Inria, Evaluation of Theme Modeling, Optimization, and Control of Dynamic Systems

Project-team Non-A

March 26 – 27, 2013

Project-team title: Non-Asymptotic estimation for online systems
Scientific leader: Jean-Pierre Richard
Permanent head: Wilfrid Perruquetti
Research center: Lille Nord Europe
Common project-team with: École Centrale de Lille, CNRS, Université de Lille 1

1 Personnel

Personnel (March 2009 - ALIEN)

<table>
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<tr>
<th>Personnel (March 2009 - ALIEN)</th>
<th>Misc.</th>
<th>Inria</th>
<th>CNRS</th>
<th>University</th>
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(1) Senior Research Scientist (Directeur de Recherche)
(2) Junior Research Scientist (Chargé de Recherche)
(3) Civil servant (CNRS, Inria, ...)
(4) Associated with a contract (Ingénieur Expert or Ingénieur Associé)

Personnel (March 26 – 27, 2013)

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<th>Personnel (March 26 – 27, 2013)</th>
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Changes in staff

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Comments: Misc. = +1 Inria secondment (from U.Bourgogne). Inria = +2 CR recruited. CNRS = −1 DR retired, −1 CR leaving. Univ. = −1 As.Pr. leaving (Lille 1), +1 As.Pr. associated (ENSAM). Not mentioned: 1 promotion As.Pr. to Pr. (Lille1).

Current composition of the project-team (March 26 – 27, 2013):

Members
- Belkoura Lotfi, Prof. Lille 1, LAGIS
- Efimov Denis, CR1 Inria, LAGIS
- Floquet Thierry, CR1 CNRS, LAGIS
- Perruquet Wilfrid, Prof. EC Lille, LAGIS, Permanent head
- Richard Jean-Pierre, Prof. EC Lille, LAGIS, Scientific leader
- Zheng Gang, CR1 Inria, LAGIS

Associate Members (with the year of their arrival)
- Barbot Jean-Pierre, Prof. ENSEA Cergy, ECS-lab (2006)
- Gibaru Olivier, Prof. ENSAM Lille (2007)
- Join Cédric, Assist. Prof. Univ. Nancy, CRAN (2005), Manager AL.I.E.N.–SAS
- Mboup Mamadou, Prof. Univ. Reims, CReSTIC (2005)
- Riachy Samer, Assist. Prof. ENSEA Cergy, ECS-lab (2008)
- Thiery Stéphane, Assist. Prof. ENSAM Lille (2009)

PhD students
- Bernuau Emmanuel, PhD std. EC Lille (Sept. 2010 – 2013)
- Guerra Matteo, PhD std. EC Lille (Sept. 2012 – 2015)
- Maalej Sonia, PhD std. Lille 1 (Sept.2011 – 2014)
- Mincarelli Diego, PhD std. Inria (Sept.2010 – 2013)
- Oueslati Marouene, PhD std. ENSAM (Sept.2009 – 2013)

Post-Doc and Non Permanent Fellows
- Delpoux Romain, PhD 2012, ATER Lille1 (01/09/12 – 31/08/12)
- Estrada Antonio, Post-Doc Inria (15/10/12 – 14/02/14)
- Polyakov Andrey, Post-Doc Inria (01/05/12 – 01/05/13)

Engineers
- Palos Ladeiro Jorge, Engineer, Inria ADT SLIM (02/01/2013 – 31/12/2013)
- Jin Xin, Engineer, EC Lille-Sysiass project (02/01/2013 – 31/12/2013)
- Qiu Zhaopeng, Engineer, EC Lille-Sysiass project (02/01/2013 – 31/12/2013)

External Collaborators
- Hetel Laurentiu, CR1 CNRS, LAGIS
- Kökösy Annemarie, Assist. Prof. ISEN Lille, LAGIS
- Kruszewski Alexandre, Assist. Prof. EC Lille, LAGIS
Current position of former project-team members (including PhD students) during the March 2009 - March 2013 period:

NB: The former position and corresponding period are given in italics.

