the spin transition. The example displays the fluorescence microscopy images of a $[Fe(hptrz)^3](OTs)^2$ thin film doped with Rhodamine 110 deposited on a gold micro-wire (80 µm-long, 1 µm-wide) biased with three different currents.

For CNTs integration we followed three objectives. The first one is a technological one consisting in the development of 'silicon technologies' compatible processes for the wafer scale integration of CNTs. We have developed two processes, one involving spray coating and µCP, the other one (project funded by INTEL) using a combination of dielectrophoresis (DEP) and capillary assembly (Figure 23) [RVSI12088].

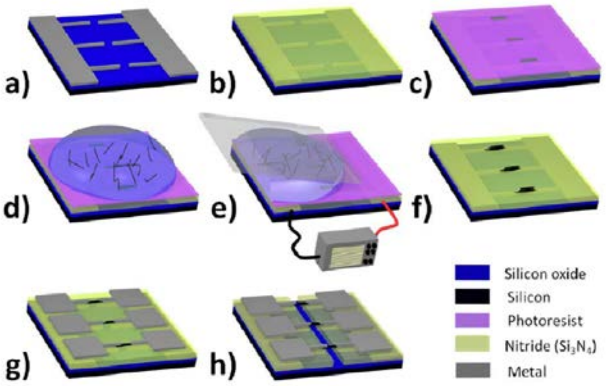

Figure 23: Schematic view of the complete process used to integrate CNTs dispersed in solution by a combination of DEP and capillary assembly.

The second objective involves the chemical modification of the surface of these CNTs in order to confer some specific affinity with respect to some molecules of interest such as antibodies or cell wall membrane proteins. Finally, the third objective is dedicated to a specific application [RVSI12775] where arrays of DWCNTs are fabricated for neural cell differentiation (Figure 24).

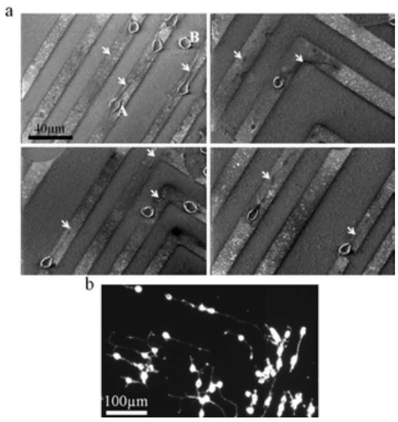

Figure 24: Neuro2a cells culture on a SiO2/CNTs micropatterned surface. (a) SEM images of neuro2a cells cultured on patterned surfaces after 2 days of differentiation. Arrows point to neurites developed on CNT patterns. The letter A indicates a specific cell body on a CNT feature, and the letter B points out a specific cell body outside of a CNT feature (on a SiO2 feature). (b) Optical fluorescence image of neural cells grown on CNT patterns (similar to Figure 1, right) after phalloidin staining. Note that neurites follow the CNT lines turning at an angle of 90°.

We also investigated new technological bricks for integrating functional biological nanomachines inside hybrid devices. A tentative has been made for assembling on-chip, some parts (rotor and stator) of the flagellar nanomotor of bacteria. We have found that by combining advanced surface patterning with lipid bilayer formation, membrane proteins and complexes can be inserted on an engineered surface. The process involved the direct synthesis of the proteins of interest using a cell free expression system inspired from synthetic biology (Coll. V. Noireaux University of Minnesota). We are currently integrating membrane pores (Figure 25) on suspended lipid bilayers [RVSI10756] for creating an electrical device able to measure the ionic conductance through the assembled pores. The application of such devices will be the pharmacological screening of drugs targeting the activity of specific membrane channels.

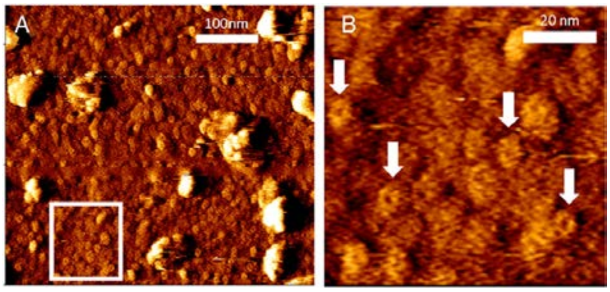

Figure 25: AFM image in liquid medium of the suspended lipid bilayer formed on the sensor surface after cell-free expression of αHL-eGFP and washing procedures. (A) 512Å~512 nm square image. (B) Blow-up of the white frame shown in A. Arrows point to αHL-eGFP pores.

2.3.3.3 Biosensing

As we mentioned previously, our work on biosensing mostly focuses on the development of fluidic platforms, biomechanical sensors and label-free biomarker detection. We will give an insight of each of these aspects of our work.

Due to reduced dimensions and thus diffusion length, nanofluidic biosensors take advantage of molecular confinement between immobilized probe molecules and flowing analytes, resulting in high binding efficiency and significantly shorten reaction time. Nanochannels and nanoslits have previously been used for protein and DNA sensing applications, however, to this date, there is still no or little research on binding affinities and kinetic information of their interactions. Our research group (PHC Orchid, collaborative support between France and Taiwan [2011-2012], LAAS (Coordinator), Academia Sinica) has developed a fluidic platform for real-time monitoring (Figure 26) of protein binding kinetics using biofunctionalized nanoslits [RVSI12090]. Binding affinities and kinetic data can be accessed with these nanoslit sensors simply by means of classical fluorescence microscopes. We have recently demonstrated proof-of-concept of our affinity sensor using streptavidin-biotin and anti-mouse/mouse IgG interactions as model protein-ligand pairs (Figure 27). Extraction of kinetic parameters is achieved through the use of a model based on finite element method to predict the sensor response.

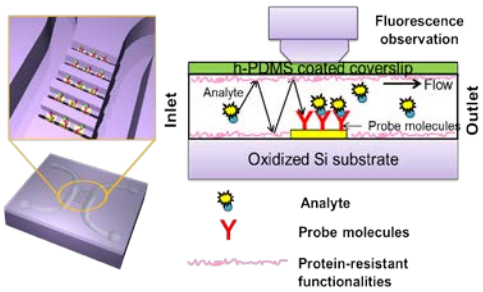

Figure 26: Schematics of a nanoslit affinity sensor device showing two microchannels connected with 500 nm deep nanochannels. The probe molecules are immobilized on gold patches at the bottom of nanochannels.

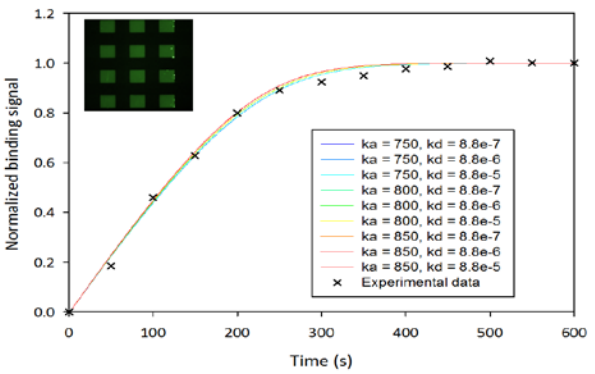

Figure 27: Kinetic curves of 30 nM streptavidin binding on a biotinylated nanoslit obtained from COMSOL simulation at different kinetic rate constants (ka, kd) compared with experimental data (×).

In the silicon-based sensors field, resonant microelectromechanical systems (or MEMS)-based physical sensors, inspired by the Sauerbrey's seminal description of the quartz microbalance principle, are among the best candidates to biosensing. The operation principle may be resumed as follows: as the squared mechanical resonant frequency is in inverse proportion with the sensor's mass, any added mass to its surface would be instantly translated into a resonant frequency shift. As a direct consequence, the lightest sensor would be the most sensitive. This involves downsizing efforts while integrating actuation and detection functionalities into the sensor's structure. Directly related to the biomechanical sensors' downsizing issue, our group proposed an innovative micro-contact printing –based (µCP) technique with nanoscale spatial resolution for the localized biofunctionalization of large-scale arrays of nanostructures [RVSI12631]. Using this method, we demonstrated the adequate functionalization/antifouling of arrays of freestanding nanocantilevers as dense as 10^5 nanostructures cm^{-2} (Figure 28) by using both fluorescence microscopy and dynamic measurements of the structure's resonant frequency.

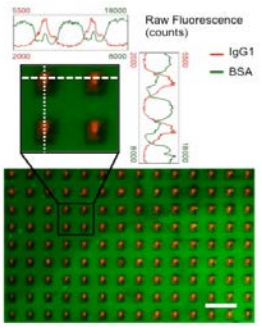

Figure 28: An array of nanocantilevers biofunctionalized using the µCP patterning technique. Superimposed fluorescence pictures of an array of nanocantilevers functionalized after printing an Alexa Fluor 660 IgG and Fluorescein-BSA in a single step (scale bar: 50µm). The inset provides a zoom of the array along with the fluorescence profiles.

Finaly, a long-term (>10 years) collaboration between the INNOPSYS Company and our team has resulted in the transfer of several patented technologies. By combining several nanotechnological processes such as µCP (Figure 29, left), directed assembly and single molecule technologies, we aim at designing novel schemes for the detection of dilute circulating biomarkers. These biomarkers (DNA, proteins or cells) need to be detected inside a very dense and complex medium such as blood. These results lead to the development of a biosensing platform currently transferred to an industrial partner (INNOPSYS), involving the label-free detection of probe/target molecular interactions (Figure 29, right).

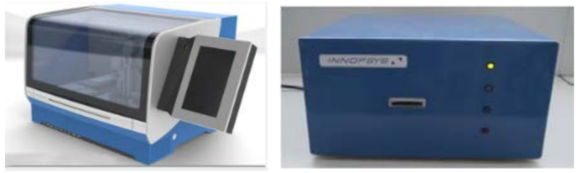

Figure 29: (Left) The InnoStamp®, a magnetic field assisted microcontact printing device. The Innostamp allows homogenously depositing micro- and nano- patterns of any kind of substrate from biomolecules to nano objects on a large scale such as a microscope slide or a 4 inch wafer. (Right) Label free biodetector based on Diffrachip® technology.

2.3.3.4 Dissemination of interdisciplinary knowledge on nanobiotechnologies and nanomedicine

In collaboration with a research team in science education, we have developed an education program [Nano-INNOV] for a citizen education to Nanotechnologies [RVSI10252]. Each year, with more than 100 pupils at secondary school, we develop lectures and workshops for combining both a scientific education to nanotechnologies and an approach to the ethical, societal and legal aspects of nanotechnologies. Since two years we also educate the educators of the Midi-Pyrénées academy to such innovative educational process.

2.4 High Frequency and Fluidic Microsystems

2.4.1 Objectives and Positioning

The scientific context of the high frequency and fluidic microsystems area deals with the interaction of electromagnetic fields and fluids at the micro and nanoscales, and notably at the molecular and cellular levels for health and life sciences. More precisely, it is based on the possibility of microwaves and millimeter waves to penetrate the matter. The crossed material may be probed due to its electrical properties, which have modified the electromagnetic waves. Microwave dielectric spectroscopy is consequently very attractive as a non-destructive and contact-less analyzing technique and widely developed since decades at the macroscale.

The major objective in this area is therefore to take advantages of **Microwave Dielectric Spectroscopy - MDS - at the microscale to investigate fluids for various applicative domains such as chemistry, environment, biology, and medicine notably.** At the cellular level, the frequency domain of micro and millimeterwaves permits indeed to overpass the bi-lipid membrane of biological cells, giving access to the interior of the cells. Since 2008, the use of microwaves to elaborate integrated sensing techniques dedicated to biological and medical applications is more and more emerging. Clemson Univ. and the NIST in the USA, Erlangen Univ, in Germany, Katholik Univ. of Leuven with IMEC in Belgium, Imperial College of London, XLIM in France are part of these research groups. The MH2F team is leader in term of miniature microwave dielectric spectroscopy of biomolecules and living cells in their culture medium.

In complementarity, high frequency signals are still creating large controversy due to their potential impacts on the living. A report of the International Commission on Non-Ionizing Radiation Protection (ICNIRP) concluded in 2009 that no consensus between the different studies was yet obtained on RF genotoxicity and that appropriate dosimetry was required. To fulfill such a gap, MH2F team is also developing miniature metrology and applicators ***to evaluate the effect of RF signals on the living***. This constitutes our second objective.

2.4.2 Methods and Scientific Approaches

Based on the above objectives, we have defined the following main research orientations:

2.4.2.1 Miniaturized microwave dielectric spectroscopy for biology and medicine

Our target is to provide new analyzing tools of the living to the biologists and physicians at the molecular and cellular levels, in order to give them access to new bio-parameters, to a new way to observe the living in complementarity to the existing techniques, which are mainly based on optics or X-rays. For that, we have started by identifying the breakthroughs brought by the technique, such as its non-invasivity, the richness of information in the RF signatures, its integration for Lab-on-Chips or massive parallelization, its ability for real time monitoring and its compatibility with in/ex vivo implementations. In collaboration with biologists, we are defining the limits of the technique compare to the targeted application, i.e. non-invasively observe living matter and extract pertinent information.

Strong investigations in close collaboration with biologists are consequently on going in order to respond to the following questions: May RF non-invasively sense cells in their culture medium? Is the RF signature specific and to which extent? May MDS discriminate cells and why? May MDS discriminate pathological state of cells and why? What about reliability issues of the MDS technique applied to living matter? May the technique be applied to the real time monitoring of biological processes? Which processes may be sensed?

To answer these questions, we are following a progressive approach in term of model complexity, in conjunction with the development of appropriate RF device architectures, heterogeneous microtechnologies and multifunctional metrologies. We are investigating elementary constituents of cells such as biomolecules (amino acids, carbohydrates, nucleic acids...), looking at cells themselves both at the population and also at the single cell levels, and even now up to the tissue.

Several biological models have been identified and constitute our main biological tools, where the HF technique may bring a breakthrough: the evaluation of blood parameters (for glycaemia detection and physiological parameters assessment), the sorting and analysis of Circulating Tumorous Cells in blood, the detection of melanoma on skin, as well as the vascularization degree of tumors.

2.4.2.2 Miniaturized microwave dielectric spectroscopy of highly absorbent carbon-based colloidal solutions

Microwaves are not only sensitive to organic materials as with the living. It may also be applied to various types of materials, dielectric and also conductive ones. Therefore, we have identified that microwave dielectric spectroscopy can be particularly adapted to characterize highly absorbent carbon-based colloidal solutions. Such a technique is therefore very promising, where traditional optical techniques may not respond any longer due to opaque liquid solutions.

In collaboration with the CIRIMAT (Emmanuel Flahaut), we have demonstrated that MDS may be applied to eco-toxicity issues, with the concentration evaluation of carbon nanotubes ingested by Xenopus larvae (Figure 30).

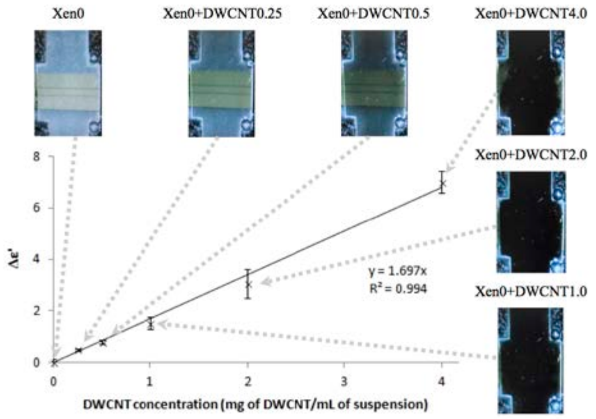

Figure 30: Dielectric calibration curve generated with double wall carbon nanotubes (DWCNT) based suspensions of Xenopus larvae with known DWCNT concentrations. The photographs present the DWCNT solutions in the sensor for different concentrations.

2.4.2.3 Impact of microwaves on the living matter with a microscale approach

As a counterpart to (bio-)materials characterization with microwave dielectric spectroscopy, evaluating biological effect of electromagnetic waves on the living matter is also an important and societal question to answer. Past studies were mainly performed at the scale of an entire body. Few teams are focusing on investigating potential impact of RF through 2D culture cell plates, notably at XLIM and IETR, in France.

However, one key difficulty to express reliable results and interpretation is to apply homogeneous electromagnetic fields, which is particularly difficult at a large scale. There is consequently a strong interest to downscale the experiments and to develop new metrology. Since 2012, MH2F team is working in close collaboration with biologists from ITAV on the development of new RF applicators and metrologies, which permit the application of homogeneous electrical fields at a microscale, to evaluate the clastogenic effect of RF waves on biological cells. The biological model, which has been chosen, corresponds to spheroids of cells. These are indeed representative of tissues behavior and adapted to complementary biological investigations.

2.4.3 Highlights and Major Achievements

The two objectives of the team have reached different levels of maturity and therefore achievements. The investigation of miniature microwave dielectric spectroscopy applied to biology is the most mature one and provides a key position in the world to the team (member of the technical committee on Biological Effect and Medical Applications of RF and Microwave of the IEEE Microwave Theory and Technique Society; Chair of the IEEE BioWireleSS 2015 conference). Among the most important results, we may highlight that.

With biomolecules in aqueous solutions, we have demonstrated that the RF response is linearly proportional to the concentration of the biomolecules. This RF response is also specific to the biomolecule under test [RVSI13496], as shown in Figure 31 for saccharose and albumin proteins. This specificity has been demonstrated on various biomolecules: amino acids, nucleic acids, carbohydrates and other proteins.

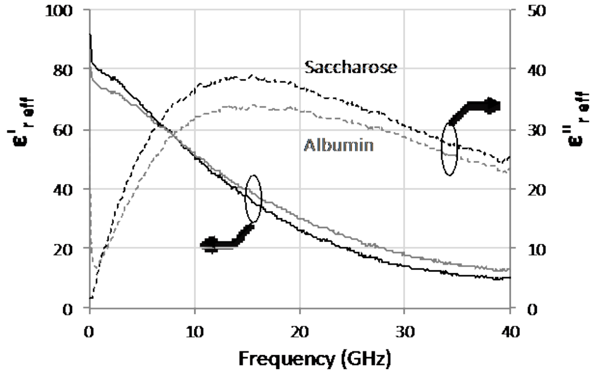

Figure 31: Real and imaginary parts of the complex permittivity of the 100 mg/ml Bovine Albumin Serum (in grey) and Saccharose (in black) proteins up to 40 GHz. Measurements performed with nanoliter volumes of liquid using a coplanar-based miniature microwave biosensor.

Toward the blood parameters evaluation context, multi-frequency based sensors associated to a 3D technology have been developed to discriminate several constituents of heterogeneous liquids and to evaluate their respective concentration [RVSI13495]. Moreover, we have demonstrated that it is possible to apply this technique to multiple fluidic samples toward parallelization analysis.

As far as cells are concerned, we have shown that microwave dielectric spectroscopy may be applied to living or dead human cells, which may be non-invasively characterized directly in their culture medium, without any labeling, staining or other preliminary cells preparation. The RF response is proportional to the cellular concentration [RVSI12566] and, at a fixed concentration, the microwave readouts depends on the cells' viability [RVSI13496]. The technique has also been developed to evaluate the impact of solvents and therapeutic drugs on cells both at the population level to avoid any artifact due to the intrinsic heterogeneity of the living, but also at the single cell level for further observation of biological mechanisms. Real time monitoring of the cell permeabilization has been successfully recorded at the single cell level for the first time with the MDS technique (Figure 32). These results constitute the state of the art. These results let foresee important impacts in cancer investigations as the technique is non invasive and non destructive for the cells.

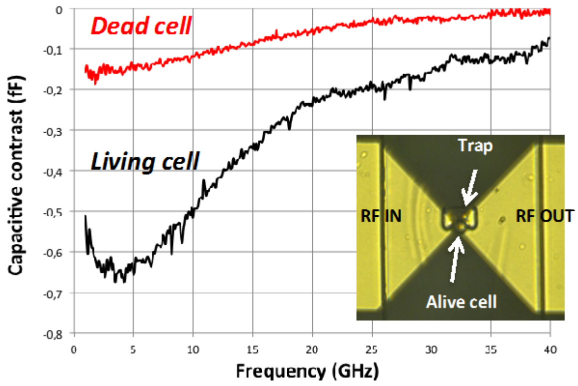

Figure 32: Capacitive contrast of single B-cell lymphoma for the 2 pathological states: living (black curve) and dead (red curve); Microscope image of a live B-cell lymphoma (with a diameter close to 10 µm), which is trapped above a capacitive gap and surrounded by its culture medium (RPMI with 10% of FBS).

One of our test-setups is notably implemented directly to the CRCT platform, part of the Toulouse Cancer Campus, in the Canceropole itself in order to enable the measurements of not only cancer cells lines but also patients cells in direct collaboration with biologists and physicians.

3 Academic Reputation and Appeal

Research projects and subsequent results as described in section 2 are only part of the day-by-day activities managed by the MNBT scientific staff. For a scientific endeavor to become a success, especially when research at the intersection of disciplines is concerned, it is mandatory to set-up the appropriate networks allowing to get funded, hire the right people, work and communicate in the right places so that such effective cycles restart as long as possible. Actions and successes in that sense are listed hereafter.

3.1 Main International and National Collaborations

3.1.1 International Collaborations

The MNBT scientists established international (extra-European space) worldwide collaborations with research institutes and universities, with a particular focus on the North America and Asia. Such opportunities were originated either by transforming informal professional relationships in formal collaborations or by MNBT young doctors which applied for opened postdoctoral positions abroad and set-up links with their home-lab. All but those collaborations were financed by *opportunistic* funding (internal leftovers) – collaborations with PennState University, UQAM…– except international projects supported by the ANR (France-Taiwan, in our case).

3.1.2 Europe

MNBT was very active during the previous 7th European Framework Program and successful when applying to various funding schemes: FP7-ICT (ATEMOX and ATOMICS – Streps, PULLNANO – Integrated Project, NANOTECH and NanoICT – Coordinated Actions) and ERA-NET (DetectMUNE project).

3.1.3 National Collaborations

The national collaborations and resulting projects are the major part of the MNBT funding. Thus, during the evaluation period, 17 ANR and 27 not-ANR (Region, CNRS, Universities…) projects gathered together national consortia where MNBT scientists were either leaders or partners. Most of our ANR projects were or are still funded either by the NANO-related calls (PNANO, P3N, then P2N) or the so-called BLANC calls (mostly "Physics-Chemistry-Biology"-oriented calls).

3.2 Journal Editorial Boards

3.2.1 International

Several senior scientists from MNBT are members of international journals editorial boards such as Physica Status Solidi, Plos One, ISRN Biophysics and Microelectronics Engineering. In the latter case, four special issues of the Microelectron. Eng. Journal dedicated to the MNE 2012 Conference were guest-edited by NBS team members.

3.3 Organization of Major Conferences and Workshops

It is now well-established for members of MNBT theme to be actively involved in the organization of major conferences in their expertise areas. Beside chairing conferences such as Micro & Nano Engineering (2012, Toulouse) or workshops such as the 2nd Int. Workshop on NEMS (2011, Toulouse), our researchers are for several years members of IEEE conferences (NEMS, IMS, BioWireleSS, NewCAS, ICECS…) or other various international events (SPIE Photonics Europe) Technical Program Committees.

3.4 Major and Long Term Visits

3.4.1 Sojourns of Researchers Abroad

One of our senior scientists (Daisuke Saya, CNRS Researcher) is staff seconded from LAAS to the LIMMS laboratory (Tokyo) since 2012 for a three years period of time.

3.4.2 Researchers Hosted

Three categories of hosted researchers by MNBT theme could be identified: *Confirmed Researchers* (such as Prof. Chia-Fu Chou for Academia Sinica), *Junior Researchers* (such as PhD Students or Post-Docs) and *Other Categories* (such as Dr. Sylvain Sanson, Urologist Surgeon working on the fabrication and testing of intravascular nanotechnology-based devices under the supervision of Dr. Aline Cerf).

It has to be pointed out that the major part of our foreign PhD students and Post-docs are coming from extra-European space (China, Vietnam, Indonesia, South Africa, Northern part of Africa, Brazil, Russia).

3.5 Scientific Evaluation Committees

3.5.1 International

When requested to be part of international evaluation committees, the MNBT researchers are answering favorably. For some of them, they took part to ERC panels, FRNT Quebec expertise and other international boards detailed in the *MNBT Reputation And Appeal Tables*.

3.5.2 National

At the national level, most of the MNBT scientists were actively participating to various committees of the past ANR, CNRS, Universities calls, either as members or, occasionally, presidents of different disciplinary panels. Specific details are provided in the *MNBT Reputation And Appeal Tables*.

3.6 Major Roles in National Animation and Evaluation Structures

3.6.1 CNRS, University

Several MNBT researchers were members or presidents of Selection Committees (set-up to hire teaching personal) for local or national Universities or Engineering Schools (e.g. INSA Toulouse).

Two of our CNRS researchers were elected members – and actual President, for one of them - of the CNRS National Committee (section 08). On top of that, the same CNRS researchers were part of the Engineering Sciences Institute (INSIS-CNRS) management staff.

A detailed list is provided in the *MNBT Reputation And Appeal Tables*.

3.6.2 GDRs, …

Since the National Micro and Nano Technologies Observatory (OMNT) foundation, in 2005, the MNBT theme scientists were taking actively part to the various experts groups (such as NEMS, Micro- and NanoSystems for Biology and Medicine, Biomimetism…). The Micro and NanoSystems GDR was co-founded and directed (for a one-year period) by C. Bergaud and other MNBT members are part of the GDR's bureau.

3.7 Awards and Distinctions

Three awards were granted to MNBT members during the referred period:

- The L'Oreal-UNESCO "Pour les femmes et la science" 2011 Award and the "Prix de l'Innovation Académie des Sciences et Belles Lettres Toulouse" 2013 award granted to Amélie Béduer (PhD Student) for her work on polymer-based neuronal implants;
- The "George McCracken Infectious Disease Fellow" 2013 Award granted to Etienne Dague for his work on use of the Atomic Force Microscopy for microbes investigation and antimicrobial agent evaluation.

4 Interaction with Social, Economic and Cultural Environment

4.1 Projects with Industrial Partners

The different projects shared with industrial partners over the past 5 years may be classified in two categories: *Privileged Partnership* (based on historic ties regularly updated to fit both with industrial objectives and academic ambitions) and *Opportunistic Collaborations* (stemmed from specific Calls for Projects or industrial requests):

- *Privileged Partnerships* concern long-term collaborations with companies such as ST Microelectronics (related to nanoelectronics developments), Hemodia (focused on the industrial transfer of IsFET devices to be implemented onto operational dialysis systems), Innopsys (based on the integration of soft lithography techniques onto automatic printing tools), Renault (related to gas sensors development dedicated to cabin air quality system). A joint lab between NBS team and Innopsys has been founded in February 2014 (see Section 1.3, Salient Facts).
- *Opportunistic collaborations* are generally based on the initiative of industrial partners looking for specific know-how to build up or complete R&D consortia for answering to national or European Calls for Projects. During the referred period we had the opportunity to collaborate with companies such as Paul Boyé Technologies, Pierre Fabre, Intel, Nanomade etc.

4.2 Scientific Popularization

Communicating, sharing information, disseminating knowledge in understandable ways for the layman, give rise to specific concerns and subsequent actions towards the general public. Upon request, we are according interviews to the local press (related to MNBT salient facts), we are participating to specific manifestations such as days related to the Mondial Year of Chemistry (2013) and, on a regular basis, we are participating to the annual organization of the “Fête de la Science”.

Occasionally, whenever concerned or commissioned to, we take part to public debates such as those related to the Nanotechnologies (on a national scale) in 2009 and 2012.

5 Involvement in Training through Research

5.1 Research Seminars in Training Programs

We are strongly concerned by and actively involved in the education of young pupils through the “Nano-Ecole” initiative, an educational engineering experiment on nanotechnologies at school. Up to 6 classes per year (30 hours/class) are ensured on topics such as writing at the nanoscale, nanobits and data storage, biomimetism, nanomotors in the living and debates on socio-ethical issues. Over the 5 years referred period, our action impacted up to 700 pupils.

5.2 PhD and Internship/Master Programs

5.2.1 Thesis supervised

The number of PhD students being supervised by the MNBT theme scientists during the referred period is (without discriminating the kind of funding support) of 59. When divided by the number of permanent scientists, it reduces to a ratio of 2.5.

All but half of them are currently occupying permanent positions in different companies (for most of them in France), while the others are occupying academic positions (either CNRS or University assistant professors) or post-doctoral positions abroad (IMTEK, LIMMS, EPFL, etc.).

5.2.2 Co-Supervised Thesis

The co-supervised thesis are only a small fraction of the overall PhD thesis running within MNBT; part of them are CIFRE thesis (funded by and co-supervised with industrial partners such as Innopsys, ST Microelectronics or Renault) while the others are inter-teams within MNBT (such as A. Casanova shared by MPN and NBS teams on the neuronal signals recording using nanowires) or inter-themes within LAAS (such as A. Simaite working on artificial muscles between MNBT and RO themes).

5.3 PhD/HdR Committees

12 of the 24 permanent MNBT members obtained the Habilitation to Drive Research (HDR) which qualifies them to be part of PhD thesis or HDR committees as referees while the second half of the staff participates to PhD thesis committees as experts. During the past 5 years, the MNBT researchers took part to 99 PhD thesis committees and 13 HDR committees either as referees or experts, 5 of them having been defended abroad.

IX - Energy Management (*Gestion de l'Energie* — GE)

Leader: M. Bafleur

Research Teams: Power Management System Integration (ISGE), Energy and Embedded Systems (ESE)

Keywords: power devices, energy conversion, energy management, power integration, energy harvesting, robustness, predictive reliability…

Personnel Status (as of January 01, 2015):

Team — ISGE	Power Management System Integration (Intégration de Systèmes de Gestion de l'Energie)
Leader	F. Morancho (PR)
Permanent Researchers	C. Alonso (PR), P. Austin (PR), A. Bourennane (MCF), M. Breil-Dupuy (CR), M. Brunet (CR HDR), B. Estibals (PR), K. Isoird (MCF), B. Jammes (MCF), J.P. Laur (MCF), C. Lefrou (MCF), L.F. Lavado Villa (MCF), D. Pech (CR), H. Schneider (MCF HDR), J. Tasselli (CR), D. Trémouilles (CR)
PhD Students	A. Barroso, G. Delamare, G. Dulout, A. Ferris, A. Lale, R. Meunier [03/11], T. Y. M. Nguyen, S. Noblecourt, T. Phulpin, H. Rizk
Post-docs; Engineers	M. Bressan, T. T. M. Dinh, Y. El Basri , M. Gaetani, A. El Khadiry, A.N. Kyeremateng, E. Marcault, H. Tahir, G. Toulon, N. Videau, , M. Zerarka
Team — ESE	Energy and Embedded Systems (Energie et Systèmes Embarqués)
Leader	J.M. Dilhac (PR)
Permanent Researchers	M. Bafleur (DR), S. Bendhia, V. Boitier (MCF), A. Boyer (MCF), F. Caignet (MCF), N. Nolhier (PR), P. Tounsi (MCF HDR) Retired: J-M. Dorkel (PR) [09/13] – Associated researcher: V. Boitier (PRAG) [01/09-08/12], J-L. Massol (MCF) [09/09-08/13]
PhD Students	R. Bèges, B. Courivaud, P. Durand-Estebe, C. Ghfiri, H. Huang, V. Tomasevic,
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1 Presentation

1.1 Objectives and Scientific Positioning

One of the big challenges that our society will have to face over the next decade is related to energy issues. Worldwide, most of the energy is consumed into transports and buildings, both residential and industrial, thus resulting in a significant increase of CO_2 emissions and global warming. The majority of this energy is generated by non-renewable and non-environmentally friendly coal, fossil fuel and natural gas. In the objective of a sustainable development, the widespread of alternative energy sources in transportation and buildings is the solution that will require a major paradigm shift in the power industry:

- Transports will have to become more electrically driven thus demanding for new generations of power devices and converters.
- For a large penetration of renewable energies, it is more appropriate to move from a centralized generation approach to a distributed one.

The information economy of the 20th century was built around silicon technologies to revolutionize computing and communication. In the same way, silicon and semiconductors in general will play a key role in the emerging energy economy of the 21st century for the transmission, distribution and consumption of electricity. Concurrently, the advances in micro and nanotechnologies allow a drastic miniaturization of systems for power generation and management, thus increasing the autonomy of embedded systems and making possible the dissemination of wireless sensor networks in a large variety of applications so called "ambient intelligence". This last objective requires, on the one hand, the development of innovative approaches for energy harvesting coupled to low-power converters and on the other hand, the integration of high-density storage devices.

The research activities of the Energy Management Theme deal with the optimization of energy efficiency, robustness and reliability of conversion architectures dedicated to electrical grid - including alternative energies - to transport vehicles and to embedded systems, from elementary power devices to full modules. Main research areas are threefold:

- Power integration: from device to system
- Robustness and reliability: ESD/EMI, radiation hardening, electrothermal modeling
- Energy autonomy of embedded systems

These research activities are carried out with the support of LAAS-CNRS technology platform that is part of the RENATECH network and is the only one with the label "Energy system integration". In addition, we have dedicated electrical characterization platforms (ESD, EMC, power) and an experimental building, ADREAM, with 100kWp photovoltaic platform.

On the University of Toulouse campus, LAAS-CNRS has complementary activities with LAPLACE laboratory and is member of 3DPHI GIS (http://www.3dphi.fr/), which has setup a technology platform dedicated to hybrid power integration, in perfect complementarity with LAAS-CNRS technology platform. At national level, we are part of SEEDS GDR and have several cooperative projects in the field of power electronics systems with G2elab, AMPERE, LAPLACE, LPCIM, CEA LITEN and INES to develop new integrated devices, functions and converters with several complementary research activities on very high voltage devices, on the one hand, and very low voltage/high current solutions, on the other hand.

Internationally, we are in competition with CNM-Barcelona whose specificity is SiC, the University of Cambridge (UK), the Fraunhofer Institutes (IISB and IMS, ISE in photovoltaic field) in Germany, EPFL of Lausanne, Tyndall in Cork in passive components and energy harvesting, Tokyo Tech, the Hong Kong University of Science, University of Toronto, CPES from Virginia Tech (USA), University of Colorado and from Rensselaer Polytechnic Institute (USA) in converters and associated controls. The leadership of our teams is well recognized worldwide: partnership in WIDELAB LIA (AMPERE, CNM, LAAS) on wide bandgap semiconductors, participation to several FP7 European projects (one as coordinator), involvement in Next-PV LIA with Tokyo Tech, invited talks, active involvement in program committees of major conferences of the field and in international associations (ESD Association, Electrochemical Society…).

1.2 Organization and Life

The Energy Management (GE) Theme is organized in two complementary research teams:

- Energy Management System Integration (ISGE)
- Energy and Embedded Systems (ESE)

ISGE team mainly works on the challenges of power integration, both monolithic and hybrid, from design and technological realization of active and passive power devices to innovative architectures of conversion systems.

ESE team tackles the challenges of the management of energy in the environment either to capture it to improve energy autonomy or to increase the immunity of the embedded electronics system to disturbances (electrothermal management, electrostatic discharges (ESD), electromagnetic interferences (EMI)).

1.2.1 Activity Profile

Table 1 hereafter depicts the activity profile for the Theme. Since energy is a strongly multidisciplinary societal challenge, to carry out its research activities, GE Theme has strong and well-balanced interactions with both academic and industrial partners.

Table 1: Activity Profile

%	Academic research	Interaction with environment	Research Support	Training
GE	45	25	10	20

1.3 Salient Facts

Over this period, there were major evolutions both in terms of recruitment and of research topics. Our major activity on innovative power devices, originally focusing on silicon, evolved towards wide bandgap semiconductors (GaN, SiC, diamond). Within the framework of ADREAM transverse project, we participated to the definition of the energy aspects of an experimental building, which opens a new field of research related to the efficient management of renewable energies in a microgrid dedicated to urban applications.

In addition, two new research topics started during this period:

- EMC immunity and related long-term reliability.
- Energy autonomy of wireless systems: energy harvesting and microstorage.

Hereafter are summarized some salient facts organized by research topic.

Power integration

- State-of-the-art results for innovative wide bandgap power devices:
- GaN HEMT on 6" silicon wafer: 1000V breakdown voltage and 2.5 mΩ.cm^2 specific on-resistance.
- Diamond Schottky diodes: 3.8 kA/cm^2@5V and 3.75 MV/cm maximum breakdown electric field.
- CNRS Bronze medal in 2011 awarded to Magali Brunet for her remarkable results in the field of passive devices and pioneering work on microsupercapacitors.
- Strong innovative activities on renewable energy converters and their management with several academic collaborations, CEA and Total S.A contracts (ANR LiPV, PHD CiFRE) and the creation of the 100 kWp PV platform of ADREAM building.
- Doc'Innov 2011 Price for the best innovation research work: J-F Reynaud Ph.D. thesis.
- Innovative work in the field of lifetime improvement of photovoltaic power converters: best paper award at conference IECON 2012, Montréal, 10/2012.
- GEET best thesis award for original work related to PV converter efficiency under shading conditions: Y. El Basri, 2013.
- 4 international patents with Total S. A.
- Involvement into two Research Federations: SH&HD (co-direction: C. Alonso) and FEDESOL related to renewable energies.
- GEET best thesis award and UPS Physics Award of « Académie des sciences, inscriptions et belles lettres » of Toulouse for the work related to the design of a monolithic self-switching power device: F. Capy, 2010.
- Member of LABEX GaNex, national network on GaN.
- WISEA Alliance: IISB Fraunhofer Institute, Nuremberg University and CEMES (as a result of fruitful MOBISiC project)

Robustness & reliability

- Strong activity in the field of ESD with 7 PhD theses defended, the development of original test benches (near-field scan, Transient TLP, double pulse TLP) and the proposal of a behavioral methodology for system level ESD modeling that is currently being discussed at ESDA standard committee for becoming a new standard.
- Pioneering work on characterization and modeling of the impact of ageing on EMC properties (both emission and immunity): ANR JC EMRIC, 14 publications in journals, best paper award at EMC Compo 2013.
- Original radiation hardening techniques for IGBT devices.
- Adaptive and distributed electrothermal and thermo-mechanical modeling methodologies for predictive reliability simulation of advanced power devices in harsh environment: 4 ANR projects (FIDEA, MHYGALE, MOSiSTAR, REMAPODE). Transfer of this methodology to smart power design center of Freescale (Toulouse).

- GEET best thesis award for pioneering work on ESD protection devices operating at high temperature: H. Arbess, 2012.

Energy autonomy

- Two new research topics, energy harvesting and microstorage, with a strong activity: 2 FP7 projects, one as coordinator, CORALIE "Investissements d'avenir" project, ANR JC MIDISTOCK, 1 FUI and 1 FNRAE.
- State-of-the-art results for microsupercapacitors integrated on silicon: up to 675 mF/cm^2 specific capacitance and extremely high power densities (700 mW/cm^2).
- Valorization and transfer of results obtained within SACER project: implementation of photovoltaic powered wireless battery-free sensors for flight tests. Successful flight tests realized in June 2014 on an Airbus A321.
- Two original techniques for energy harvesting in the harsh environment of aeronautics:
- Use of a phase change material (water) in the case of thermal gradients (FNRAE AUTOSENS): 15J harvested over one-hour flight.
- Proof of concept of efficient aeroacoustic energy harvesting.

2 Scientific Production

Given the large range of energies associated to each application (from mobile electronics to electrical traction) and the corresponding current and voltage levels, the challenges of power integration and management are different from those of signal processing systems. As a result, the design of new power devices and their integration requires a top-down approach starting from the application needs.

Our strategy then consists in a global analysis of the different aspects of the final system: converter architectures, active and passive devices, energy autonomy and environment constraints, protection and robustness to propose innovative concepts and related technology solutions. This approach is supported by a strong expertise in modeling, design, realization and characterization in the field of energy systems.

As silicon is a key semiconductor material for embedded electronic systems, we are still carrying out research on silicon-based power devices with the objective of pushing away the limits of silicon. To this aim, we have chosen to develop specific 3D silicon technologies (deep trenches, double-side lithography...) to take advantage of the full semiconductor volume and to design bidirectional switches. Introducing new materials (magnetic, high-K dielectrics…) in the silicon process is also a key step. Moreover, to fulfill the requirement of a higher switching frequency for power conversion, we study new topologies based on interleaved structures and their digital control laws.

Nevertheless, further increasing power device performance requires a technological breakthrough. We have then chosen to study wide-bandgap devices (gallium nitride, diamond, silicon carbide) that offer the possibility to overcome both temperature and power management limitations of silicon.

Regarding power systems, to validate in real conditions new concepts on the management of renewable energy and its storage, we have designed a "zero-energy" building, named Georges Giralt, which is an innovative experimental platform with 7000 sensors. Within the framework of ADREAM transverse axis, this platform was designed to carry out real-scale experimental validation of multidisciplinary research projects related to energy issues.

Finally, with the development of energy storage micro-devices (micro-supercapacitors), we are aiming to provide energy storage on chip, which can be co-integrated with its control circuit and/or the sensor requiring power. This microstorage activity was concurrently started with the one in the field of energy harvesting that focuses on providing efficient energy management for battery-free wireless sensors. These two activities are tightly related, the main objective being to provide new breakthroughs for energy-autonomous wireless sensors both in terms of technological integration and energy-efficient architecture of the node.

The activity of robustness and reliability is mainly related to power devices and systems but also extends to any other type of electronic system. The approach is first to get a thorough understanding of the involved physical mechanisms via multi-physics modelling and simulation as well as dedicated characterization. From this knowledge, efficient protection strategies such as radiation hardening techniques or novel ESD/EMC protections can be devised to improve the system immunity to the related disturbances. Another important challenge is to provide predictive simulation methodologies.

Electromagnetic compatibility (EMC) is a new activity in the theme started in 2011 with the arrival of two researchers whose integration was easy given the strong convergence between ESD and EMC methodologies. The common approach consists in developing dedicated characterization techniques with reduced intrusiveness and predictive modelling methods. Two complementary approaches are contemplated: on-chip sensors for their good resolution and large frequency range as well as near-field scan for system level analysis. The proposed modeling ESD/EMC methodology aims at being as generic as possible by providing a hierarchical and behavioral approach from chip to printed circuit board (PCB) or even electronic equipment.

Regarding electrothermal and thermo-mechanical strain management, the main challenges are related, on the one hand, to multi-physics phenomena and on the other hand, to multi-scale issues either temporal or spatial. To cope with these problems, our methodology is based on 3D electro-thermal simulation, to investigate the involved failure mechanisms. To this aim, a new procedure to create communication between electrical modelling solver and thermal one has been developed.

2.1 Power Integration: *From Device to Systems*

2.1.1 Passive Devices

Nowadays, the trend toward miniaturization of mobile electronic products requires higher power density for systems such as DC/DC converters. Up to now, power semiconductors and control circuits can be fully integrated but the passive components, especially inductors, are still an obstacle for further reducing the size of these converters. For future power system on chip with high efficiency and high power densities, passive components should be integrated onto silicon and show high specific values, together with high DC current, reasonable breakdown voltage (depending on the system output power) and most importantly low losses at relatively high operating frequencies (> 1 MHz). Research activities in this field are focused on high-density integrated capacitors and micro-inductors.

In terms of capacitor topology, 3D structuration combined with the deposition of high-k dielectrics is necessary to reach very high specific capacitance values (above 500 nF/mm²) [***RVSI12694***]. The deposition of conformal high-k dielectrics in 3D high-density structures made of submicron micropores is a real challenge. First structures with $SrTiO_3$ high-k dielectrics were realized in the context of a collaborative industrial project (PRIIM) and electrically characterised at LAAS-CNRS. For $SrTiO_3$ deposited by MOCVD (at LEMHE Orsay) from a single source hetero-metallic precursor, good dielectric properties were obtained but deposition is not conformal. For $SrTiO_3$ deposited by Atomic Layer Deposition (ALD) (at TU Eindhoven), from two precursors, step coverage is improved. These studies of $SrTiO_3$ high-k material allowed identifying that crystallization and dielectric properties largely depend on the Sr/Ti ratio, the sub layer employed (Ti, Pt, Ru) and the annealing conditions (temperature and gas: O_2 or N_2). This work will continue on recently acquired ALD equipment at LAAS-CNRS.