- Bejarano-Rodriguez Francisco, Post-Doc 01/10/10 to 30/09/11: Assist. Prof. SGSR, National Polytechnic Institute (IPN), Mexico City
- Delpoux Romain, PhD std, 01/10/09 to 22/11/12: ATER Post-Doc U. Lille 1, LAGIS & Non-A
- Fliess Michel, DR CNRS, LIX, Scientific leader of ALIEN: Retired (DR Emeritus), Manager of the AL.I.E.N-SAS spin-off (http://alien-sas.com)
- Ibn-Taarit Kaouther, PhD std 15/11/08 to 31/12/10: Assist. Prof., Ecole Nat. d’Ing. de Monastir, Tunisia
- Jacquelin Lucie, shared Engineer –Inria FUN–, 15/10/2010 to 14/10/2012: Engineer at SOPRA Rennes
- Liu Dayan, PhD std 01/09/08 to 17/10/11: Post-Doc Fellow, KAUST, Saudi Arabia
- Ollivier François, CR CNRS, LIX, Member of ALIEN: CR CNRS, LIX
- Rios-Barajas Hector, PhD Internship 01/09/12 to 30/11/12: PhD std UNAM, The National Autonomous University of Mexico
- Sauter Pierre, Post-Doc 01/01/08 to 31/07/09: Unknown, no more contact
- Sédoglavic Alexandre, Assist.Prof. Lille 1, Member of ALIEN: Assist. Prof. Lille 1, LIFL
- Sert Hugues, PhD std, 01/10/09 to 11/01/13: Engineer, EOS Innovation, 7 rue Montespan, 91000 Evry, France
- Tiganj Zoran, PhD std, 01/09/08 to 08/11/11: Post-Doc Fellow, Dept. of Neuroscience, Brown Univ., Providence, Boston, USA
- Yangui Rahma, Engineer, 01/09/09 to 31/08/11: PhD std, centre IFSTTAR Lille, Villeneuve d’Ascq

Last Inria enlistments

- Efimov Denis, recruitment Inria CR1 01/09/11, today CR1 (HDR 28/11/2012)
- Zheng Gang, recruitment Inria CR2 01/09/09, today CR1

Other comments

The researches of Non-A have been partly initiated in the framework of ALIEN and we shortly recall the story here.

- From ALIEN to Non-A

After being initiated by Michel Fliess as a team in 2005 (Inria-Futurs in Saclay), ALIEN jumped from 51 to 10 members in 2006 by integrating colleagues from Lille. It became a project-team on July 1st, 2007, the scientific leader of which was Michel Fliess, while Jean-Pierre Richard was the “permanent head” in charge of the Lille’s side2.

1 Cédric Join and Mamadou Mboup are two of the scientific founders of the ALIEN/Non-A’s ideas. The other associated members joined ALIEN between 2007 and 2009.
2 Note that ALIEN was bi-localized, Mamadou Mboup being in charge of the Saclay’s side.
met his first evaluation committee in March 2009, recruited its first Inria researcher in September 2009 (Lille), and was reconducted for 4 years in January 2010.

Because of Michel’s retirement, ALIEN gave rise to the new Inria research team Non-A on January 1st 2011, which became an Inria project-team on July 1st 2012.

The researches developed by Non-A are within the continuity of ALIEN in what concerns the algebraic tools that are developed for finite-time estimation purposes. However, Non-A also aims at developing complementary estimation techniques, still aiming at the finite-time performance but based on the concept of homogeneity and giving rise, for instance, to higher-order sliding mode algorithms.

Last, let us mention that Non-A is localized in Lille but there was no question of removing the scientific founders who initiated many of the ideas developed in ALIEN and, now, in Non-A. Besides, some other colleagues also closely contribute to our activities. For these reasons, Non-A includes several associated members, the arrival year of which are mentioned in the above lists.

• About the evaluation period of Non-A
Considering the above administrative and scientific arguments, it was decided to evaluate our activities over a ‘classical’ 4-year period. This is why we have described our activities starting from the ALIEN’s evaluation of March 2009.

2 Work progress
2.1 Keywords
• automatic control, signal processing,
• numerical differentiation, identification, estimation, observer, control,
• non-asymptotic techniques, finite-time convergence,
• algebra, operational calculus, homogeneity, higher-order sliding-modes,
• delay systems, impulsive/switched systems, nonlinear systems, model-free control,
• networked robots, nano/macro machining, multicell chopper, i–PID for industry.

2.2 Context and overall goal of the project
2.2.1 Motivations
For engineers, a wide variety of information is not directly obtained through measurement. Some parameters (constants of an electrical actuator, delay in a transmission...) or internal variables (robot’s posture or torques, localization of a mobile...) are unknown or are not measured. Similarly, more often than not, signals from sensors are distorted and tainted by measurement noises. In order to simulate, to control or to supervise processes, and to extract information conveyed by the signals, one often has to estimate parameters or variables.