Concerning micro-inductors, the activity focused on the fabrication of ferrite-based inductors on silicon for hybrid integration in low power (few Watts) DC/DC conversion. This work was carried out in cooperation with LAPLACE, with the support of 3DPHI platform and within the framework of PRIIM OSEO-funded project coordinated by IPDIA Company. Due to their high resistivity, soft NiZn ferrites are good candidates for magnetic cores working in the 5 to 10 MHz switching frequency range. The inductors were fabricated using micromachining and assembling techniques, and the process consisted in a sintered ferrite core placed in between thick electroplated copper windings. The cores produced by three methods (commercial tape-casted films, home-made ferrite powder or without magnetic layers) were characterized with respect to their magnetic properties, microstructure, composition and losses by Vibrating Sample Magnetometry, Scanning Electron Microscopy and impedance analysis. At 6 MHz, 890 nH of inductance has been recorded with a 1.2x2.6x0.2 mm^3 core using a commercial film (ESL 40011 - Electro-Science® Company) corresponding to ~290 nH/mm^2 [***MAI13442***]. Moreover, we developed a new simulation tool dedicated to the design of conductors for multi-layers and high frequencies, including several parasitic effects and interactions. Several researchers of our lab and the TEAM service now use this tool.

The co-integration of an LC filter was also demonstrated and successfully implemented in a real converter [***RVSI10568***].

2.1.2 Active Devices

Although we still carry out research activities on silicon power devices (Superjunction MOSFETs and thyristors), the main research activities are now focused on wide band gap (gallium nitride, silicon carbide, diamond) devices.

Concerning diamond, a platform of simulation was developed to design high-voltage and high-temperature diamond device [***RVSI10100***]. From results of simulations, Schottky diodes were realized by deposition of nickel (Ni) on p- homoepitaxial layer of diamond [***RVSI11643***] [***TH11899***]. Their electrical characterization under operation temperatures ranging from 300K to 625K resulted in a forward current density close to 3.2 kA/cm^2 @ 5 V and a maximum breakdown electric field of 3.75 MV/cm. These results, among the best in the state-of-the-art [1], also showed thermal stability of diamond Schottky diode characteristics. For the first time, electrical measurement was complemented with mechanical adhesion testing and demonstrated that Ni is a suitable contact metallization for high power, high temperature and good mechanical strength diamond Schottky barrier diode applications.

Gallium nitride (GaN) becomes more and more popular for power applications. Using heterostructures for carrier confinement allows offering high electron mobility and consequently, to achieve very low on-resistance devices.

In ToPoGaN1 project, the main technological process steps were validated, allowing the realization of functional AlGaN/GaN HEMTs on 150 mm silicon substrates. These devices exhibited breakdown voltages well above the targeted 600 V value (Figure 1) and specific on-state resistance of 2.5$m\Omega.cm^2$.

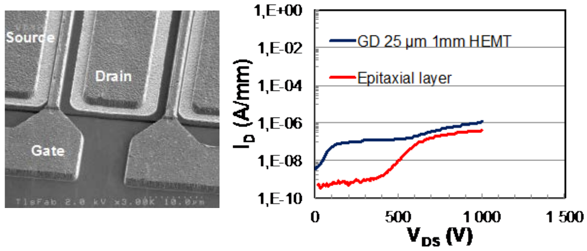


Figure 1: Photograph of realized HEMT GaN device and breakdown voltage measurement (BV ~2µA/mm@1kV).

Unfortunately, HEMTs are normally-on devices whereas normally-off ones are preferred for power applications, since it simplifies the design of driving circuits. To address this problem, new architectures of normally-off AlGaN/GaN HEMTs were recently proposed [***MAI13369***] and patented [***BR1303***], thanks to a preliminary 2D TCAD study. Furthermore, GaN MOS capacitances were realized: after the study of different interfacial treatments and dielectric (SiO_2) deposition on GaN, an optimal process was issued and resulted in minimized interface trap densities (close to 10^{10} $cm^{-2}.eV^{-1}$) [***RVSI11330***] [***TH11451***].

[1] Umezawa, H., Kato, Y. & Shikata, S. 1 ohm On-Resistance Diamond Vertical-Schottky Barrier Diode Operated at 250°C. Appl. Phys. Express 6, 011302 (2013).

For the characterization needs of wide bandgap devices, we developed a specific high-voltage (≤ 3kV) test bench for wafer-level measurement. For its implementation, we designed a circuit dedicated to energy switching measurement. To accurately estimate switching losses of fast power wide bandgap devices, chosen technique is based on the opposition method that does not involve direct transistor current measurement therefore not disturbing the switching behavior of the transistor under test (Figure 2).

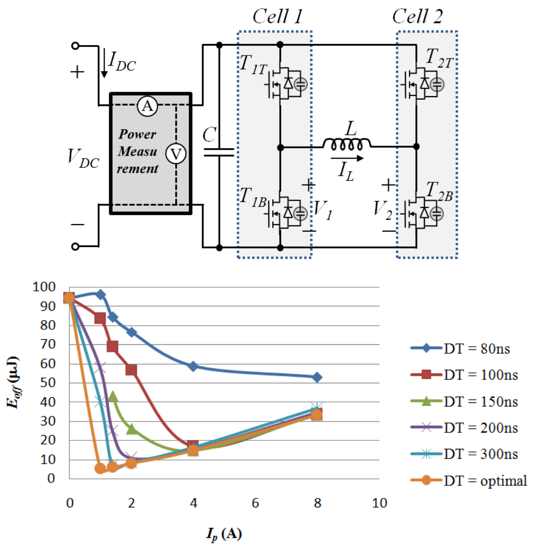


Figure 2: Proposed circuit for the measurement of energy switching (top) and example of measurement data for a commercial SiC MOSFET device.

2.1.3 Power Integration

For medium power applications (current densities of about 100 A/cm^2 and V_{BR} ≤ 1200 V), we work on both technological and design solutions for the development of monolithic multi-switches silicon chips to enable customizable power systems in the same way as ASIC does in the digital world.

The originality of the concept that was patented [*BR1108*], is to integrate an array of high-side power switches in a single die (common anode on Figure 3) and to do the same for low-side switches (common cathode). The advantages of this integration approach that could be called "Power ASIC" are twofold: improvement of electrical performance as well as reliability of the power module.

To this aim, the proposed Power ASIC chip is composed of multiple vertical Reverse Conducting IGBT (RC-IGBT) power switches that share the same lightly doped N$^-$ region. Using our flexible IGBT process, this innovative concept was implemented on silicon for the case of a three poles monolithic chip called "common anode" chip (Figure 3).

Moreover, using the same process, we realized and experimentally validated the operating modes of an RC-IGBT structure [*MAI13285*] [*RVSI13693*] [*[TH14239*]. We are currently working on the development of a specific P$^+$ wall technological step for its integration in our flexible IGBT process. This isolation step is essential to experimentally validate the multi-switches chip called "common-cathode".

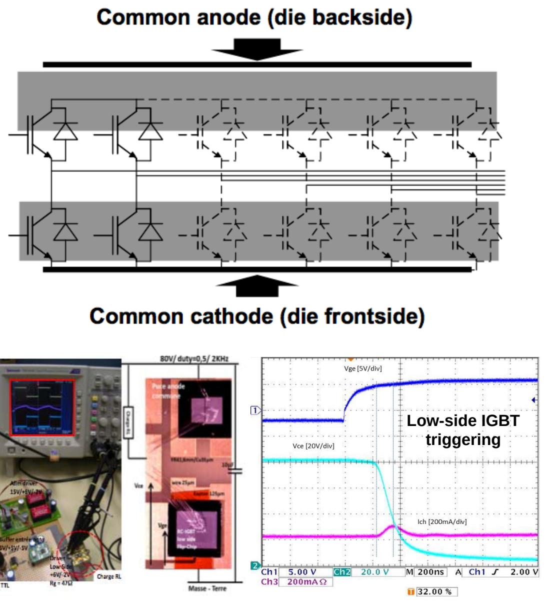


Figure 3: Schematic illustration of "Power ASIC" concept (top) and experimental validation of a functional H-bridge.

2.1.4 Energy Conversion Architecture

Within the framework of LISPA Freescale-LAAS joint lab (2005-2008), we developed and experimentally validated the concept of multi-phase and interleaving step-up and step-down DC-DC converters (1V, 1-4MHz, 150A) for embedded applications (from phone, laptop to computers) with high efficiencies over a wide range. In cooperation with TOTAL Company, this concept was applied to photovoltaic (PV) energy power conversion to improve efficiency and reduce stress in active and passive components, then resulting in lifetime increase of the global power system [*TH13266*]. This work was awarded the *Best Paper and Best Oral Presentation* at the 38th Annual Conference of IEEE Industrial Electronics **(**IECON 2012) in Montreal (CA) [*MAI12516*]. These studies resulted in two international patents [*BR0911*] [*BR0912*] in collaboration with URV University in Spain [*RVSI14192*], [*RVSI12660*].

Furthermore, we developed a high expertise in efficient PV energy production even in shadowed (Figure 4) or aging modules, proving each year that the dream concept of one converter including its MPPT for a small group of PV cells will drastically improve the energy production. We developed MPPT control laws based on extremal control that are at the same level as the state-of-the-art ones designed by American research teams, achieving a static efficiency better than 99.4 % and over 96 % in transient mode.

A new concept of electronic management system was designed to optimize matching during the global lifetime of the PV system. It is based on new distributed architectures, arranged as independent modular ones which are only used in optimal power transfer and can be disconnected by a dedicated control management if a default occurs. This work was initiated with a first patent [2] filed in 2008 and

[2] M. Vermeersch, B. Estibals, C. Alonso, Electronic management system for photovoltaic cells, Patent n° WO2010070621, Filed 18/12/08, Published 24/06/10.

additional improvements were recently proposed and protected by a second patent [*BR1302*] [*TH13269*]. These distributed architectures require new low-power integrated circuits and functions.

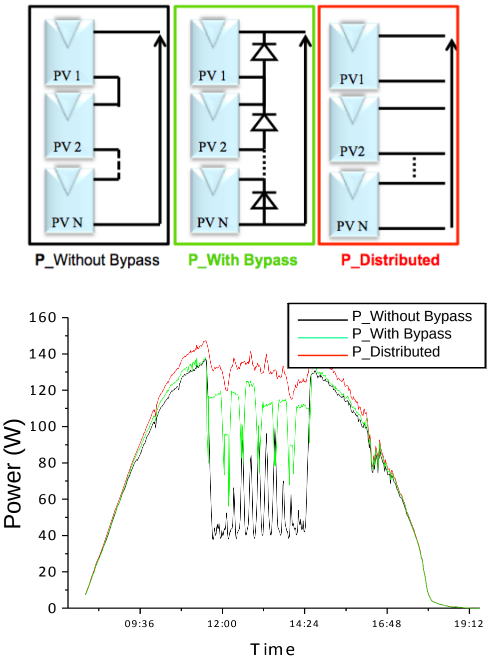


Figure 4: Different types of PV architecture (top) and experimental comparison of resulting output power in shadowing conditions.

When using renewable energies such as the photovoltaic one, an important issue is the management of intermittence that requires efficient storage solutions. Within ANR LiPV project and the PhD work of Jean-François Reynaud [*TH11004*], we have proposed and experimentally validated various architectures for innovative PV modules integrating lithium batteries and their associated battery management system (BMS). This PhD study was awarded the Doc'innov price by the Doctoral council of the University of Toulouse. For the experimental validation of management algorithms and the qualification of conversion chains, a specific testbench was developed [*MAI10337*].

2.2 Robustness And Reliability

Taking into account the requirements for robustness and reliability of a device or a system at an early stage of the design is essential. It is even more essential in the field of power electronics where in addition to environment constraints the system can undergo harsh functional operation conditions (high voltage, high current, high electric field).

In GE Theme, we have focused our activities on improving the robustness of power devices under Natural Radiative Environment, ESD protection strategies and predictive multi-physics modeling.

2.2.1 Radiation Hardening

Electronic systems embedded in aeronautics and space applications are subjected to severe constraints of Natural Radiative Environment (NRE). Electrical energy management systems use power components such as VDMOSFETs, IGBTs and SuperJunction devices, which are particularly sensitive to NRE particles. In order to propose radiation-hardening solutions at component and/or system level, we have studied and compared the various involved physical mechanisms in advanced power devices in radiative environment using 2D and 3D TCAD simulations. Three PhD theses [**TH09913**] [**TH13401**] [**TH13823**] were defended that allowed defining a simulation methodology with a good correlation to experiments based on laser testing and heavy ions. Several original design and technological solutions were also proposed for power structures hardening [*RVSI12621*] [*RVSI14204*].

2.2.2 ESD Protection Strategies

To tackle the pressing challenges of the ESD protection of advanced CMOS and smart power technologies, we established strong and fruitful cooperation with industrial partners (Freescale, STMicroelectronics, ON Semiconductor). The motto is high efficiency both in terms of silicon area and robustness level. Concurrently, we also carried out more prospective studies on the protection of MEMS devices and on integrated ZnO-based varistors.

To provide efficient ESD protection to advanced technology nodes (45nm and 32nm), in partnership with STMicroelectronics, we have studied SCR-based structures to significantly improve the robustness of these technologies. Main result is an innovative global protection strategy based on a network of 3 bi-directional SCR, called « Beta Matrice ». On a CMOS 32nm technology, it resulted in 2kV HBM robustness with a reduced silicon footprint [**RVSI10273**] [*TH11396*].

We also initiated an original activity on the effects of high temperature on the ESD robustness of smart power technologies that allowed proposing an innovative solution to improve both robustness and temperature behavior of ESD protections. Proposed solution combines in the same device a MOS (for fast triggering), and an IGBT as well as an SCR (for its better temperature behavior and lower on-resistance). This resulted in dividing by 10 the silicon area of the ESD power clamp together with drastically improving the robustness from 2kV to 8kV HBM. Original solutions (reduced MOS channel) have been implemented to control the SCR triggering. This latter solution has also an interest for providing improved radiation hardening to an IGBT device [**RVSI13419**] [*TH12329*].

A pioneering work was also achieved on the ESD reliability of MEMS in cooperation with MINC team within the framework of AMICOM European Network of Excellence. The studied device was a 40GHz MEMS RF capacitive switch. Two major results were highlighted. Firstly, the MEMS ESD robustness is extremely low (under 100V) and some external protections are needed. Secondly, an innovative method for accelerated testing of capacitive MEMS have been proposed [**RVSI12049**].

Finally, we are carrying out a long running and very high-risk but exciting project whose ambitious objective is the on-chip (or above IC) integration of varistors based on zinc oxide (ZnO) material. We recently achieved and demonstrated the first functional integrated varistor on silicon wafer using inkjet printing technique (**Figure 5**). It exhibits an excellent robustness for a high voltage clamping device: higher than 4 mA/µm, 0.4mA/µm^3 for 100ns current pulse with a maximum current density higher than 400 kA/cm^2 and limited leakage current of 50µA at 40V. This multidisciplinary project involves three different laboratories in Toulouse (CEMES, LGC and LAAS). This first important breakthrough paves the way for future studies and developments.

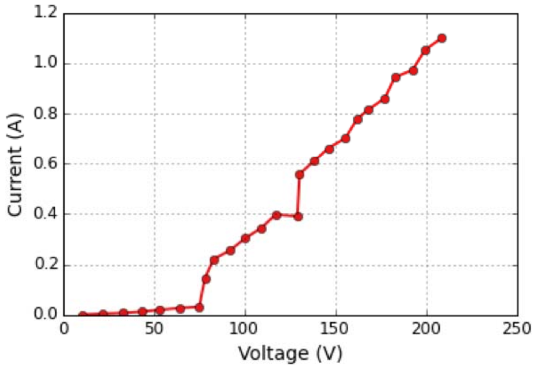


Figure 5: First proof of concept of ZnO-based integrated varistor. 250µm-width device electrical characteristic under 100ns-pulse IV characterization.

2.2.3 Predictive Multi-Physics Modeling

Electro-thermal-mechanical modeling. Electro-thermal-mechanical modeling was carried out within the framework of an inter-Carnot ANR project "ReMaPoDe (Reliability Management of Power Devices)". The overall project objective was to provide a sensing device that could assess the real-time ageing status of a power assembly by monitoring its thermal and mechanical states during operation.

This work [[*TH12444*] mainly consisted in highlighting the relationship between the assembly mechanical ageing and the observed electrical evolution. Moreover, given the thermal issues related to embedded applications, the electrical characteristics identified as an ageing indicator should allow overcoming the detrimental effects of temperature. Consequently, after a thorough analysis of the different ageing and failure mechanisms encountered in power assemblies, we have identified relevant electrical characteristics that are promising for real-time monitoring of the mechanical ageing status of a power device assembly despite ambient temperature variations and assembly material ageing [*RVSI14032*].

With respect to thermo-mechanical strain modeling, an efficient simulation methodology permitting simultaneous computation of distributed electrical and thermal modeling has been developed. This is especially suited to model hot spot emergence and local electro-thermal runaway phenomenon [*RVSI11578*] [*RVSI11204*] [*TH13358*].

Electromagnetic compatibility (EMC). Between 2010 and 2013, several important breakthroughs have been achieved.

A pioneering work about the impact of ageing of ICs on the long-term EMC has been initiated (EMRIC ANR JC project). For the first time, we have demonstrated by several experimental and modeling studies that the IC aging (accelerated in nanoscale technologies and in harsh environment) can induce non-negligible drifts of electromagnetic emission (EME) and/or electromagnetic susceptibility (EMS) levels (Figure 6). The evaluation of the non-compliance risks can be done either by adapted qualification tests (EMC tests on aged samples) or by EMC modeling which integrates the ageing factor.

We have started to build up equivalent electrical models for this purpose. All the results have been published in numerous articles and presented in several international workshops about EMC and reliability [**RVSI13690**] [**RVSI14018**] [*TH11897*], some of them as invited presentations. Part of these studies obtained the best paper award at EMC COMPO 2013 in Nara (Japan) [**MAI13692**].

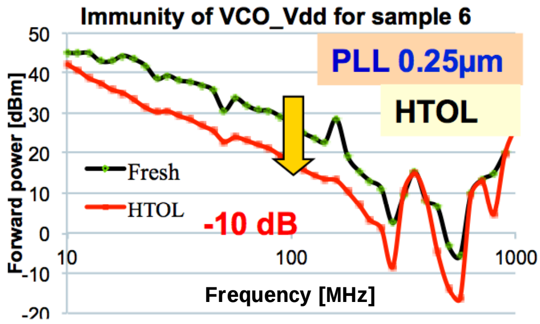


Figure 6: Impact of ageing on measured EMI immunity of a VCO circuit that was submitted to High-Temperature Operating Life (HTOL) tests.

For the first time, we used on-chip sensors to characterize electrical signals induced in an IC during conducted susceptibility tests, with a good time resolution (10 ps) [*RVSI12305*]. These experimental results have shown the strong influence of IC interconnects on the coupling of electromagnetic interferences and, thus, their importance in the modeling of IC susceptibility. This preliminary work has initiated our participation to European AUTOMICS project, focused on the modeling of substrate coupling issues in automotive circuits.

An on-chip sensor has also been integrated in a test chip (Milady) developed in collaboration with Freescale Semiconductor, within E-Mata-Hari project. This circuit is dedicated to the characterization and the modeling of miniature injection near-field probes developed by our team and other partners. The main application of this study is cryptographic attacks.

This on-chip sensor was also successfully adapted for monitoring the ESD current paths within a powered IC when submitted to an ESD stress [**RVSI13700**].

Electrostatic Discharges (ESD). Regarding system level ESD, the main challenge consists in developing efficient and accurate predictive simulation methodologies. On this topic, in partnership with industrial partners, namely FREESCALE, VALEO and On Semiconductor, 2 PhD theses were carried out and defended [*TH11906*] [*TH13270*]. We developed new investigations techniques that allow, on the one hand, injecting well-defined ESD stresses (like TLP or double pulse TLP) and on the other hand, providing accurate techniques to characterize real ESD stress propagation and waveform at PCB level but also at chip level [*RVSI13689*].

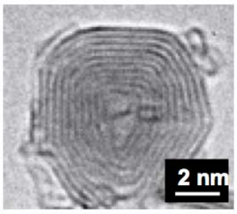
In parallel, we proposed and experimentally validated a behavioral modeling approach to predict functional and hard failure [RVSI10099]. Since 2009, LAAS (F Caignet) has also been involved in the international ESDA standard committee related to system level ESD, and is leading a discussion group whose objective is the writing of a white paper on parameters extraction for system level ESD modeling.

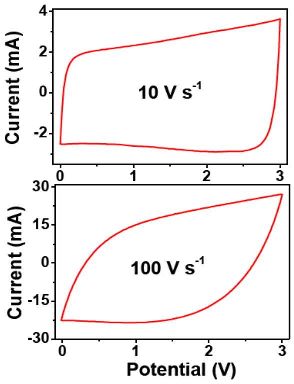
Characterization methods are essential for modeling validation. In particular, we carried out an original study on a new transient TLP (T-TLP) setup that allows characterizing the ESD protection behavior within the sub nanoseconds of the ESD stress and then detecting excessive overshoots. With this measurement technique, we showed that some ESD protections exhibit important over-voltages during the turn-on phase, which can have catastrophic impact on the protected circuit. Concurrently used with TCAD simulations, this tool was applied to the optimization of ESD protection devices for smart power technologies [MAI13792] [TH12410].

Regarding TLP techniques, we initiated a worldwide network (France, Belgium, USA, Japan) aimed at developing open-source software dedicated to the analysis of such measurement results (import of different setup results, graphical comparison…). LAAS wrote about 95% of software codebase. There were also important contributions from all main commercial-setup vendors to write import's code from their proprietary format. The latest version of this software was downloaded more than 700 times http://code.google.com/p/esdanalysistools/downloads/list.

2.3 Energy Autonomy of Embedded Systems

The development of low-power integrated circuits (such as sensors, microprocessors or wireless communication chips) has made embedded systems increasingly popular. These systems are meant to operate in controlled/uncontrolled environments, gathering, processing, storing and communicating information wireless. In order to supply efficiently and continuously the power to these systems, an attractive solution is to combine energy harvesting (thermal, vibrational or solar energy) with an energy-storage micro-device.





(a) (b)

Figure 7: Carbon onion based micro-supercapacitors: view of a carbon onion (a) and cyclic voltammograms (CVs) of at different scan rates.

On-chip micro-supercapacitors show very interesting characteristics when it comes to these applications, because of their extended lifetime and high power density. Given our expertise in the field of power integration, and in cooperation with CIRIMAT laboratory, we have chosen to start a new field of research aiming at developing these on-chip micro-supercapacitors.

Concurrently, in cooperation with different teams at LAAS (MINC, N2IS) and partners in the field of aerospace (Airbus, CNES, Thalès Alenia Space), we have initiated a research activity related to the energy autonomy of wireless sensors in harsh environment. To tackle this challenge, we have focused our studies on battery-free systems and are working on the efficiency of energy management circuits, on storage methods using supercapacitors, and on the implementation of energy transducers: photovoltaics, thermoelectricity, and in the long term aeroacoustic.

2.3.1 Microstorage

The challenges of on-chip microstorage are related to the integration of an active material (generally carbon-based) and an electrolyte on silicon. This includes nanostructuration techniques, cost-effective deposition methods and hermetic packaging [BR1007]. To this aim, we have developed different IC-compatible technological processes (inkjet printing [RVSI09320], screen-printing [RVSI11646], electrophoretic [RVSI10534] and electrolytic [RVSI13016] deposition, thin film processing [RVSI12608]) to integrate various innovative materials (activated carbon, carbon onions, carbide derived carbon, carbon nanotubes, carbon nanowalls, RuO_2…) for the development of enhanced micro-supercapacitors. Specific capacitances up to 675 mF/cm2 were obtained with carbon nanowalls and components with extremely high power densities (700 mW/cm2) using carbon onions (Figure 7) were realized.

Most of micro-supercapacitors are nevertheless based on liquid electrolytes (aqueous or organic), which can be a major problem when it comes to the realization of functional components using the silicon micro-fabrication technology. We are therefore currently investigating all-solid-state micro-supercapacitor based on innovative solid electrolytes.

Figure 8: A321 left wing implementation of the wireless sensors together with the battery-free power supply based on solar energy harvesting and storage on supercapacitors.

2.3.2 Energy Harvesting And Power Management Of Battery-Free Wireless Sensor

Over this period, this new activity has significantly developed with the recruitment of an assistant professor, and through one project funded by the

"*Investissements d'avenir*" within the CORAC program and one European CHIST-ERA project as coordinator.

First results had been initially obtained within the framework of SACER FUI project and AUTOSENS FNRAE project. The main challenge of SACER, dedicated to aeronautic in-flight tests, was to provide 3W energy autonomy to a real-time wireless sensor network. To this aim, we proposed a battery-free architecture based on supercapacitors, solar energy harvesting and appropriate power management including MPPT and startup techniques [*RVSI11665*] [*RVSI13440*] [*[TH10797*]. The results of this project are currently being transferred through a bilateral relationship with Airbus Group (in-flight tests department) and a first successful flight was realized in June 2014 (**Figure 8**).

Within AUTOSENS project dedicated to Aircraft Health Monitoring (AHM), we proposed an original multisource battery-free architecture using transient thermal gradients (during climb and descent) as a primary source and permanent mechanical vibration as a secondary source. To increase the efficiency of the transient thermogeneration, the thermoelectric transducer was coupled to a capsule with a phase change material (water) [*RVSI13300*]. A dedicated low-power multi-source power converter was designed and successfully tested[3] exhibiting a very low quiescent current of 300 nA and a maximum efficiency of 82% that is within the performance of proposed LDO regulators of the state-of-the art[4].

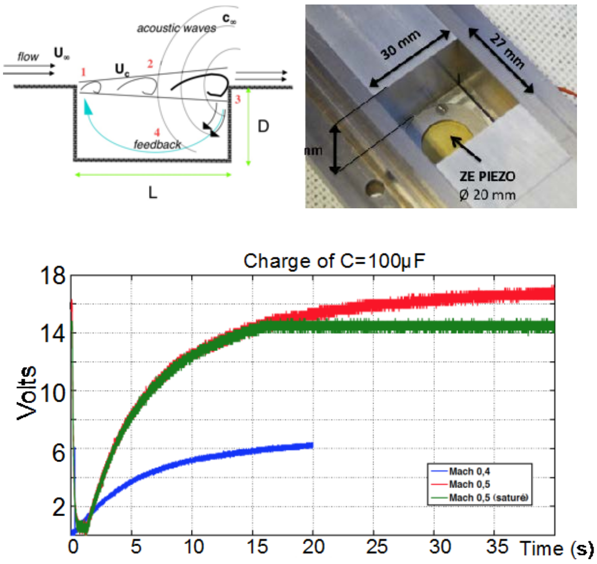


Figure 9: Aeroacoustic energy harvesting principle and implementation (top) and resulting harvested energy on a capacitive load as obtained in a wind tunnel.

In the field of energy capture, we carry out a more prospective work on the capabilities of aeroacoustic energy harvesting. This work was co-funded by DGA and Intesens and continues within CORALIE project (Investissements d'avenir). We have demonstrated the possibility of powering an electronic system by the mechanical energy generated by the noise created on purpose by disrupting the laminar flow of an aircraft aerodynamic surface (Figure 9) [*MAI12610*]. On this topic, we are collaborating with ONERA and IMFT labs.

We have also proposed a novel adaptive topology to optimize the dynamic performance of supercapacitors used to store energy that will be integrated within the framework of CHIST-ERA SMARTER project in cooperation with the University of Barcelona and the University of Exeter [*MAI12609*].

2.4 Tools and Demonstrators

For the needs of our research studies, several original tools, in the field of characterization, software and modeling were developed. Another important step for the validation of innovative research concepts is the realization of demonstrators. They are both summarized in Table 2.

HV-CARAC and **DIAMOND_design** tools were motivated by the new research activities related to wide bandgap power devices. **ADREAM_NRJ** concerns the photovoltaic platform of ADREAM building and the related characterization test benches for assessing either new photovoltaic solar cells or new converter architectures in real conditions. **Near-field scan** and **Satellite/Thunderstorm** are related to electromagnetic compatibility and electrostatic discharges (ESD) research issues. It has to be noticed that the listed demonstrators successfully validated a full function: powering of a wireless sensor, one of them was embarked for flight tests onboard an Airbus A321 and the realization of a functional H-bridge using monolithic integration on silicon (Power ASIC). Main Publications

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Table 2: Tools and Demonstrators

Acronym	Description
HV-CARAC	High-voltage devices (> 1 kV) characterization platform.
ADREAM_NRJ	Photovoltaic platform and related characterization test benches.
DIAMOND_design	TCAD platform for diamond devices design.
Near-field scan	Near-field scan test bench.
SATELLITE/[THUNDERSTORM	Software tool : ThunderStrom is a python library to manipulate ElectroStatic Discharges (ESD) measurement-setups data.ThunderStorm is heavily used by Satellite (http://esdanalysistools.github.io/Satellite/).
FLYING_NRJ_HARVESTER	Demonstrator: Autonomous battery-free photovoltaic system for sensor powering during flight test.
SDS	Demonstrator: Wireless battery-free system (thermal energy harvesting, sensing & communication) for the monitoring of hatch opening in an airliner.
Aeroacoustic harvesting	Demonstrator: Aeroacoustic energy harvesting battery-free system for data logger powering.
Power ASIC	Demonstrator: Functional integration on silicon of (≤1200V) multi-switches.

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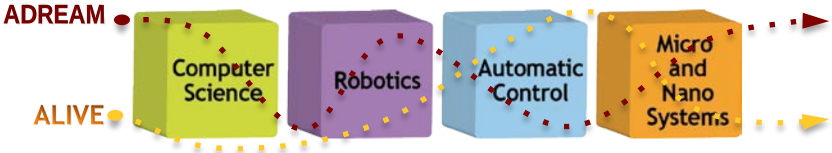

X - The Transverse Axes: ADREAM and ALIVE

During the period, the LAAS-CNRS has been developing and implementing the scientific strategy put forward collectively to address two major scientific challenges under the form of two strategic transverse axes:

- ADREAM: Architectures for Dynamic Resilient Embedded Autonomous Mobile systems (*Architectures Dynamiques et Reconfigurables pour les systèmes Embarqués Autonomes Mobiles*).
- ALIVE: AnaLysis and Interaction with the liVing and the Environment (*AnaLyse et Interaction avec le Vivant et l'Environnement*).

These two axes build upon the necessary skills along the scientific themes developed within the Lab. (See Chapter 1, Section 2.3) and they benefit from the sufficient critical mass deployed by the teams engaged.

In the sequel, the activities developed within these two axes are reported.

1 ADREAM

Leader: Michel Diaz

Themes involved: IC, RC, ROB, DO, HOPES, NII, GE

Keywords: *Advanced embedded systems, sensor networks, internet of things, machine-to-machine communications, software services, companion robots, security, privacy, energy production, energy optimization, design, implementation, validation, evaluation, cyber-physical systems, experimental platform, smart building.*

1.1 Presentation

1.1.1 Introduction

The ADREAM project has been submitted in 2006 to the Call of Proposals of the French *CPER* 2007-2012. Its goal, in the framework of future embedded systems, was: first, to conduct research on the design of new advanced, autonomous, interconnected, secure and adaptable architectures for embedded systems, by integrating the domains of information, computing, robotics, electronics and energy; and, second, to anticipate the synergies of these domains by developing new advanced approaches and tools, supported by a set of significant validation platform and experiments.

The ADREAM research must in particular address the emerging problems of future embedded systems:

- based on a large set of cooperating objects,
- having adaptable behaviors using a distributed autonomous intelligence,
- able to fulfill stringent performance, robustness and resilience requirements, even in the presence of unpredictable adverse events.

1.1.2 Objectives and Scientific Positioning

In this context, the primary objective of ADREAM was to conduct a research program to propose methods and technologies needed for designing massive networks of entities embedded in smart environments having multiple sensors, actuators and objects.

The second objective was to develop an experimental, complex, and manageable evaluation platform. This has led to the definition of an experimental innovative multidisciplinary building, unique in its kind, in which LAAS and its partners will integrate and validate parts of the research results, particularly in the fields of computing, electronics and energy, by integrating sensors, networks, and robots and by optimizing energy production and consumption.

The ambition is to coherently build hierarchies of complex cooperative layered objects, including multi-service robots around the internet of the things, and to address many challenges, as interoperability, security, resilience, adaptability, autonomy and intelligent interactions with the users. Also, the deployment of the evaluation experimental building will help the improvement in the future of the quality of life in offices and at homes.

ADREAM is one of the very few projects in the world that address at the same time all these research areas, from sensors to robots, from energy production to global management. Internationally and in France, it exists now many projects working in parts of the areas covered by ADREAM, and a detailed presentation of the state of the art in these domains can be found in the Scientific Program, 103 pages, in French[1]. A 12-page summary version is available in English[2].

As examples, a few typical projects are given in what follows in the different areas.

For sensor networks and more generally communication systems, ADREAM was and is still based on the Internet of Things, but, unlike many large platform projects, as PlanetLab, http://planet-lab.org, or OneLab, http://www.onelab.eu, and building on our previous experience, we developed a new machine-to-machine M2M communication layer.

In robotics and ubiquitous computing, the most related research is the QoLT Center, jointly run by Carnegie Mellon University and the University of Pittsburgh. It aim is to create revolutionary technologies to improve and sustain the life for all people. It focuses on the development of intelligent systems to improve quality of life for everyone, in particular older adults and people with disabilities – http://www.cmu.edu/qolt/.

In Europe, a set of projects is being developed in the EU ICT program, for instance KSERA Knowledgeable SErvice Robots for Aging http://ksera.ieis.tue.nl. In France, the PERSYVAL (Pervasive systems and Algorithms) LabEx will contribute to mastering the design and control of the new human-aware computer systems, including interconnected intelligent devices and interactive virtual objects, with 4 multi-disciplinary research actions: Pervasive Computing

[1] https://www.laas.fr/public/sites/www.laas.fr.public/files/general/ADREAM/pdf/ADREAM-ProgrammeScientifique113-01-15.pdf.

[2] https://www.laas.fr/public/sites/www.laas.fr.public/files/general/ADREAM/pdf/ADREAM_Research_Platform_11p.pdf

Systems, Advanced Data Mining, Authoring Augmented Reality and Modeling and Simulating the physical world.

Regarding intelligent houses, the first big project was conducted by TOYOTA and TRON (Univ. of Tokyo and private companies) in 2005 by designing the Toyota Intelligent House PAPI, to investigate future ubiquitous computing for intelligent homes (http://tronweb.super-nova.co.jp/toyotadreamhousepapi.html).

Now the design of all intelligent houses includes optimization of energy consumption and quite often energy production, and many projects exist all over the world. In France, the aim of the INES, the *Institut National de l'Energie Solaire*, is to develop solar, thermal and photovoltaic energies and energy management in buildings.

In the general field of energy, many studies are now underway in all developed countries to design all levels of the future Smart Grids. For example, UCLA started the SMERC Smart Grid Energy Research Center to perform research, create innovations, and demonstrate advanced communications and sense-and-control technologies. It is currently working on the topics of Automated Demand Response, Electric Vehicle Integration, Microgrids, Distributed and renewable integration, and Cybersecurity. The University of California Berkeley has been awarded an ARPA-Energy grant over three years to develop new ways to monitor the stability of electric power grids.

In Denmark, the NetBeans platform, supported by EnergiFyn, a Danish Energy concern, has as a main objective to bring a more intelligent control of every day usages of energy consuming devices to bring down energy consumption (http://netbeans.dzone.com/nb-danish-intelligent-homes). In France, many projects have been started and recently a roadmap about Intelligent Power Systems was presented to the *Président de la République*. Many projects have been started with the ADEME support, as the SoGrid project, that uses electric links as its network physical layer.

1.1.3 Scientific Coordination

The complexity of ADREAM had led to the creation of committees to structure the project, coordinate the research, define the building and integrate the results.

The first committee "ADREAM Project", started in 2007, had to organize the beginning of the full project. A second one has defined and detailed the different levels of the building specifications and descriptions. The third committee has followed and checked the progression of the construction. A forth one has written the detailed Scientific Program. Its members included all the research domains and research themes of the laboratory. The fifth one, "Scientific and technical building management", has to manage the laboratory resources, including people, that are needed by the internal and external research projects that use the building as a supporting platform. Also, a sixth committee, Technical maintenance, handles the everyday behavior of the building, to analyze the measurement values, to check all problems and to propose the needed actions.

Finally, a seventh committee has been defined to support the research integration. This committee proposed to divide itself into two working groups, respectively to deeply analyze the system data, and to model the layered behavior of the communicating objects and services.

The first working group « Structuring the data and services » deals with the logical naming and the semantic relationships of the data. It proposed to use as a starting basis the ETSI and OneM2M standards for M2M communications and OBIX for data representation. The second working group, « Functional and Energy modeling of the project and building», addresses the complex integration of the different models (developed or not by the laboratory) that have to be connected for defining a global model, able to include at least sensors, networks, robots, photovoltaic production, energy control, autonomy and security.

As a consequence, many internal working meetings, seminars and workshops have discussed, improved and consolidated the project.

1.1.4 Salient Facts

- Writing the Scientific Research program.
- Administrative and technical, global and detailed, texts, and construction of the building.
- Organization of two prestige conferences, for the starting of the construction and for the official opening of the building.
- Development of a freeware software implementation of the ETSI Machine-to-Machine standard
- Presentation of the first experiments during the two prestige conferences and for the laboratory Open Days.
- Development of innovative collaborative projects.

1.2 The Scientific Program

1.2.1 Introduction

The Scientific Program committee proposed to create 7 area groups (6 scientific and 1 technical) to address the main research domains, each leaded by two people and including participants of all themes and services. They are: Formal system development and simulation; Autonomic computing systems; Energy systems; Localization and navigation; Sensors, robots and mobility; Optimization and control; Technical support.

The first 6 groups have studied the multidisciplinary state of the art, and proposed the scientific research that has to be conducted in cooperation with a set of partner organizations. The last one, technical, has detailed the constraints and requirements needed for the life and maintenance of the new experimental building.

1.2.2 The Research Domains

These area groups have met and decided to propose and write the domain research actions to be taken in eight main scientific texts, each having the same table of contents: Background, Research Objectives, Partnership, and Bibliography.

The following texts were written:

1. Formal Development of Dependable Adaptive Mobile Systems.
2. Environments for Co-simulation and Co-validation of Systems.

3. Micro and Nano-Sensors.
4. Autonomic Computing Systems.
5. Localization, Navigation and Mobility of Robots.
6. Optimization and Control.
7. Energy Systems.
8. Safety and Privacy.

These texts outline first the general issues, interests and scientific obstacles, as well as their underlying socio-economic issues. They then position the work to be done and present the research actions developed, together with their main current partnerships. A bibliography closes the presentations.

A ninth text presents a list of inter-thematic research domains that have to be conducted by the laboratory. Selected in a large set of potential examples, their goal is to combine and highlight the LAAS different research domains.

They are the following ones:

- Modeling and semantic description of cyber-physical systems. Their characterization and their control lead to the need of clear and unambiguous descriptions by formal or semi- formal models.
- Sensors and sensor networks with guaranteed quality, to interconnect all physical objects and provide machine-to-machine autonomic communications for the Internet of things.
- Services for autonomous transportation, using a fleet of vehicles for services on request, for example using electric shuttles available to all users in a given area. Shuttles can move in standalone mode or controlled by a driver.
- Energy and smart grids, in particular to optimize the solar production of electricity by photovoltaic sources, and to optimize in defined contexts the triple production-consumption-storage.

1.2.3 A Few Salient Results

1.2.3.1 National and International Collaborations

ADREAM collaborates with many national and international partners, i.e., research centers, universities and industries, depending on the research domains, and major projects and actions are developed with contractual collaborations, in particular with the following companies:

- The French companies: Actia, Airbus, AKKA, Astrium, Bull S.A.S., CS Communications and Systems, EADS, France Telecom R&D, INTESENS, Kineo CAM, KUKA Lab GmbH, Liebherr, Messier Bugatti, NXP Semiconductors Netherlands BV, Orange, PSA, Renault, Siemens AG, ST Microelectronics, Thales Alenia Space, Thales Avionics, Thales Communications and Security, Thales Research Center, Total, Valeo.

- The SMEs: Axess Europe, Beenetic, eDevice SA, ELLIDISS Tech, Epsiline, Gemalto SA, Inovaltis, I-Trust, LivingObjects, MAGELLIUM, MEDIALIS, MobiGIS, ORME, Petalslinks, QoS Design, Robosoft, SmartGrains.

- The foreign societies: ABB (CH), Deep Blue (IT), IBM Research Zurich (CH), Kinetik Ltd (GB), Kuka Labs GmbH (DE), Nomis Oy (FI).

- The research centers and universities: CEA, CNES, INRIA, ISAE, ONERA, Fraunhofer (DE), DLR Institute of Robotics & Mechatronics (DE), Technalia (ES), VTT (FI), Tokyo Inst. of Tech (JP).

1.2.3.2 Salient Scientific Results

ADREAM includes many cooperative projects that appear in the reports of the different themes. Only a few of them are given in the list below, because they include a strong collaboration between at least two themes of the laboratory or define a strong collaboration between a set of organizations in which ADREAM provides a significant support.

SACER. This project, supported by the competitiveness pole AESE and the DGE, follows the LAAS project TRANSCOM that was given as a first example in the proposal of the ADREAM project, for building advanced communications in sensor networks. SACER was a cooperation of the GE, DO, HOPES and RC themes.

Approved by Aerospace Valley, the aim of SACER was to enable the wireless acquisition of signals from on-board quality sensors. This autonomous system is to be used in embedded system to replace the wired connections for acquiring and transmitting physical data (temperature, pressure, vibration, etc.), supporting on board acquisition, computation and storage, and securely transmitting data to the central monitoring and control system. Numerous complex problems have been addressed by the different teams of LAAS: the architectural definition and the system simulation by N2IS; the embedded energy aspects by ESE; and the communication system by the HOPES and RC using the Ultra Wide Band technology. The communication system was made strongly reliable and synchronous, its recovery being able to redirect the measurements to the cabin. In particular, a wireless communication protocol providing a very high precision clock synchronization, less than 10 ns, has been developed.

NanoComm. NanoComm (Reconfigurable wireless nano-sensors networks) was one of the nine projects of the NanoInnov program of the French government started to re-launch the economy in nanotechnologies. Lead by LAAS-CNRS, it involved LPCNO, CIRIMAT, EADS Innovation Group (now Airbus Group Innovation), CEA, IMS, and the Nanomade Concept start-up.

Three themes were involved in the project, i.e., MNBT for new innovative sensors, HOPES and RC for energy efficient wireless communications. NanoComm developed an energy efficient, reconfigurable and robust wireless architecture based on IR-UWB (Impulse Radio - Ultra Wide Band) for Sensor Networks and demonstrated the feasibility of a 3D heterogeneous integration on flexible substrate of the wireless sensors nodes. The innovative sensors using nanotechnologies and a flexible substrate were developed by a cooperation between LAAS-CNRS and Nanomade Concept. This collaborative work has led to the industrial development of nanoparticles-based stress gauges for flexible touch applications (this collaborative work is on-going with the creation of a joint laboratory in 2015). The project led to a total of 9 patents pending, 6 patents being filed by LAAS-CNRS.

ROSACE. This project was supported by the RTRA of the STAE Foundation. It was a forwarding of the ROSEAU project of LAAS that was the second example given in the ADREAM proposal. ROSACE aimed at studying and developing means to design, specify, implement and deploy a set of mobile autonomous communicating and cooperating robots with well-established properties, particularly in terms of safety, self-healability, ability to achieve a set of missions and able to perform self adaptation actions in a dynamic environment. The main application target domains were the surveillance and intervention systems.

The project was focused on the design of the software architecture (models, algorithms and systems). Its new vision was to address in a systematic and convergent approach, at the same time the robotics software levels and the system constraints coming from both the middleware level, corresponding to the real-time embedded systems, and the network level, by including the inter-layer communication management. The related research was conducted by the following different themes of LAAS: ROB for the robotics architecture, RC for the communication architecture, IC for the dependability architecture, and DO for the diagnosis architecture.

SAPHARI. Safe and autonomous physical human-robot interaction-aware, FP7-ICT, led by the University of Rome (IT), involving ROB and IC at LAAS-CNRS. The aim of SAPHARI is to progress in physical Human-Robot Interaction (pHRI) for actively and safely sharing a common workspace. The robots must physically interact at the cognitive level with humans in a safe and autonomous way for limiting potential injuries (http://www.saphari.eu).

Safe operation will be derived from a smart fusion of proprioceptive and exteroceptive sensory information, sensor-based task planning, human gestures and motion learning, task-oriented programming, and configuration and programming of safety measures. The project focuses on two industrial use cases and on a service scenario in hospitals, with explicit physical interactions between a human and a robot. The results from the Universities of Genoa and Rome, as well as those from LAAS, will be integrated at LAAS.

SPENCER. Social location-aware perception and cognitive robots for Action, in FP7-ICT, led by the University of Freiburg (DE). The results of SPENCER will be integrated at LAAS before being deployed at the Schiphol airport (NL).

SOUK. Social Observation of hUman Kinetics is a multidisciplinary research project partially funded by the University of Toulouse. It involves as primary contractors LAAS-CNRS, the CRCA Laboratory of Ethology, the Laboratory of Theoretical Physics and the LabEx SMS Structuring of Social Worlds.
SOUK is twofold. On the experimentation side, it develops a platform to capture and analyze fine-grained interactions between people in a crowd, as in cocktails and in concert halls. On the theoretical side, it focuses on providing models and tools to study the dynamics of movements and groups of humans. Recent results include a model of how human groups evolve in closed environments, and a model of aggregation of people subject to different external stimuli. SOUK seems to be unique both in the unprecedented accuracy of its experimental platform, and in the wide multidisciplinary background of involved participants.

CONVERT. This project was supported by the Colombian program COLFUTURO, the Spanish Agency for Evaluation and Prospective (ANEP Projects) and the Chairs of Excellence Program of the University Rovira i Virgili of Tarragona, Spain. It involved the teams MAC and ISGE of LAAS-CNRS and the team GAEI of the University Rovira i Virgili.

The project focused on the problem of optimizing the conversion of energy coming from photovoltaic solar panels and it was motivated by the need for power processing systems characterized by high frequency, reliability and low costs. In this context, a grid solar micro-inverter, supplying 220 V-RMS at 50 Hz, delivering an active power value not bigger than 2kW, optimizing conversion efficiency with reduced cost, and using a transformer-less topology, was developed. All the experiments conducted in the ADREAM building demonstrated the feasibility of such a micro-inverter by a prototype that was designed and realized using an advanced control technique, i.e., non linear control with variable frequencies based on sliding modes. In particular, such a new MPPT (maximum power point tracking) adapted to a quadratic boost was developed and associated to an inverter to supply current on the grid.

SYCYPH. Multidisciplinary design of cyber-physical systems. This new working group of the RTRA STAE addresses the future generation of embedded systems, largely distributed, autonomous, dynamic and adaptive. The anticipated new scales of design difficulty, at all levels, technical, economic, legal and human, will require to take into account all respective scientific, regulatory, economic and social constraints. To satisfy such requirements, it becomes essential to settle multidisciplinary teams of experts, only able to supply full and coherent answers.

This project will undertake an initial work in this field by providing a structure for a global thinking and a design convergence. It will also study and propose the basis of a global design methodology able to integrate the main approaches being currently developed in the corresponding different domains in order to organize for future complex cyber-physical systems the needed multidisciplinary collaboration between TIC, SHS, Economy and Law.

TESTNAV. This project, Testing robot navigation in virtual worlds, using a Carnot support, implies the ROB and IC themes. Autonomous systems (mobile robots, intelligent vehicles, drones, etc.) must perform tasks without human supervision in a large variety of environments. Their deployment in spaces shared with humans puts strong dependability constraints, and in particular requires rigorous validation tests. For safety and cost reasons, these tests must be performed largely by simulation in a set of virtual worlds.

In this project, ROB and IC will work together to define and implement techniques for the automatic generation of contextual virtual worlds, such as those used in the creation of scenes for video games. The objective of the project is to test an autonomous system in a large sample of worlds, and thus in a diverse set of situations. The related challenges include the definition of the worlds in which the system will be imbedded, the stressful / dangerous features to consider, the election criteria for the adequate test sets, the integration of the "classical" test and the worlds generation. The project will investigate these challenges by taking as an example the navigation of a mobile robot.

Finally, note that a few other inter-themes projects exist, including 2 users studies started in collaboration with psychologists and ergonomists.

Also, many projects are currently under discussion for new collaborations in the next calls for projects.

1.2.4 Other Actions

1.2.4.1 General Collaborative Actions

ADREAM has been or is also involved in a set of large collaborative actions, for example:

- Strong Participation to the Aerospace Valley, to the DERBI Competitiveness Clusters, to the federation FEDESOL, to the two Toulouse clusters, Digital Place and Robotics Place.
- Entering the next LIA France-Tokyo (soon becoming an UMI) on conversion and photovoltaic production systems, materials for creating efficient III-V multi-junction cells.
- Strong involvement in the renovation project of the University Paul Sabatier through the *neOCampus* programme (PhD co-supervision, masters training, several projects on buildings under definition).
- Participation to the UPS Research Federation accepted by the MESR SH & HD, with as partners LAAS-CNRS, LAPLACE, PHASE, IRIT.
- Development of an open source software stack (OM2M) for the Machine-to-Machine ETSI standard with the Eclipse foundation for dissemination, and OM2M will be used by LAAS to provide many services, including digital intelligence, advanced robotics and energy optimization.
- Strong involvement in the ONEM2M standard group.

1.2.4.2 Presentations of the Project

The project and the building were presented at: the Scientific day of the starting of the construction, the Scientific day of the Official opening of the building, the Cluster Sensing Valley, *Science Animation* of the *CCSTI* of *Midi-Pyrénées*, the *Mêlée Numérique*, the *Association Rayonnement* of CNRS, the Workshop Autonomic Services in M2M Networks, the Thematic group « *Bâtiment* » of the CNRS Interdisciplinary Energy Programme, the Workshop « *Capteurs, Instrumentation pour l'Environnement et les GéoSciences* », the delegations of the University of Zhengzhou, the Northwest University, Chine, of the *Ecole Nationale des Sciences Appliquées* and the *Ecole Nationale des Arts et Métiers*, Maroc, the Days "Internet of the future" in Tokyo, the days "Machine to machine" of ASPROM FIEEC , the day "*Enjeux et défis de l'intégration d'objets intelligents dans le secteur pétrolier*", the Europ Conf on Nanoelectronics and Embedded Systems for Electric Mobility, the Workshop Jacques Cartier "*Intégration futée des énergies renouvelables*" held at LAAS on November 2013, the ICAM and the ENSEEIHT Toulouse, the Universities of Chile, Uruguay and Brazil (COPPE), the 9th International Conference on Design & Technology of Integrated Systems in Nanoscale Era (DTIS), 2014.

1.2.4.3 Scientific Popularization

- TV Reports of *France 3 Television* in 2010 and 2012.
- Shooting of a movie produced by the company *Gedeon Programmes* for the TV Channel "Encyclo" and broadcasted for the first time in May 2014.
- Video by the CNRS "*Habitat auto-suffisant, l'exemple Adream*", J.-J. Guérard, B. Lhoste, L. Ronat.
- Presentations in several national and international newspapers, as *Le Monde, La Dépêche*, *Le Devoir* (Canada), *Le Parisien, L'Usine Nouvelle*.
- Participants of the LAAS visit during: i) the "Open Doors" since 2012 in the framework of the annual "*Fête de la science*" in October, ii) the bike ride "Discovery of projects funded by the EU in Toulouse", May 2013, iii) the public conference-panel "Connected Objects" of the *Club Audiovisuel et Multimédia du Grand Toulouse*, March 2014, iv) two Panels at the FUTURAPOLIS congress organized by "*Le Point*" newspaper in May 2014.

1.3 The Platform, the Experimental Building of the ADREAM Project

1.3.1 Introduction

To define and realize the ADREAM building, many meetings were needed throughout this period between the researchers, engineers, and administrative staff of the CNRS Regional Office and of LAAS-CNRS, and with the architect and the *Bureaux d'Etudes*, to clarify all requests and solve all problems.

Let us recall that the project started in 2006, and that, from 2007 to 2009, we participated to the pre-specification of the ADREAM building with the programmer, ATHEGRAM, ended by a Publicity of the *Cahier des Charges* at the French *Journal Officiel*, with 55 responses received from the architects.

1.3.2 The Main Steps of the platform

From 2009 to 2014, the project got through the following main steps:

- January-July 2009: Selection by the Jury of 3 architects for the corresponding detailed proposals and the final choice of the building.
- September-December 2009: Internal meetings with the architect, final version of the APS, cost estimation, Final ODA.
- January-March 2010: version 1, comments and finalization of the PRO, Publication at BOMAP.
- April-June 2010: Selection of the construction companies, Scientific Day for the first stone.
- July 2010: Start of construction work.
- November 2011: End of the construction, Acceptance of keys with reserves about data acquisition.
- March 2012: First occupants in the building, preparing the analysis of its behavior.
- 2013-2014: Analyses of the building.

Figure 1: A South West View of the Experimental Building

1.3.3 The Building

It covers an area of 1700 m^2, and contains a scalable modular experimental room of 225 m^2, a technical platform of 500 m^2, 700 m^2 of offices and 720 m^2 of photovoltaic panels. Figure 1 and Figure 2 provide respectively outside and inside views of the building.

First, the "energy-related" part of the platform includes a photovoltaic production of 100kW peak of electricity, inverters, sensors for measuring the electricity production and consumption, environmental sensors, energy storage capability, and benches connected to the photovoltaic panels. This production, combined with a Canadian well, three geothermal heat pumps and a ventilation system, is a rather complex energy system. More specifically, the energy facilities include:

- a façade of photovoltaic bi-glass and tri-glass modules, producing 36 kWP (peak),
- a terrace equipped with reclining photovoltaic panels, for 35 kWp,
- a roof with a weather station and a set of fixed solar panels inclined at 10°, for 29 kWp,
- a buffer gallery, behind the facade, with an adiabatic air free cooling circuit,
- a Canadian well, 5 m depth, connected to a heat exchanger, that delivers air at 15 °C,
- three heat pumps, combined with 18 geothermal probes, 100 m-depth,
- three automated supervision systems that manage lighting, heating and ventilation.

Figure 2: Inside the Building:
The Corridor between the Photovoltaic Windowed Façade (Left) and the Robotics & Ambient Intelligence Area (Right)

Second, the "Computing, sensing and robotics - related" part of the platform (See Figure 14 in Section I) consists of five robots, a set of cameras, various sensors as motion tracking, temperature detection, etc. It will be used for conducting experiments in machine-to-machine communications, in movement analyses, and in humans-robots interactions for service and companion robots, etc. It uses a specific experimental setup, a realistic sketch of an apartment, for developing this multi-disciplinary research. This ambient environment has been used first for developing machine-to-machine communications, human-system synergy and assistance to fragile persons using a set of interactive robots, sensors and smart devices.

Since the middle of 2012 the building hosts about 90 people, mainly from the RIS and ISGE teams.

1.3.4 Organization of the Building

1.3.4.1 Introduction

By its experimental nature, the building differs from all classical buildings, as it includes innovative technologies, provides energy production, and it has the ability to measure its behavior. In particular, its maintenance has to:

- report all the behavioral incidents,
- propose technical solutions to solve all problems and improve its behavior,
- coordinate all logistic actions.

The corresponding work has started, with a support of the BET FERRER, one of the *Bureaux d'Etudes* involved with the architect in the definition of the building. The BET FERRER has been commissioned by CNRS to participate to the behavior analysis of the building during three years, in cooperation with the LAAS Technical maintenance committee.

1.3.4.2 Maintenance

The building is operational and pleasant, but there are still a few problems with the accurate analyses of its behavior.

Since 2012, we have found a few malfunctions, a few errors in measurements, and a not fully reliable monitoring data and equipment:

- Wrong unities in the measurement data base.
- Errors on calorie counters for heat pumps, on the EC/EG batteries of the CTA.
- Discrepancies between reported information and direct reading on the water meter of the adiabatic and on the tank EP.
- Differences between the direct analysis and the Building Management System (BMS) for the calculation of various COPs and energy criteria.

1.3.5 Visits of the Building

Several official delegations and isolated visitors were presented the building:

- CNRS, Midi-Pyrénées Regional Council, Toulouse *Métropole*, *Préfecture* Midi-Pyrénées, DRRT and *Rectorat de l'Académie*, EC IST DG CONNECT (Commission Networks, Content & Technology), University of Toulouse (UT3PS, INSAT, INPT, UT2J, UT1C, ISAE), Toulouse CCI (Commerce & Industry Chamber), Mayor of Toulouse, Midi-Pyrénées DRRT, RTRA, ANRT, CDC (Court of Auditors**)**, Midi-Pyrénées CCSTI, *La Mêlée Numérique*, *Pôle Derbi*.

- Participants to the Inauguration Day of the Building, 17th seminar of the network of electronics Midi-Pyrénées, 3rd National Days "Retrieving and storing energy for powering microsystems autonomous", Workshop J. Cartier, ITEA Project A2NETAutonomic Services in M2M Networks, G. Giralt scientific day.
- Companies: Living Objects, Schneider, LEGOS, *Météo France*, TOPPAN, Sogeti High Tech, Continental Automotive France and Continental Engineering Services, Renault SA, QUALCOMM Corporate (Europe & France), GridPocket, SOMFY, ERDF, Thales Airborne Systems, *Hydro-Québec* (CA).
- Foreign Visitors: Universities of Limerick, Zaragoza, Madrid, Barcelona, Trondheim, delegations from Thailand, Korea, Morocco, China, Japan.

1.4 Conclusion

From the events and results presented in this report, it appears that the ADREAM goals set at the very beginning to the project have been achieved. The building is being occupied since 2012, hosting 90 people (researcher and faculty members, PhDs, Post-docs and Engineers) working mainly in the fields of Information Technology, Energy Management and Robotics.

The energy platform of the building, i.e., the ventilation Canadian well, the geothermal heat pumps, the photovoltaic electricity production, together with the consumptions and the potential storage, define a particularly advanced architecture, very adapted to the design and optimization of energy systems, such as micro and mini Smart Grids. The entire building, including the energy and the IT parts, constitutes a unique platform, sophisticated and original, that includes computers, sensors, robots, electronics, energy, and provides a significant path towards the best quality of live and work for people both in professional and individual buildings.

The work, results, and actions that will be carried out during the next years will allow to better design and evaluate such innovative highly complex cyber-physical systems.

The research following this 2008-2014 ADREAM project will now enter a new phase, difficult, but ambitious and promising, including a multidisciplinary development, integration and cooperation. This new research will be done by conducting two sub-sequent projects: a generic project, also called ADREAM, that is a research project continuing the present one; a new second project, called SYNERGY, that will be dedicated to Energy management and optimization.

1.5 Acknowledgements

We would like to sincerely thank all members of LAAS-CNRS and of the CNRS Regional Office who participated to the work and actions presented in this report.

The ADREAM project was supported by the CPER 2007-2013, with a funding from the FEDER of the European Commission, the French State, the *Région Midi-Pyrénées*, *Toulouse Métropole*, CNRS and LAAS-CNRS.

2 ALIVE

Leader: Christophe Vieu

Themes Involved: MNBT, N2I, ROB, DO, HOPES

Keywords: *Nanobiotechnologies, nanomedicine, nanomaterials, biosensors, biochips, microfluidics, single molecule analysis, single cell analysis, bioAFM, cell sorting, molecular modeling, molecular engineering, cell engineering, tissue engineering, biodetection, molecular diagnosis, in-vitro diagnosis, bio-inspiration, biodata processing, nano-oncology.*

2.1 Context and Objectives

During the last century, two major technologies have emerged and deeply modified our perception of science and technology, and even reshaped our society. The first one is related to the exploding field of semiconductor technology and electronic devices. The second one is related to the development of molecular biology since the discovery of the structure of DNA molecules and now reaching in-depth understanding of the processes of life. Since 2000, the idea of combining these two blooming technologies has blossomed worldwide. This interdisciplinary research started significantly at LAAS-CNRS in 2002 with the creation of a dedicated research team and has progressively gained in forces and impact and became a real strategic axis of the laboratory in 2010, expanding its activity well beyond the sphere of micro/nanotechnologies and now involving researchers in robotics or information sciences. The ambition of ALIVE orientation is to structure and promote the interdisciplinary coupling of engineering sciences, as developed in our laboratory since its creation, with life and environmental sciences. Today, this facet of our activities is fed by the research of more than 80 scientists (34 permanent) and encompasses 5 themes of LAAS (MNBT, N2I, DO, ROB and HOPES).

The general objectives of this strategic orientation are both cognitive and applied. The first is a true scientific challenge and the second a true societal expectation. Biology is a science of complexity involving various dimensional scales and both molecular and systemic aspects. It is a field where many disjunctions commonly assumed in sciences are no more valid such as open/close; order/disorder; fragile/robust… It can be approached from the bottom with molecular biology or from the top with system biology. The long term promise behind ALIVE is that the complexity of the living can be tackled by information and miniaturization technologies. In brief, the first objective is to investigate the complexity of living systems trough the multi-scale engineering sciences developed at LAAS, either from the molecular side or from the system side. The second objective is to apply the same technologies not really for gaining knowledge but for generating new devices and systems for monitoring health and human environment. The applied research carried out in ALIVE orientation is therefore in good fit with National and international research calls such as: the European H2020 challenge named Health, demographic change and well being, the national French research agency ANR program called health and well being, 7 of the 34 plans for a new industrial

"France". These facts demonstrate that there are many opportunities for funding ALIVE research while developing cutting-edge basic research at the interface between disciplines.

In our work program, we distinguish two main streams for the integration of biology in engineering sciences. In the first one, referred as "**for biology**", technologies are adapted, transformed or designed for solving problems coming from life sciences or for modeling biological phenomena while in the second one referred as "**from biology**", the central idea is to change our existing technologies through bio-inspiration. As an example, we think that the next technological step at the crossroad of nanotechnologies and biotechnologies will be the real hybridization of biological materials and biological processes with integrated circuits and devices. The future generation of systems will incorporate, at the level of individual components, biological species, either molecular or cellular, with electrical, mechanical or optical devices fabricated by modern nanofabrication techniques.

ALIVE orientation carries also a home-made method for implementing an highly interdisciplinary research. Of course this research is achieved in collaboration with many partners of all disciplines including biology, chemistry and medicine. This is vital for being sure that the research done is relevant and at the best level of each involved discipline. However, ALIVE structure gives to all researchers of the laboratory willing to develop an activity in biology and related fields, clear scientific orientations, big scientific and technological challenges, experimental tools, identified relevant partnership inside and outside the perimeter of the laboratory and internal skills and knowledge for rapidly overcoming the energy barrier that represents the starting of a new and interdisciplinary activity. In other words, by this strategic orientation, LAAS takes its fate in hand in the field of biology and medicine, rather to let be driven by successive punctual collaborations established randomly along the way. ALIVE orientation thus structures and "thinks" the coupling with external partners of the biological, medical or environmental fields.

The platform ALIVE of LAAS-CNRS, addresses the field of personalized medicine, health monitoring, molecular and cellular scale technologies, brain recording and brain implants, hybrids and bio-inspired systems, modeling and self-learning algorithms inspired from robotics. Applications in various fields of healthcare are carried out with a special emphasis on oncology. The ambition is to emulate a strong partnership in order to prove, on the battlefield, that these technologies are reliable, and useful for real diagnostics, prognosis and therapies. Embedding these engineering sciences and technologies in medical tools is one of the major perspectives.

2.2 Scientific Program

2.2.1 Introduction

The scientific workplan of ALIVE was initially the result of the inputs of the research teams included in 5 scientific themes and is based on the cross fertilizations between on one hand, internal knowledge and skills in terms of device fabrication and characterization at micro and nanoscale, modeling and data processing, with, on the other hand, medical, biological and environmental issues brought by external collaborators primarily recruited in Toulouse Campus. Along the years this initial list of innovating well identified collaborative projects transformed into a real specific and coherent vision of the ALIVE strategy at the whole lab. scale, which is now piloting the new initiatives.

2.2.2 Research and Application Fields

Six taskforces have been identified according to technologies and engineering at different length scales. The first one develops **molecular engineering** using nanofluidics or directed capillary assembly for generating single molecule biochips for epigenetics marks detection. The second one develops **cellular engineering**. Cell nanomechanics is investigated by nanopatterning and Atomic Force live Imaging. Cell sorting using microfluidic devices coupled with magnetic or RF devices, and stem cell programming by micro/nanoscale engineering are typical examples of ongoing research in this workpackage. The detection of circulating biomarkers is the core of the third task. We develop ultra high sensibility detection devices based on Micro/nanosystems (FET, M(O)EMS, N(O)EMS, SERS, MEF), coupled with Micro/nano fluidics concentrators and develop a new axis on In-Vivo **biodetection devices**. The fourth task aims at developing **bio-inspired technologies**. Indeed, a huge variety of fascinating nanoscale biomachines exist in all living cells and are essential in particular for energy production, cell division, cell motility and information processing of the cell… By coupling nanotechnologies with synthetic biology it is envisioned to integrate these functional bionanomachines inside electronic nanodevices made by silicon technology for solving technological challenges such as embedded energy, actuable nano-motors, bio-assisted assembly of novel nanomaterials and pharmaceutical screening. A dedicated task for **modeling** biological interactions and biological system is also implemented. Original approaches combining fuzzy logics algorithms or robotics locomotion programs are used for extracting molecular signatures from data banks or for modeling ligand/receptor interactions. Finally a last task concentrates on **applicative fields** with a major center of interest in oncology with our local biologist and medical partners.

2.3 Results

2.3.1 Global Results

ALIVE orientation of LAAS produces on average 30 publications in international peer-review journals per year. A third of these scientific papers can be found in journals of biology, biochemistry and medicine while the majority of them appear in journals closer to the original disciplines of the LAAS researchers i.e., devoted to technology, devices or materials.

On average, 3 patents relevant to ALIVE orientation are deposited each year, mainly in the domain of medical and biotechnological technologies, often referred in short as "Med Tech". More than 40 contractual projects participating to ALIVE activity have been developed among the various research teams at regional, national and European levels. In parallel, strong and long term partnerships with regional industrial companies (Pierre Fabre, Sanofi, Hemodia, Innopsys, Dendris, etc.) in the field of biochips and biosensors have been implemented. A new joint laboratory, called Biosoft and hosted at LAAS, funded by the ANR program Labcom, has been concluded with Innopsys company and started its activities in December 2013. The constant contribution of LAAS scientists to dedicated workshops and conferences as well as the implication of LAAS researchers to organize conferences (MicroNanoEngineering Conference MNE2012, NanoBioEurope NBE2013) has significantly increased the visibility of the laboratory in the areas of Micro and Nano Biotechnologies and Nanomedicine. LAAS-CNRS, through its ALIVE orientation has became a very well identified partner of the different organizations that locally structure the research activity in the field of oncology (*Cancéropôle GSO* labeled by the National institute of Cancer (INCa), the RITC *(Recherche et Innovation Thérapeutique en Cancérologie)* foundation) and has benefited from several supports from the *InnabioSanté* foundation. Through these interactions with the community of researchers and clinicians in Oncology, LAAS-CNRS supported strongly the emergence of the Oncopole and covered in this wide and ambitious project the technological aspects specifically around nanomedicine and nanocancer.

2.3.2 Salient Steps

- Writing the scientific program of ALIVE orientation.
- Creation of a dedicated experimental platform centered on chemistry and biology for supporting the activities.
- Linking LAAS on the long term with biological and medical partners with the emergence of a shared activity on Oncodevices with CRCT-Oncopole (*Centre de Recherche en Cancérologie de Toulouse*).

2.3.3 Salient Scientific Results

In the following section, in order to rapidly give a picture of ALIVE activities *exempli gratia*, a short subjective selection of some scientific and technological achievements is presented.

2.3.3.1 New Tools, new Methods for Sensing, Imaging and Modeling Living Systems

The main impact of LAAS technologies in coupling with biology and biochemistry has been to design, implement and validate new approaches and new methods totally original with respect to the existing methods of biosensing, bio imaging or bio computing.

Gas sensing activities for environmental purposes are very well advanced at LAAS. Conductimetric gas sensors and smart e-nose devices exhibiting both sensitivity and selectivity are now deployed for several applications including health, environment, smart buildings, security, automotive and food industry. They can be arranged as multi sensors in communication networks and have reached critical specifications of reliability for being integrated at an industrial level (Renault, Alphamos). The original technology of our laboratory is the co-integration of a nanostructured chemical sensing material with a high temperature micro hotplate (>600°c) (Figure 3). This combination turned out to provide selectivity of sensing by finely tuning temperature cycles.

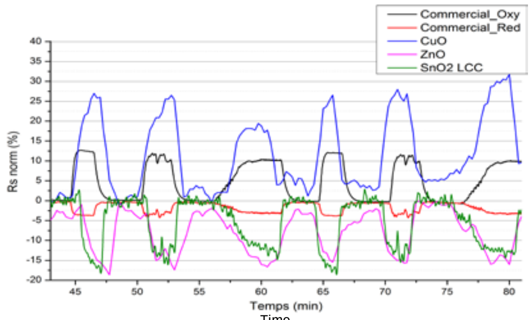

Figure 3: Typical Time Variations of the Conductivity of Multi-Sensing Devices upon Gas Absorption.

Other researches on gas sensing rely on other nanomaterials such as spin transition compounds or nanocarbon.

Imaging the living by implementing new tools or new methods has been the subject of active research. Atomic Force Microscopy (AFM) in liquid media and on living cells has gained a state of the art level of expertise in the laboratory. A new methodology derived form AFM imaging and called protrusion force microscopy (PFM) has been developed in collaboration with IPBS and allowed the first measurement of the protrusion forces exerted at nanometric scale by adhesive actin structures called podosomes developed by some typical cells such as macrophages. Another totally innovative method relying on optical microscopy has been developed in order to acquire 3D microscopic images of living cells with the perspective to unravel molecular interactions within the cell in real time, which is not possible with current confocal techniques (Figure 4). The principle of the new method involves the use of micro fabricated facetted micro-mirrors that enables the observation of a same scene under two angles and by real time image processing to the 3D movement of optically visible cell components. The research team succeeded in tracking the dynamics of chromosomes of living yeast shedding some light on yeast genome architecture.

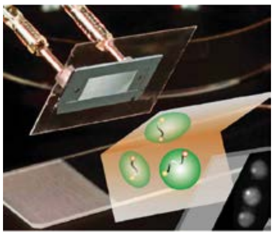

Figure 4: Schematic of the Principle of High Speed 3D Optical Microscopy with Tilted Microfabricated Mirrors.

Dedicated biochips and devices for diagnosis in oncology is currently an objective for several research teams involved in ALIVE activities. Among these researches, a transverse project in collaboration with *Institut Caludius Regaud* (ICR), has been developed with the ambition to give a better diagnosis of breast cancers by providing a tool for discriminating their grade and classify grade2 cancers into "grade1 like" and "grade3 like" on the basis of genetic analysis. For this purpose, fuzzy logics algorithms have been implemented on available international databanks of gene analysis of cohorts of breast cancer patients, then on gene signatures obtained on a specific cohort of the ICR (Figure 5). The algorithm succeeded in selecting a very reduced number of genes (<35) allowing the discrimination to be performed with around 97% sensitivity and 90% specificity. These findings have then been implemented in a dedicated DNA microarray fabricated by soft lithography in order to produce at low cost analysis slides capable to equip the clinicians with a new decision tool for adapting the right therapy.

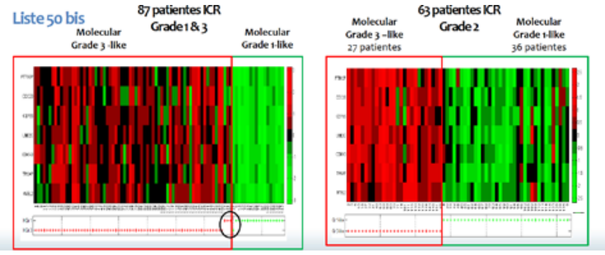

Figure 5: Typical Discrimination Maps Obtained on a Reduced Set of Genes Selected by a Fuzzy Logics Algorithm for the Prognostic of Breast Cancers.

In vivo measurements and in-vivo devices are probably the better non-invasive methods for detecting suspect tissues, cancer cells or molecular biomarkers. In the last period new projects have been developed in this perspective. An original method coming from laser optics and called velocimetry self-mixing has been proposed for accessing skin vascularization. Blood velocity can be directly measured thanks to Doppler effect by a self-aligned optical feedback interferometry, using a semiconductor laser diode as both the transmitter and the receiver, enabling to combine fast response, spatial resolution and a compact optical design. The methodology enables the reconstruction of the velocity profile inside fluidic microchannels but has also been proved to measure, through the skin, blood velocity in individual capillaries and is now developed as a medical instrument for the diagnosis of melanoma.

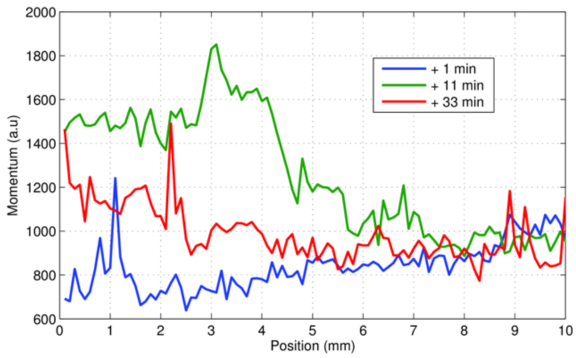

Figure 6: Typical Blood Vascularization Signals Measured by Velocimetry Self-mixing on Skin after Treatment with a Cutaneous Rubefacient Cream Showing the Effect after 11 Minutes.

Another in-vivo device is currently developed as a micro-catheter in order to capture Circulating Tumor Cells (CTCs). The device can be introduced in the blood stream as a conventional catheter but is equipped with a 3D capture object fabricated by two-photons 3D optical lithography, in order to selectively capture in a few minutes, the CTCs, based on their size and mechanical stiffness.

Modeling the living has also been the subject of intense research in ALIVE activities. On one hand, atomic simulations previously used for modeling silicon technology processes have been transformed elegantly for being able to compute molecular events occurring on huge macromolecules such as proteins and on the other hand, robotic-inspired models have been adapted to simulate molecular motions and ligand/receptor biomolecular recognition events. The two approaches have the advantage of allowing fast simulations of large time-scale motions on a single CPU. An exciting project of structural oncology based on the development of the so-called "Static modes" method, enables the virtual screening at high speed of a large number of mutations of RAS protein involved in more than 30% of all human tumors (Figure 7).

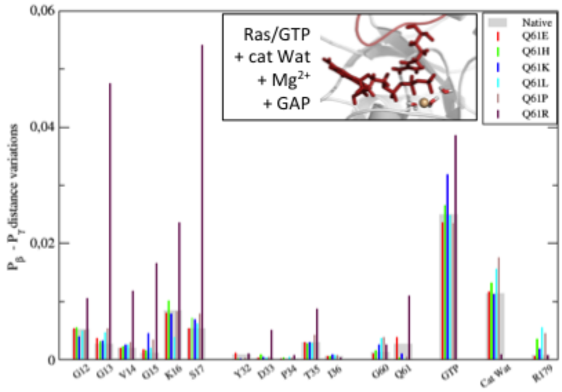

Figure 7: Typical Screening of the Activity of some Specific Mutations on RAS Protein using the Static Modes Approach

This protein is known as an "ideal" target for cancer therapy, but up to know has never been drugged, despite huge international efforts. The ambition of the method is at the end, to identify new sites and mechanisms for designing active molecules for this protein.

Researchers in robotics have shown that by formulating ligand/protein interactions as a disassembly problem of pseudo articulated mechanisms (Figure 8), they could describe properly various ligand-induced conformational changes in several membrane proteins of interest. A Manhatan-like Rapidly exploring Random Tree algorithm has been specifically developed for simulating ligand diffusion inside flexible proteins within tens of minutes of computing time on a single processor.

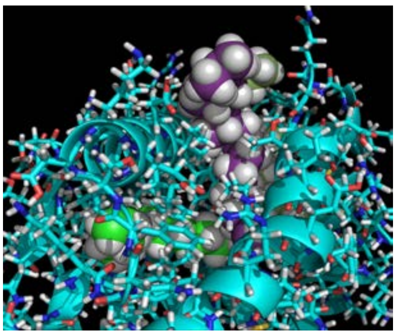

Figure 8: Typical Images of Ligand/protein Interactions as Modeled using Robotic-inspired Algorithms.

2.3.3.2 New Investigation Fields

The interdisciplinary momentum generated by the ALIVE LAAS orientation has conducted researchers to open totally new investigation fields during the period. Among them, activities in relation with brain stimulation, brain recording or brain regeneration have been implemented. These activities are extremely linked to a network of external collaborators in neurology from CHU Toulouse and CerCo *(CEntre de Recherches Cerveau Cognition)* for example. An innovative flexible technology for fabricating Implantable brain electrodes is developed in order to improve the stability and lifetime of these devices, used nowadays in advanced medicine for supplementing highly disabled patients. The association of electro-deposited conductor polymers and biocompatible materials such as parylene, turned out to increase significantly the biostability and biocompatibility of the devices (Figure 9).

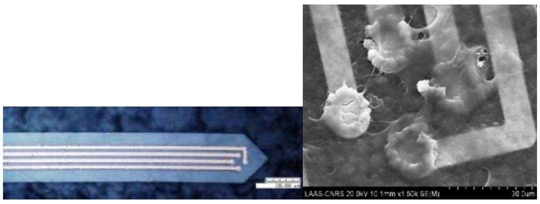

Figure 9: Images of Biocompatible Flexible Brain Electrodes

Ion sensitive Field Effect Transistors (ISFET) have also be combined with neurone patterning in order to record the electrical activity of living neurons and for measuring the velocity of nervous impulse. Bioprosthesis made of a biocompatible micro and nanostructures material and equipped with neural stem cells have also been designed, fabricated and validated in murine models for the brain regeneration after stroke. The topograhical cues imprinted at the material surface, when optimized, turned out to promote cell differenciation, and neurite extension in well controlled and perfectly designed directions. Implanted disabled rats showed higher and faster recuperation as attested by behavioral tasks and the technology is currently tested in primates.

A new project dedicated to the generation of artificial muscles in collaboration between researchers in nanotechnology and in robotics is also under implementation and demonstrates that new horizons and original ideas are growing in the frame of ALIVE activities.

2.4 The ALIVE Platform

A dedicated experimental room has been set-up for structuring the experimental spaces and activities devoted to biology and related fields. This new infrastructure sounded as a strong mutation of our laboratory traditionally oriented towards electrical characterization rather than biological and biotechnological laboratory methods. The old space having hosted the clean room facility of LAAS-CNRS before 2005 has been re-designed, adapted and equipped as a Bio platform. This experimental space is a crucial tool enabling rapid in-home access to various lab techniques of molecular and cell biology and to various associated imaging methods. It is today possible to claim that LAAS-CNRS is equipped for achieving by its own, its specific research projects in biology. The platform is constituted by a space of 400 m^2 gathering most of the equipment but other smaller zones devoted to experimental techniques or conditions not compatible with the main room are affiliated. A huge step forward has been made when cell culture laboratories were set-up in ALIVE platform (Figure 10). Level 1 and Level 2 zones are now available for the culture of primary and immortal cells, bacteria, yeasts and algae. We have learned by now, how to adapt the culture media for being compatible with some microelectronics processes. Conventional techniques of optical microscopy mainly relying on fluorescence have been gathered inside a dedicated zone where microfluidic networks can be imaged and recorded in video modes and cell immunostaining can be performed. Several fluidic set-ups are also available. A dedicated Atomic force microscope from JPK (nanoWizard 3) is also widely used in liquid media for molecular coatings and patterns characterization but also for living cell characterization and force spectroscopy. This microscope enabled us to implement a series of works dedicated to cell mechanics and the investigation of mechanosensing properties.

Figure 10: Image of the Cell Culture Lab. of ALIVE Platform

Electrochemical technics are also available with various potensiostat/galavanostats and impedance spectrometers. This park of instrument was the core of a project with Pierre Fabre dermocosmetics society devoted to the skin detection of anti-oxidant molecules.

Moreover, as many nanomaterials are embedded in many of our biodevices, several equipments for characterizing (Zetasizer) and manipulating nano-objects, DNA, lipids and other assembling molecules are also available.

2.5 Conclusions

The ALIVE strategic orientation set during the current period (2010-2014) has now reached internally a good level of maturity and externally has gained in visibility.

The range of investigated questions, application fields and involved methodologies is growing continuously and each year, new collaborators have joined the research teams of ALIVE with new projects and new ambitions in the coupling of technologies with biology.

The interdisciplinary research deployed in the ALIVE framework leads to a form of scientific excellence as attested by some publications in high impact factor journals of fields that were never present before in the LAAS publications.

Our laboratory thus clearly envisions its future through this strategic orientation, which will be strengthened and enlarged towards new scientific challenges and by encouraging new projects involving several scientific themes of the lab and also by involving new disciplines that are still not yet included.

XI - A Project for the Future

1 The Laboratory

1.1 Context and Challenges

One can anticipate that the trend towards **cyber-physical systems**, **sustainable-energy management**, and **interactions between nanotechnology and life-sciences** observed during the past years will continue and even expand. Actually, such an evolution results in more interactions between increasingly miniaturized, energy-aware and smarter (and thus software-intensive) systems embedded into open and communicating larger systems (notion of systems of systems) and a wide set of real-life and critical application domains.

Thanks to the progress in:

- hardware technology (nanoscale trend, integration and hybridization, low-consumption, communicability, reconfigurability, biologization, etc.),
- software-based developments (emergence of virtual machines and adaptive middleware layers for implementing resilient architectures, rigorous design and verification, focused testing and assessment, efficient algorithms and computations, etc.),
- deployment and operation of large-scale complex systems (distributed control, optimization, diagnosis, wireless communications, efficient protocols, interactive robotization, energy multisourcing and management, etc.),

it can be confidently predicted to increasingly witness a penetration of ICT-based systems into societal areas well beyond the classical application domains (e.g., transportation, internet-based communication) where "embedded systems" are now unavoidable. Such areas that will require multidisciplinary progress include: health-care and medicine, agriculture, future production systems, resource distribution and optimization, etc.

On the basis of the wide span of the research activities (as reported in the previous sections that show that many of the items listed above are actually investigated), LAAS possesses the competencies and has developed the skills and a pro-active policy to pursue and expand the two strategic axes (ADREAM and ALIVE) that were developed during the past period and that form good media allowing the Lab. to be a key player in the emerging areas.

These ambition and goal are of course to be fortified and mitigated by accounting for our own strengths and weaknesses and also by referring to the opportunities and threats provided by the local and global environment.

1.1.1 Strengths

Being in the core of ICT research activities and spanning a wide spectrum of disciplines, LAAS is well positioned to address the major scientific evolutions sketched in the previous paragraph. The research activities developed within the themes and the cross-roads established within the axes have already paved the way for LAAS to play a legitimate role in tackling, for the decade ahead, the scientific challenges attached to the three trends identified above.

The focused expertise of the human resources and the high quality of the equipment (reinforced via the ROBOTEX and LEAF EquipEx) and platforms, present at LAAS prepare us to address unresolved issues and develop innovative solutions.

As already pointed out, the wide-range of skills available, the interdisciplinary actions launched via the transverse strategic axes and the strong connections established with academic research in different domains (oncology, biomechanics, biology, etc.) including the recent recruiting for the last two items, consolidate our capacity to address issues at the frontier of existing disciplines.

The close links with industrial partners through the Affiliate Club and the renewal of the Carnot label entails us with a privileged position at the crossroad between research and innovation.

During the period external recruiting (at various levels, PhD, Postdoc, faculty, researcher) has expanded, also with respect to the international dimension, thus revealing the attractiveness of the Lab.

Sharing of resources, mutualization of our revenues (while increasingly difficult to maintain — see hereafter), our Carnot label enable us to support internal cooperation and resourcing research exploring novel scientific orientations.

The strong links established for years with academic partners (via our faculty members and proactively via the action of the Training-Research Commission) concerning education and training enable us to disseminate cutting edge knowledge, to motivate students for research and to play an expanded role in the recruiting processes.

The integration of LATTIS (INSAT) and LOSE (INPT) has been handled properly and has also contributed to increase the exposition of the Lab. within the community and to enrich our connections with respect to the local academic partners.

During the recent period, we have accompanied the mutations that occurred within the various academic partners, reinforcing our positioning in the governance of these establishments. The signature in July 2013 of the site convention including CNRS as part of the ComUE (*Communauté d'Universités et d'Etablissements*) ***Université Fédérale de Toulouse Midi-Pyrénées*** has further strengthened our position in that context.

The on-going Continuous Improvement (*Amélioration Continue*) process, that we are currently conducting to enhance the way we interact with our partners, will definitely help us in rationalizing several types of activities: administrative, technical, hosting, prospecting, training, etc.

1.1.2 Weaknesses

The evolution of the age pyramid reveals predictable difficulties for the rest of this decade, concerning both

CNRS researchers and ITAs. Indeed, maintaining a good level of both technical and administrative personnel is essential to sustain the activities developed by the researchers and respond to the increasingly demanding operational procedures.

As mentioned in Chapter I, the dominant national financing model (based on multiple calls for proposals) induces both stress and load (writing proposals, evaluating them, monitoring them, justifying them, etc.) on research personnel and administrative staff, as well.

In addition, the now prevalent project-oriented model for research funding (calls for proposals and "marginal cost") weakens the capacity of the Lab. to develop an autonomous scientific strategy and has a detrimental impact on the ability to cope with the increasing infrastructure cost.

The heterogeneity of the distribution of the CNRS researchers and faculty members among the research teams induces a bias in their respective activity profile.

The non-selection of our proposal submitted to the 2015-2020 CPER will weaken our innovation strategy, echoing the roadmap assigned to the Carnot institutes, for adapting our platforms to respond to the demands of our industrial partners (especially SMEs) for hosting them.

In spite of the recovery that occurred in 2013, the overall low level of funding concerning direct contracts with industry (as opposed to cooperative projects supported by public funds[1]) reflects our difficulty in maintaining this form of cooperation (including joint Labs.) and constitutes obviously a negative point in our Carnot profile. Of course, external contextual aspects interfere with this frailty: one example of these difficulties concerns the abortion of the long-term (more than five years) project to establish a joint Lab. with TOTAL on PV electricity conversion and energy management that was also impacted by the major reconfiguration that took place during the period within the company.

Due to the large size of the Lab. and the increased number of research teams at the beginning of the period, the governance and management of the Lab. has become particularly demanding. Accordingly, the roles of the themes and of the responsible for Management and Decision Support need to be revisited and reinforced.

1.1.3 Opportunities

The role and dominance of **Information & Communication Technologies and System Engineering** disciplines, the core expertise developed at LAAS, is now recognized as the leading vector for development and growth in many application areas at all decision levels: Region (UT, Midi-Pyrénées Region, Toulouse Métropole), Nation (SNR), Europe (H2020) and world-wide.

The cross-cutting competencies available at LAAS, and for several of them already deployed jointly within the transversal axes (ADREAM and ALIVE), confer a critical mass to our research in this area. Accordingly, the close interactions developed with the community in oncology (*Centre de Recherches en Cancérologie de Toulouse*, *Institut Claudius Régaud*, etc.) around the ALIVE axis are expected to allow for developing further our activities in this area. Likewise, federative initiatives (e.g., FERMat and SH2D Federations, NeOCampus supported by UT3PS, the WGs supported by the RTRA STAE, etc.) provide good environments to develop interdisciplinary research in connection with the ADREAM axis. The roadmap of IdEx UNITI is explicitly oriented towards supporting interdisciplinary research projects.

The mutation of the local environment (emergence of new instruments issued from the PIA, settling of CEA Tech) provides additional prospects for further developing our interactions with industry and the transfer of our innovative results:

- Antoine de Saint Exupéry IRT is expected to provide a framework to establish long-term cooperation with industrial partners.
- Based on the initial prospects, when reaching a steady state operation, the Toulouse Tech Transfer SATT should provide a close and helpful support for valorizing our research results, including beyond our usual industrial partners.
- The installation and planned expansion of CEA Tech is expected to allow for building up cooperative actions taking advantage of our complementary expertise and respective capabilities.

The on-going PIA call for proposals aimed at structuring and combining the offer of Carnot Institutes targets various economic sectors where LAAS is well positioned.

1.1.4 Threats

The evolution in the financing modalities of research that was already pointed out has significantly modified the context for research Labs. Indeed, this trend impacts the balance between the recurrent endowments to the Lab. and the Lab. own resources featuring numerous projects — for most of them rather small — and with no increase in overall amounts. In addition, the stringency of the justification process attached to the "eOTP-ization" of the accounting procedures constitutes a major burden. Actually, this prevent from a convenient handling of the type and amount of financing resources that can be made available for mutualization purpose.

The generalization of calls dedicated to cooperative projects (requiring the participation of a minimal number of partners) penalizes sized research units that actually host multidisciplinary teams. The teams are thus compelled to look for external partners rather than to approach other teams within the Lab. with complementary competences to develop real interdisciplinary research actions. Accordingly, it is not always easy to take advantage of such sources of funding to actually promote our transverse axes.

The enforcement of the ZRR procedures (rigorous screening, lengthy decision delays) has resulted in augmented load and burden to recruit members of the laboratory (including permanent members recruited via selective entrance examination both at CNRS or University) and foreign hosts. Indeed, an unprecedented and alarming number of refusals occurred during the past nine months. LAAS still being the only one Lab.

[1] In addition to the weakness mentioned, this could also be assumed as a threat induced by the multiplication of funding opportunities made available for cooperative research.

ruled by the ZRR procedures in the site, this situation has resulted, in a few occasions, in penalizing us with respect to neighbor labs for what concerns hiring PhD or master students. Finally, such a level of stringency looks seldom adapted to an academic research Lab., for which openness and pro-activeness in international cooperation are among the major missions.

1.2 Main Scientific Orientations

For the next period, the Lab. will develop its research activities along the same scientific themes. Compared to the previous organization into 4 disciplinary *poles*, the organization into 8 scientific themes proved useful in procuring a better visibility of the research being developed by LAAS-CNRS, especially in the domain of Micro and Nano Systems. This level of management proved also useful in ensuring the coordination among research teams and in providing a suitable interface with the transverse axes. At this stage we do not foresee any major change into theses themes for the next period. As previously stated, we believe that it might be useful to fortify their role within the governance of the laboratory. The developments and new orientations of the research activities carried out into the themes will be exposed in Sections 3 to 10.

The goal is also to pursue and enhance the proactive commitments on the strategic transverse axes — **ADREAM** and **ALIVE** — that were developed during the 2009-2014 timeframe. In that context, in order to better expose the joint research activities being carried out — so far in the framework of ADREAM — on the various facets of the topic of energy, we propose to bring out a new axis entitled: **SYNERGY** (SYstems for smart eNERGY management).

The ALIVE axis on health and environmental issues will be continued with the same perimeter. Concerning **ADREAM**, based on the work that was carried out in the framework of ADREAM, we are planning two axes of research for the coming years: one on the general scientific design of cyber-physical systems and the other, **SYNERGY**, will be dedicated to the challenges of energy systems and smart grids. The goal is in particular to put more emphasis on the various facets of energy management that were originally contributing to the ADREAM axis.

The rationales for the evolution of these three axes are briefly presented in the subsequent sub-sections. More in-depth exposition will be presented in the subsequent sections.

1.2.1 About ALIVE

Based on LAAS's large range of resources and skills in engineering sciences, quite unique in Europe, that span from robotics to nanotechnologies, our resolution to couple these sciences with life sciences will be strengthened in the next period by encouraging even more the interdisciplinary orientation of **ALIVE** with projects involving several scientific themes of the lab and also by involving new disciplines still not yet included. In particular, this research activity will rely on strong collaborations with major actors of the domain (CRCT, IPBS, *Institut Claudius Régaud*, CHU) and will be reinforced by the federative project ONCODEVICE. This latter one will initiate a strategic and long-term alliance with CRCT aiming at developing innovative tools for tracking biomarkers in oncology.

It is clear for us that one of the most challenging advances will rely on the convergent involvement of nanotechnologies, information sciences, telecommunication sciences, robotics and energy. This is the complex challenge we want to address.

1.2.2 About ADREAM

For the coming years the research and experiments in **ADREAM** will rely on a scientific program aiming at designing, implementing and assessing intelligent distributed cyber-physical systems. This research will develop in particular the following aspects:

- semantics modeling and description of complex cyber-physical systems, including design requirements and implementations and using formal or semi-formal models;
- provision of a guaranteed quality for the applications, mainly based on integrated performance and security properties;
- definition of architectures for autonomous mobile intelligent entities, as robots, vehicles and people, for new services on request;
- acquisition, characterization and management functions able to understand, analyze and control the distributed mobile sensors and actuators to fulfill the system specifications.

1.2.3 About SYNERGY

Future energy challenges require multidisciplinary competences ranging from new materials for innovative photovoltaic solar cells or harvesting devices and advanced power electronics with improved efficiency control, to smart and autonomic energy management systems. Many of these competences are readily available at LAAS-CNRS. This has motivated the definition and proposal of a new transverse axis called **SYNERGY** (SYstems for smart eNERGY management). At this stage, the relevant topics that have been identified, include:

- **Energy generation**: emerging PV production (both organic-based and III-V-based), efficient conversion, etc.,
- **Integration of renewable energy sources**: HVDC-grid deployment, storage management in particular, bidirectional battery chargers and solid-state transformers,
- **Smart energy management**: development of a generic heterogeneous simulation platform for the modeling and the optimization of the energy management of a microgrid.

It is noteworthy that these activities constitute transverse projects among several themes. Moreover, the ADREAM and SYNERGY activities will benefit from the intensively instrumented and energy-optimized **Georges Giralt** building. These activities are also planned as joint research with other laboratories (e.g., CIRIMAT, IRIT, LAPLACE, PHASE), in particular as part of the **neOCampus** initiative.

1.3 Looking Ahead and Positioning

For a long time LAAS has taken up the challenge of the "intelligence of systems" and of their consistent development according to a wide spectrum of applications. The paradigm of systems that are evolving and reconfigurable, dynamic and interactive, distributed and interconnected, efficient and resilient, autonomous and mobile has been put up and expanded over time thanks to conceptual and technological advances, and to the development of means suitable for their emergence and deployment.

In that context, our strategic line is anticipating the major changes according to upstream approaches, while remaining attentive to industry demand, that may carry both fundamental questions and sometimes require short-term answers. This extensive and rather unique positioning, that has earned LAAS the Carnot label, is a mark of this commitment and of the care that the Lab. dedicates to industrial partnership.

The virtue of and requirement for interdisciplinarity have been clearly recognized as major drivers for managing the key challenges posed by the pervasive deployment of ever “smarter” systems.

From the progress of ADREAM and ALIVE, we already experienced the benefits resulting from the synergies created by the sharing of complementary competences found within the Lab. and elsewhere. Indeed, we have found that interdisciplinarity is able to shape both scientific and technological orientations in many interesting ways (novel research topics, equipment and resource sharing, etc.).

This rather singular competency and ability for interdisciplinary research that characterizes LAAS, is really something on which we want to invest more and pursue for the three strategic axes that we are now exhibiting. The association of the Lab. to two institutes (INS2I and INSIs) is a clear recognition of that interdisciplinary dimension. This is essential for the actual grasp of our orientations and requirements. At the same time, this is an asset for providing us with the adequate support, thus concurring with the emphasis put by CNRS on promoting interdisciplinarity, in particular via the *Mission pour l’interdisciplinarité* (MI).

In addition, it is worth pointing out that the rationale of the research opportunities attached to these three axes are also evidenced by the various European, National and Regional priorities and are reflected in many calls for proposals (ANR, Carnot, H2020, etc.). They are also echoing the strong expectations from the society in the domain of health monitoring, silver economy, advanced manufacturing, alternative and renewable energies, etc.

More specifically, it is worth pointing out that the activities developed in the ALIVE, ADREAM and SYNERGY axes span 7 priority topics among the 12 identified by UT3PS as shown hereafter.

Links to 7 of the 12 UT3PS Priority Topical Axes (2014)

- *Recherche translationnelle (de la molécule à la population) : cancérologie, vieillissement et pathologies dégénératives - ALIVE*
- *Molécules, matériaux, dispositifs et procédés pour la santé, le vivant et l'environnement - ALIVE*
- *Modélisation, simulation numérique, modèles de calcul, calcul intensif - ADREAM*
- *Des masses de données à la connaissance dans la société, l’exploration spatiale, la biologie et la santé - ADREAM & ALIVE*
- *Atomes, molécules et nano-objets : du concept à l'expérience - ADREAM & ALIVE*
- *Systèmes embarqués intelligents : vers les systèmes cyberphysiques - ADREAM*
- *Energie : stockage, conversion, transport, matériaux et optimization - SYNERGY*

Our 3 transverse axes are also well inline with 4 of the 6 federative strategic axes put forward by INSAT.

Links to 4 of the 6 INSAT Federative Strategic Axes (2014)

- *Matériaux Nano et multifonctionnels pour les dispositifs et les structures -* ADREAM & ALIVE
- *Conversion et gestion optimisée de l'Energie -* SYNERGY
- *Modélisation, Simulation et Statistique pour la physique, l'ingénierie et la biologie -* ADREAM & ALIVE
- *Systèmes cyberphysiques, micro-nano-systèmes pour la santé, l’aéronautique et l’espace -* ADREAM & ALIVE

A match can be found as well with the 5 strategic themes identified by INPT.

Links to the 5 INPT Strategic Themes (2014)

- *Gestion des ressources, des risques, et traitements chimiques et biologiques des eaux et effluents -* ALIVE
- *Ingénierie de la santé humaine et animale pour une meilleure qualité de vie -* ALIVE
- *Nouveaux itinéraires technologiques pour la transformation de la matière et de l’énergie, notamment l’hydrogène et les énergies renouvelables -* SYNERGY
- *Eco-conception des systèmes industriels ou de production agricole -* ADREAM
- *Calcul intensif et modélisation des grands systèmes -* ADREAM & SYNERGY

Issued from the 10 WG[2] settled in 2013-14 to define the new SNR (*Stratégie Nationale de Recherche*), a list of 15 priorities have emerged. It is worth pointing out that the activities developed at LAAS within our axes fit 8 of these priority actions

Links to Priorities Actions Issued from the SNR WGs (2014)

- *Recherche hospitalo-universitaire en santé - ALIVE*
- *Biomasse et biotechnologies comme piliers de la transition écologique - ALIVE & SYNERGY*
- *Ilots urbains à énergie et environnement positifs - SYNERGY*
- *Technologies et services pour des mobilités durables intégrées - ADREAM, & SYNERGY*
- *Interaction Humain-Machine dans les industries du futur - ADREAM*
- *Données et ingénierie de la connaissance - ADREAM*
- *Vers des systèmes complexes résilients - ADREAM*
- *Information, risque, décision - ADREAM*

2 The Continuing and Novel Transverse Axes

2.1 ALIVE

2.1.1 Context

The ALIVE strategic orientation set during the current period has now reached internally a good level of maturity and externally has gained in visibility.

The range of investigated questions, application fields and involved methodologies is growing continuously and each year, new collaborators have joined the research teams of ALIVE with new projects and new ambitions in the coupling of technologies with biology. Our laboratory thus clearly envisions its future through this strategic orientation, which will be strengthened and enlarged.

[2] A member of LAAS-CNRS, Malik Ghallab, has been leading the WG entitled ”*Société de l’information et de la communication*”.

The opportunities of this field are held by the various European and national priorities expressed in various calls for projects (ANR, Carnot, H2020), by a strong expectation from the society, in the domain of health monitoring, but also by the evidence that the interdisciplinary research deployed in the ALIVE framework leads to a form of scientific excellence as attested by some publications in high impact factor journals of fields that were never present before in the LAAS publications.

Threats are linked to a huge international competition in this emerging field and also to a possible aspiration of our activities towards applications, inducing some works closer to engineering rather than academic research. This is rather conventional for a laboratory such as LAAS, but we will be very attentive to maintain a good balance between these two types of activities in the future and also to keep the good position occupied by our lab at the international level on this field.

Innovation and industrial transfer of our technologies will be deployed by the dynamic of joint laboratories with nearby SMEs (see for example the joint laboratory "BioSoft" between LAAS and Innopsys), by the hosting of industrial projects, benefiting from the services of our clean room facility and of the ALIVE platform, and finally, by our involvement as a Carnot Institute inside the national "Med-Tech" action dedicated to interfacing SMEs and ETIs of this industrial sector with the innovation and research centers of the Carnot network. Apart from industrialization topics, issues of cost, market, business model, etc., the crucial point is now to become a fully-fledged contributor to medical advances.

As a matter of fact, the management of the confrontation between our new technologies and the medical and clinical environment will become more complex. Big issues are in front of us: will these new devices and techniques be really employed in medicine? What about their potential toxicity? What about their approval by the medical institutions? What about their acceptance by patients? Answers to these critical questions need to be brought during the next period of activity.

The partnership with the *Toulouse Cancéropôle* will be, in this context, a major element of strategy. The positioning of this project, defined in close cooperation with the CRCT *(Centre de Recherche en Cancérologie de Toulouse)*, targets both drug candidates development and quantification of tumor heterogeneity. The development of effective anti-cancer drugs is hampered by the extraordinary heterogeneity of cancers. In the era of targeted therapies, only certain tumor cells may be eliminated because they express the target of the candidate drug, while other cancer cells reduce the therapeutic benefit, causing resistance and adaptation or relapse in response to the treatment. Therefore, some cellular components (genes, proteins or metabolites) whose expression variation or qualitative differences explain the therapeutic gain, act as potential biomarkers for the stratification of new patients. The development of tools to overcome this issue as soon as possible in the life of drug candidates is a major challenge in terms of public, economic health and an asset to the pharmaceutical industry. In this context, the project aims at designing and building a family of miniaturized tools for the monitoring of biomarkers in oncology. Five co-supervised PhD theses will start in 2014 and another set of three theses is planned in 2015.

Research activities will be accompanied with the reinforced participation of the laboratory in the organizational and animation structures of the Cancéropôle: coordination of a new axis "Health Technology" in the frame of the *Cancéropôle Grand Sud-Ouest*, supported by INCa, participation to the scientific committee (council) *Collège Recherche* of the IUCT (*Institut Universitaire du Cancer de Toulouse*).

2.1.2 Scientific Challenges

The ALIVE scientific taskforce structuring the research activity will be continued and oriented towards new scientific challenges.

Molecular engineering processes enabling the manipulation of single DNA molecules inside confining nanochannels or through capillary assembly and transfer printing will be developed with the ambition to analyze chromosomic DNA extracted from a very small number of selected cells. A challenge will be to perform the detection of genetic or epigenetic marks at the level of a single cancer cell.

In **Cellular engineering,** two main routes will be intensively developed. In the first one, the idea is to sort individual cells based on the expression of specific biomarkers on their external membrane, on their dielectric properties, their size or their mechanical stiffness. This sorting can be achieved in-vitro inside dedicated fluidic devices but will be also performed directly in-vivo, by the development of original devices of cell capture, mounted on medical catheters inserted in the blood stream. Some applications will target the quantification of CTCs (Circulating Cancer Cells) in blood for the prognostics of prostate cancers and for the monitoring of cancer therapies. We will also target the fabrication of miniaturized in-vitro cell assays for investigating and quantify genotoxicity effects. In the second route, the mechanics of individual cells and cell agglomerates will be investigated by means of engineered devices. One of the most important challenge in this field will be to generate original devices and structures rendering the measurement of cell forces and stiffness while the cells are confronted to a 3D micro-environment and not simply in adhesion on a 2D surface, as done currently. This requires advanced fabrication schemes capable to reach the third dimension in link with the EquipEx project LEAF. Some aspects of basic mechanisms of biology such as migration, mechanosensing and morphogenesis will be investigated in collaboration with biologists in 3D models of tissues or in 3D models of Extra-cellular matrixes (ECMs). New projects aiming at fabricating on-demand, 3D models templates for tissue engineering, by additive fabrication, will be developed and validated through collaborations with clinicians.

In combination with molecular engineering and cell sorting, the main challenge in the area of **biodetection devices** will concern their integration inside complete fluidic systems for producing portable medical diagnosis devices of high sensitivity, low cost and fast response-time. A typical objective will be, for example, to integrate on a single device, blood filtration, the pre-concentration of rare biomarkers, and their detection with a limit of detection, well beyond 1ng/mL of blood. Circulating DNA, proteins, exosomes, are typical targets that will be used for validating these processes. Digital microfluidics manipulating biphasic fluids inside confining channels will open new perspectives in the processing (sorting and analysis) of individual cells or for achieving biochemical reactions and assays inside a train of droplets. This technique, coupled to cell sorting methods offer very interesting applications for the diagnosis of various pathologies.

Biology offers inspiration for the assembly of new materials, devices and systems with biomolecules. Among promising **bioinspired technologies**, DNA technologies will be developed to create multi-scale and multifunctional nanostructures with hierarchical order. On the other hand, by coupling nanotechnologies with synthetic biology we will develop some technological hybrid processes where functional membrane proteins (ion channels) will be integrated over a silicon microfluidic and electric device, for screening drug molecules targeting these channels.

Modeling activities of biological interactions and biological systems will be intensively continued and extended towards the simulation of bio-inspired technologies (like DNA tech) and hybrid systems. Calculation tools will use existing methods but new ones specifically tailored to biological and hybrid systems and displaying fast computing time, will be developed. The approach derived from robotic motion into dynamical environments, for modeling molecular motions and interactions, will be further developed. The main focus will be the development of high-performance, atomic resolution, simulation techniques for providing a new research tool in the field of structural biology.

LAAS-CNRS owns a large range of resources and skills in engineering sciences, quite unique in Europe, from robotics to nanotechnologies. Our resolution to couple these sciences with life sciences will enable LAAS researchers to address original problems with totally new approaches, as attested by the current dynamics of ALIVE. We will strengthen even more this interdisciplinary orientation in the next period by encouraging ALIVE projects involving several scientific themes of the lab and also by involving new disciplines that are still not yet included. It is clear for us that one of the most challenging transverse project of LAAS will be to **BIOLOGIZE** systems, by the convergent involvement of nanotechnologies, information and telecommunication sciences, robotics and energy. This is the big challenge our laboratory wants to address in the near future by the complementary actions of our three strategic axes.

2.2 ADREAM

2.2.1 ADREAM as a Framework

For the coming years the research, developments and experiments in **ADREAM** will rely on a interdisciplinary scientific program aiming at designing, implementing, deploying and assessing intelligent dynamic distributed cyber-physical systems (CPS).

This research will develop in particular the following aspects:

- Semantics modeling and description of complex cyber-physical systems, including design requirements and implementations and using formal or semi-formal models;
- Provision of a guaranteed quality for the applications, mainly based on integrated performance and security properties;
- Elaboration of new inter-layered architectures for autonomous mobile intelligent entities, as autonomous and interactive robots, vehicles and people, for new services on request and pro-active capabilities;
- Acquisition, characterization and management functions able to understand, analyze and control the distributed mobile sensors and actuators to provide machine-to-machine communications and to fulfill the system specifications;
- Investigation and development of techniques to program, deploy and exploit generic ambient intelligence systems, in particular by integrating networked autonomous robots and devices (including dedicated sensor networks) and humans, in order to deploy collaborative activities and assistive services to the human users of the considered environment;
- Study and consideration, at the design level and when deploying the system, of users, as well as societal acceptance, privacy and legal issues.

Working groups and road-mapping activities: We will commit to maintain a permanent and open initiative for investigating potential applicability of our contributions.

We will seek to develop effective and concrete objects for collaborative work between LAAS research teams and also as framework to further develop collaboration locally and at national, European and international levels.

An example of such activity is SYCYPH (Multidisciplinary design of cyber-physical systems). This new working group of the RTRA STAE addresses the future generation of embedded systems, largely distributed, autonomous, dynamic and adaptive. It will deal with the anticipated new scales of design difficulty, at all levels, technical, economic, legal and human which require taking into account all respective scientific, regulatory, economic and social constraints. The working group will gather multidisciplinary teams of experts.

This project will undertake an initial work in this field by providing a structure for a global thinking and a design convergence. It will also study and analyze the basis a global design methodology able to integrate the main approaches being currently developed in the corresponding different domains in order to organize, for future complex cyber-physical systems, the needed multidisciplinary collaboration between TIC, SHS, Economy and Law.

Other initiatives will be launched at various levels and particularly in the H2020 framework.

2.2.2 ADREAM as a Context & a Set of Tools

We are also developing ADREAM within concrete contexts: indoors and outdoors.

1) Concerning **indoor** applications, we are considering the workshop of the future, the home or the public space of the future. The Georges Giralt building and its equipment is a pertinent place for such context.

For instance, we plan in the near future to implement results from the FP7-SAPHARI project (the teammate robot collaboration with workers in a workshop), the FP7-SPENCER project (a robot guide which will be ultimately deployed at Schiphol airport), and the assistive robot (for fragile persons in ANR RIDDLE project, situated dialog and interaction in the ANR MaRDI and ROBOERGOSUM projects). Another complementary aspect is the deployment of smart sensing devices and machine-to-machine communication standards for Health & wellness monitoring and safety monitoring.

The equipment and the developed software will also be used to perform user studies in collaboration with psychologists and ergonomics experts.

2) Concerning **outdoor** applications, we are considering and building networked heterogeneous mobile devices (e.g., rovers and UAVs) for various applications, sensors networks, fleets of autonomous or semi-autonomous vehicles and associated mobility services. This is also referred to as field robotics applications. Here also, ADREAM will develop and maintain equipment and platforms based essentially on several fully equipped rough terrain robots as well as a set of UAVs. For instance, this equipment is currently used in the framework of the PEA ACTION project and the FP7-ARCAS project. It will be also used by a new H2020 project named AEROAMS and involving UAVs interacting physically with the environment and with humans.

2.2.3 Projects and Initiatives

A number of projects dealing with the deployment and validation of CPS systems are already underway and others are under construction with local, national or European partners.

As they cover a large spectrum of contributions, each of them corresponds to an activity that fits with the ADREAM context and with a collaborative research effort including two or more partners (LAAS themes, national or European projects, direct collaboration with industry). We briefly discuss hereafter, a selected set encompassing: i) the communicating component devices and future networks, including their deployment as a software technology, ii) the development of perception, interpretation and decision-making functions, iii) the assessment (validation, verification and evaluation) of CPS functions and architectures.

Toward zero-power self-adaptive wireless sensors networks: Our long-term objective is to develop a fully cross-layer self-adaptive and energy-aware multi-mode wireless communication system able to integrate heterogeneous network through flexible MAC and PHY protocols, reconfigurable RF and antennas and energy harvesting.

This research is typically an example where co-design is crucial to achieve low complexity and energy-efficient radio. The interdependencies between all communication levels, as well as the technological limits at each level (system, algorithm, circuit and antenna, device), have to be explored.

The future WSN or M2M systems have to provide end-to-end adaptive communication systems, which can reconfigure according to the instantaneous application requirements in order to provide only the minimum required performance at minimum energy consumption. Thus, reconfigurability has to be introduced at every layer of the system, and wireless devices should be able to perform this adaptation autonomously, being energy-aware, self-adaptive communication systems. Collaboration between HOPES and RC themes (including other partners, such as IRIT lab.) just started in order to develop this cross-layer communication architecture.

Heterogeneous integration of wearable and embedded systems for remote human monitoring: We propose to develop global technological solutions for wearable and embedded systems for remote monitoring system, consisting of arrays of sensors attached to Humans to continuously monitor physical and physiological parameters, and to transmit wirelessly these data to a remote monitoring station. Then, the data is correlated, analyzed to study the overall health status of the structure and an alert is sent if necessary. A collaborative research program will be built around a technological generic kernel that is able to support different applications.

Towards the Internet of everything: We are moving to the often-cited “Internet of Things” where CPS entities (e.g., sensors, actuators, home appliances, vehicles, power-grid nodes, factories, etc.) regularly exchange data using services over the Internet.

We will elaborate new methodologies for the design and the runtime adaptability management for the Internet of everything. The goal is to manage agile service provisioning lifecycle and to create generic software that could be adapted during the design time; but also at runtime, to handle the strong dynamicity requirements for the complex systems that are cyber-physical systems. Processes based on a multi-scale approach with semantic or formal models managed with runtime autonomic computing will be explored.

We will also design network-inspired mechanisms, functions, protocols and services, within a component-based, service-oriented and ontology-driven architecture, in order to build a new generation of autonomic cloud computing and big data platform well suited for smart and dynamic environments including manufacturing, extended enterprises, healthcare, buildings, transport systems, etc.

Towards fully open, programmable and virtualized networks: Network virtualization and network programmability are key design principles for future networks. With network virtualization, multiple isolated virtual networks relying on different network architectures can coexist on the same physical network infrastructure. This enables the efficient support of diverse services, such as network programmability (e.g., according to the SDN approach) and adds flexibility to networks so that they can continuously and dynamically evolve to adapt to the changing requirements of application services and/or to changes in the operational environment.

CPSELABS project (H2020): Mastering the engineering of complex and trustworthy CPS is a key issue. Current CPS, however, are often engineered and maintained at very high cost and sometimes with unknown risks, and recent technological progress from R&D projects is not readily available to most innovators. ROB theme, jointly with Verimag, will study the use of GenoM3 (a tool to deploy functional components for embedded systems) and BIP (a formal framework for validation and verification of embedded systems) to program CPS and to formally prove that the overall system fulfills some given properties both on line (runtime verification using the BIP engine) or off line (V&V with D-Finder). IC theme will study the development of additional independent safety devices launching emergency interventions, based on a HAZOP-UML system safety analysis. IC and ROB will also carry joint work on the robustness testing of autonomous CPSs. There will be a link to the TESTNAV project carried out jointly by the two themes, which will benefit from the use cases provided by the SME partners of CPSELABS.

TESTNAV, an iC LAAS CNRS project: This project is supported by the Lab. via the Carnot contribution. It involves a collaboration between ROB and IC themes. Autonomous systems (mobile robots, intelligent vehicles, drones, etc.) must perform tasks without human supervision in a large variety of environments. Their deployment in spaces shared with humans adds strong dependability constraints, and in particular requires rigorous validation. For safety and cost reasons, these tests must be performed largely by simulation in a set of virtual worlds.

ROB and IC will team up to define and implement techniques for the automatic generation of contextual virtual worlds, such as those used in the creation of scenes for video games. The objective is to test an autonomous system in a large sample of worlds, and thus in a diverse set of situations. The related challenges include the definition of the worlds in which the system will be embedded, the stressful/dangerous features to consider, the selection criteria for the adequate test sets, the integration of the "classical" test and the worlds generations. The project will investigate these challenges by taking as an example the navigation of a mobile robot.

Perception and interpretation of human activities: The G. Giralt building will also be used as a testbed to evaluate monitoring strategies, using a network of video and audio sensors. First, we will extend and deploy works on visual tracking of people from non-synchronized videos acquired by a network of cameras: several modalities will be evaluated (RGB, RGB-D), and cooperation issues within the network will be investigated (so as to control the overlap of the fields of view, etc.). In parallel, microphone arrays will be deployed, allowing for localizing noisy targets (following the experience gained in robotic applications). Their cooperation with a moving binaural head will also be studied. Finally, visio-auditive fusion as well as the SLAM technique will be investigated in order to update the state of the dynamic system made of all detected persons or objects. Our work in the ADREAM context will also concern the design and implementation of smart sensors, integrating advanced communications, time management and dedicated computations.

Teams of autonomous cooperative systems in large-scale applications: Within the scope of field robotics applications, researches on models, algorithms and architectures for distributed systems operating in uncertain environments and under communication constraints will be pursued. These researches span a wide spectrum of topics, which range from data fusion (e.g., for situation assessment functions of localization) to decision-making (e.g., to allocate tasks or optimize the achievement of given, missions), and they will all be embedded and studied in a distributed context. Communications play here a crucial role, as on the one hand, they impose constraints on the systems evolutions within space, and on the other hand, the system itself constitutes an essential part of the communication infrastructure. This role is all the more crucial that most of the considered missions are information-centered, and come down to gather data in the environment. Communication tasks need then to be explicitly modeled and planned: this induces spatiotemporal constraints, that the decision-making algorithms has to deal with, and of course impacts the design of the systems decisional architecture.

This research will be supported by various on-going and starting projects:

- The PEA ACTION (DGA), in which scenarios involving up to 9 robots (3 UAVs and 6 UGVs) in a patrolling and target tracking task must be demonstrated.
- The SkyScanner project (RTRA STAE), aiming at deploying fleets of enduring drones to probe atmospheric phenomena within clouds.
- The AgriDrone project (FUI), within which we will study the cooperative observation of crop fields by a team of drones.

Towards autonomous robots in ambient systems: A number of projects and collaboration agreements are under construction. For instance, we plan to investigate and experiment new devices to be developed and deployed to provide various services to the public: including fleets of mobile and flying indoor robots for public spaces and/or industrial applications such as the workshop of the future. Collaboration has started and will be developed with psychologists (particularly from CLLE lab. of UT2J) to investigate fundamental and practical issues of human-ambient system interaction, the first common work involving user-studies and human-robot joint action.

2.3 SYNERGY

2.3.1 Introduction

Given the proven impact of energy related activities on climate changes, European community has committed to the so-called “3 times 20” strategy by 2020 horizon (H2020): 20% reduction of green house gas, 20% improvement in energy efficiency and 20% increase of renewable energies. These requirements are the driving forces for a drastic modernization of the electricity delivery system, also called Smart Grid.

Indeed, the electric energy industry is undergoing the same sort of fundamental change that has already transformed telecommunications and computing with a multitude of telecom providers offering a wide variety of wired and wireless options and services. Large-scale changes to the power system can take decades to put in place, but it is timely to envision what this Smart Grid should look like in 2030 and beyond.

These drastic changes, also called Third Industrial Revolution[3], require complex and powerful technologies where Information and Communication Technologies (ICT) are central key enablers.

The main disruption is the move from a centralized generation of energy towards a distributed one with a large deployment of renewable energies that is one of the three goals of H2020. In this context, the consumers are becoming energy providers, or prosumers, thus paving the way of a new economy model in the field of energy.

To set up this new energy network, or Internet of Energy[4], bidirectional, real-time information data are needed to guarantee the stability of the grid, its safety and quality of service. To provide these data, Internet of Things (IoT) or Cyber-Physical Systems (CPS) will constitute a central technology with critical challenges such as low-power autonomous wireless sensors, powerful real-time algorithms for diagnostic and control/command, big data management, ensuring security, safety and security as well as privacy, all these tasks being “autonomically” performed.

LAAS-CNRS, ICT-centered Lab. covering most of the aspects of the field from hardware to software, had already anticipated these needs by putting in place an ambitious research program, ADREAM focused on Cyber-Physical Systems and Energy.

ADREAM project was funded by the last *Contrat de Projets État-Région 2007-2013*. Within this framework and with the support of the French State, *Région Midi-Pyrénées*, EU via its FEDER program, *Toulouse Métropole* Urban Community and CNRS, LAAS-CNRS has imagined and setup an experimental building, named *G. Giralt*, that includes 100kWp photovoltaic energy production system, battery storage and geothermal heating/cooling. This building that can be considered as a microgrid, is also a real “living lab” where human behavior and its impact on energy usage has to be taken into account since the energy will be consumed by the actual users of the building.

The *Georges Giralt* energy platform is meant to be an open platform dedicated to cooperative research and LAAS-CNRS is member of FEDESOL, FedPV (linked to IPVF institute) and SH2D (*Système Habitat & Habitant*) national research federations as well as of DERBI competitive cluster. At the international level, within CNRS LIA Next-PV, we are starting a cooperation with the Tokyo Institute of Technology in Japan and the support of their Environmental Energy Innovation (EEI) building.

[3] J. Rifkin, The third industrial revolution. *Engineering & Technology*, 2008, vol. 3, no 7, p. 26-27.

[4] O. Vermesan et al, Internet of Energy – Connecting energy anywhere anytime, Advanced Microsystems for Automotive Applications, 2011 – Springer.

The technologies and systems that have to be deployed in this context require smart energy management at very different scales ranging from the energy autonomy of wireless sensors dealing with milliwatts to hundreds of kilowatts in a microgrid or even megawatts in a smart grid.

To tackle these multi-scale energy challenges, multidisciplinary competences are required: new materials for innovative photovoltaic solar cells, harvesting devices or very low-power electronics, advanced power electronics with improved efficiency and control as well as smart energy management systems. Many of these competences are already available at LAAS-CNRS and several projects were successfully carried out as detailed in ADREAM Transverse axis activity report. However, most of these projects were independently developed without a real common vision.

To build such a common vision, we have worked on the definition and proposal of a new transverse axis called SYNERGY for “*SYstems for smart eNERGY management*” aimed at developing *original building blocks for smart energy management*, both at hardware and software levels. To describe these transverse research activities, we will organize them in three main topics:

- Efficient energy generation and processing
- Integration of renewable energies
- Smart energy management

2.3.2 Efficient Energy Generation & Processing

Efficient energy generation and processing are essential to provide high-performance green energy, on the one hand and to build the future low-power ubiquitous electronics that will provide the data, on the other hand.

To increase the part of renewable energies within the power grid, it is necessary to improve their conversion efficiency. To this aim, we focus our efforts on emerging photovoltaic sources, organic-based on the one hand and III-V based on the other. The first ones have the advantage of a low thermal budget and then a low cost. The latter allows providing very high efficiency for applications such as concentrated photovoltaics based on multiple junction solar cells (MJSC) that has rapidly progressed from a proven space technology to become a feasible clean energy technology.

Regarding organic-based photoconversion, we are working on the so-called “bulk-heterojunction” solar cells. Our studies focus on the impact of the interfacial electronic interactions on the energetic aspect of the photo-conversion process in organic materials. As ageing is one of the major issues of organic solar cells, in partnership with LAPLACE, LCPQ and LCC laboratories within IDEX Transversalité project (“Dessine-moi OPV”), we will study small molecules whose intrinsic properties should allow increasing lifetime.

For III-V solar cells, the stacking of multiple junction solar cells (MJSC), also called tandem photovoltaic cells, enables to efficiently collect the generated photocurrent from a wide electromagnetic spectrum. Within the framework of “*SolCell*“ EURAMET European project, we propose to take advantage of our strong expertise in molecular beam epitaxy (MBE) nanostructures to develop new III-(BiAsSbN) alloys to further improve III-V MJSC efficiency in the infrared range but also to exploit new physical concepts for the photovoltaic conversion such as high-performance tunnel junctions.

The future smart grid and many other applications will require large-scale deployment of smart sensors for real-time sensing of numerous parameters (temperature, irradiance, power consumption, etc) for its autonomic operation. In many cases, it could be advantageous for these sensors to be wireless. However, one strong roadblock is their energy autonomy: for both cost and environmental issues, it is inacceptable to change the dead batteries of hundreds of wireless sensors. An alternative solution consists in harvesting energy from the surrounding environment in combination with low-power energy management to extend the battery life or even to suppress it. Research activities range from ultimate nanoelectronic devices with drastic energy efficiency to new harvesting and storage devices and strategies.

III-V nanowires will be studied and explored to integrate ultra low-power nanoelectronics based on gate-all-around transistor architecture to reduce both the power supply and the off-current, on the one hand and to investigate new concepts of efficient energy harvesting, such as thermoelectricity, on the other.

RF energy harvesting techniques are based on capturing ambient RF energy source that is converted in DC using generally a rectenna (microwave rectifier and a RC low-pass filter serially connected with an antenna through a matching network). The major challenge is to provide high-efficiency design with an ultra-compact footprint and ultra-wide or multi-band behavior. These activities will be carried out with the framework of a R&T CNES project and European COST project (WIreless Power Transmission for Sustainable Electronics, Oct 2013 - Sept 2016)

Various energy management strategies and architectures taking advantage of the available energy in the environment will be modeled and developed to maximize the energy harvesting efficiency. This includes using innovative organic solar cells for energy harvesting under low irradiance conditions in the building, acoustic noise or thermal gradients in industrial environments. For battery-free architectures, with the development of high-energy density microsupercapacitors combined with adaptive storage approaches and efficient energy management, we expect to almost reach the infinite autonomy of wireless sensors. These activities will be developed within CORALIE (*Investissements d'Avenir*), SMARTER (European CHIST-ERA) and MIDISTOCK (FP7) projects.

2.3.3 Integration of Renewable Energies

Probably the greatest challenge of the 21st century energy economy lies in low-cost and efficient electricity generation and utilization from clean distributed renewable energy generators. Many experts believe that photovoltaic generation may become the dominant source for renewable clean electricity production in the near future. Within this context, the major challenge concerns the efficient integration and utilization of electricity produced from this renewable source. Nowadays, this renewable energy is fed back to the main utility AC grid using solid-state power inverters. A much more attractive and cost-effective alternative is to directly use the DC electricity produced by the renewable energy generator since a majority of house-hold electrical loads are DC-powered. This is particularly interesting for the lighting application since it will migrate from incandescent bulbs to solid-state technology within the next decade.

In cooperation with LAPLACE laboratory, we propose to envision the HVDC grid of future buildings dedicated to lighting (LED, OLED) and to develop the associated power systems together with their control and management. The first experimental validation will be implemented in the *G. Giralt* building.

An important drawback of distributed renewable energies is their intermittency. To cope with this issue, efficient energy storage is the solution to minimize grid disturbances as well as energy cost. Power electronics are expected to play an essential role in interfacing battery energy storage systems to the grid. In particular, bidirectional battery chargers and solid-state transformers are key components. Based on the acquired expertise in a previous project (ANR LiPV), we will work on the architecture of such energy storage systems and their related battery management systems at the scale of *G. Giralt* building microgrid.

Another key enabler for improving the efficiency and the lifetime of photovoltaic generators is advanced power electronics. Over the previous period, we have demonstrated the significant performance improvement of distributed converters compared to a single centralized one. We will continue to work on these distributed architectures by also taking into account the benefits of wide bandgap semiconductors and developing advanced control and command for efficient, high-lifetime PV generation.

2.3.4 Smart Energy Management

While distributed generation is already taking hold in many places, a new vision of the power grid emerges (ElectriNet[5], Internet of Energy[4]) as a highly inter-connected and interactive network of power systems that also combines telecommunications, the Internet and e-commerce. The objective of this so-called Smart Grid is to provide to the consumers a highly reliable, flexible, resilient, efficient and cost effective power supply network enabling the full deployment of distributed renewable power sources in combination with large centralized generators.

Within this context, LAAS-CNRS is willing to put in synergy its various competences to tackle the challenges of Smart Grid and provide the generic building blocks for smart energy management.

The control of a smart grid or a microgrid including a large part of distributed renewable sources requires automated energy management so that real-time data are converted to information fast enough and problems

[5] https://www.nae.edu/Publications/Bridge/TheElectricityGrid/18870.aspx.

are diagnosed instantly, corrective actions are identified and executed dynamically in the field and feedback loops provide metrics that verify that the actions are producing the desired effects. The main objective of this optimized control is to significantly reduce the energy consumption by adapting in real-time the load to the available energy. To this aim, grid modeling is a key enabler. It will allow designing and sizing the envisioned grid, predicting ahead of delivery up to real-time the output production of a massive amount of volatile, intermittent generators and the demand of many flexible electricity consumers, whereas monitoring in real-time the ageing of present electricity materials and cost-efficiently signal predictive maintenance times.

A first ambition is to federate all the required competences to setup and integrate a generic heterogeneous simulation platform for the modeling and the optimization of the energy management of a microgrid. This includes developing the following building blocks:

- Efficient and predictive modeling of energy production (PV) and consumption.
- Energy storage modeling.
- Co-simulation.
- Dynamic thermal model of building (collaboration with **PHASE** laboratory, SH&HD federation).
- Optimized/smart energy management strategies of demand-response-storage using:
  - efficient management of multiple sources of energy;
  - discrete and continuous optimization;
  - planning and scheduling algorithms;
  - efficient service access based on standardized machine-to-machine (M2M) communication;
  - autonomic distributed management of energy consumption aware of human activities and behaviors.

The main objective is the development of generic building blocks and approaches that will be validated in a first step on *Georges Giralt* building microgrid with the ambition to extrapolate them at a larger scale.

To this aim, LAAS-CNRS is involved in neOCampus project launched by UT3PS, to implement these concepts at the scale of a university campus in cooperation with CIRIMAT, IRIT, LAPLACE and PHASE laboratories.

Moreover, the global management of energy, and more generally, of future smart grids will involve more and more complex and open interconnected systems. Such systems have to be highly available and may be subject to malicious attacks. Analysis of system availability as well vulnerability to external attacks will be required in order to provide confidence.

Finally, it has to be noted that the future smart grid cannot be devised without integrating the evolution of transports towards full electrification. For example, managing the on-board energy of a long-range airliner raises similar challenges as a microgrid does and approaches developed in this latter context might be adapted. Moreover, we have to imagine a world with only electric vehicles requiring to be regularly recharged. Although they can be considered as a very disturbing load for the grid, they can also be viewed as a huge distributed energy storage that could help managing peak demand on the grid. Long-term work will take into account this feature as well as new energy economy models.

Le LAAS est un laboratoire de recherche du CNRS dans le domaine des Sciences et Technologies de l'Information, de la Communication et des Systèmes. Il est associé à cinq établissements d'enseignement supérieur de l'Université Fédérale Toulouse Midi-Pyrénées : l'Université Toulouse 3 Paul Sabatier, l'Institut national des sciences appliquées, l'Institut national polytechnique de Toulouse, l'Université Toulouse 1 Capitole et l'Université Toulouse Jean Jaurès. Il est labellisé institut Carnot depuis 2006.
Il regroupe environ 700 personnes (chercheurs, enseignants-chercheurs, doctorants, post-doctorants et ingénieurs, techniciens et personnels administratifs).
Ses recherches sont menées au sein de 22 équipes réparties en 8 thèmes scientifiques dans 4 champs disciplinaires :

- Informatique : Informatique critique, Réseaux et communications ;
- Robotique ;
- Automatique : Décision et optimisation ;
- Micro et nano systèmes : Hyperfréquences et optique : de l'électromagnétisme aux systèmes, Nanoingénierie et intégration, Micronanobiotechnologies, Gestion de l'énergie.

LAAS is a laboratory of the French National Center for Scientific Research (CNRS), within the department of Information and Engineering Sciences and Technologies. It is associated to University of Toulouse. The lab is labelled «Carnot Institute» since 2006.
It hosts about 700 people (research scientists and faculty members, PhDs, postdocs and engineers, technicians and administrative staff).
The topics cover the following areas:

- *Computer science: Crucial computing, Networks and communications;*
- *Robotics;*
- *Automatic control: Decision and optimization;*
- *Micro and nanosystems: Microwaves and optics: from electromagnetism to systems, Nano engineering and integration, Micro nano bio technologies, Energy management.*

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