Estimation techniques are, under various guises, present in many parts of control, signal processing and applied mathematics. Such an important area gave rise to a huge international literature that cannot be summarized here. However, from a general point of view, the performance of an estimation algorithm can be characterized by three indicators:

• Indicator 1: The computation time. Here, we mean the time needed for obtaining the (accurate-enough) estimation. Indeed, estimation algorithms should have an as small as possible computation time in order to provide fast, real-time, online estimation for processes with fast dynamics (for example, a challenging problem is to make an Atomic Force Microscope work at GHz rates).
• **Indicator 2: The algorithm complexity.** Here, we mean the easiness of design and implementation. Estimation algorithms should have as low as possible algorithm complexity, in order to allow embedded real-time estimation (for example, in networked robotics, the embedded computation power is limited and can be even more limited for small sensors/actuators devices). Another question about complexity is: can the engineer appropriate and apply the algorithms? For instance, this is easier if the parameters have a physical meaning w.r.t. the process under study.

• **Indicator 3: The robustness.** Estimation algorithms should exhibit as much as possible robustness with respect to a large class of measurement noises, to parameter uncertainties and to discretization and numerical implementation. A complementary point of view on robustness is to manage the compromise between existence of theoretical proofs versus universalism of the algorithm. In the first case, the performance is guaranteed in a particular case (a particular control designed for a particular model). In the second case, a same algorithm can be directly applied in ‘most of the cases’, but may fail in few situations.

Within the very wide area of estimation, *Non-A* addresses 3 particular theoretical challenges (see the upper block “Theory” of Figure 1):

1. Design annihilators for some general class of perturbations;
2. Estimate online the derivatives of a signal;
3. Control without sophisticated models.

All of them are connected with the central idea of designing or exploiting algorithms with the finite-time convergence property. In particular, the non-asymptotic estimation techniques (numerical differentiation, finite-time differentiators or observers) constitute a central objective of the project, explaining the name *Non-Asymptotic estimation for online systems*. Below, these 3 challenges will be shortly described in relation to the above indicators.

*Non-A* also wants to confront these theoretical challenges with some application fields (shown on the bottom of Figure 1): Networked robots, Nano/macro machining, Multicell chopper, i-PID for industry. Today, most of our effort (i.e., engineering staff) is devoted to the first item, according to the theme ‘Internet of Things’ promoted by Inria in its Strategic Plan for the Lille North-Europe research center. Indeed, WSNR (Wireless Sensor and Robot Networks) integrate mobile nodes (robots) that extends various aspects of the sensor network.

### 2.3 Objectives for the evaluation period

*Non-A* was created as a project-team 9 months ago, with the objectives we reproduce below.

• **General annihilators**

Estimation is quite easy in the absence of perturbations. It becomes challenging in more realistic situations, faced to measurement noises or other unknown inputs. In our works, as well as in the founding text of *Non-A*, we have shown how our estimation techniques can successfully get rid of perturbations of the so-called structured type, which means the ones that can be annihilated by some linear differential operator (called the annihilator). *ALIEN* already defined such operators by integral operators, but using more general convolution operators is an alternative to be analyzed, as well as defining the “best way to kill” perturbations. Open questions are: *OQ1*) Does a normal form exist for such annihilators? *OQ2*) Or, at least, does there exist an adequate basis representation of the annihilator in some adequate algebra? *OQ3*) And lastly, can the annihilator parameters be
Non-Asymptotic Estimation

Theory

3 challenges → annihilation | derivation | model-free

2 classes → model-based techniques | model-free techniques

Domains

Control & Diagnosis

Signal & Image

Applications

networked robots

nano/macro machining

multicell chopper

i-PID for industry

Figure 1: Non-A is a method-driven project, centered around non-asymptotic estimation techniques (i.e. providing estimates in finite-time), and connected to applications.

derived from efficient tuning rules? The two first questions will directly impact Indicators 1 (time) and 2 (complexity), whereas the last one will impact indicator 3 (robustness).

• Numerical differentiation

Estimating the derivative of a (noisy) signal with a sufficient accuracy can be seen as a key for numerous problems in control and diagnosis, as well as signal and image processing. At the present stage of our research, the estimation of the $n$-th order time derivatives of noisy signals (including noise filtering for $n = 0$) appears as a common area for the whole project, either as a research field, or as a tool that is used both for model-based and model-free techniques. One of the open questions is about the robustness issues (Indicator 3) with respect to the annihilator, the parameters and the numerical implementation choices.

Two classes of techniques are considered here (Model-based and Model-free), both of them aiming at non-asymptotic estimation. In what we call model-based techniques, the derivative estimation is regarded as an observation problem, which means the software-based reconstruction of unmeasured variables and, more generally, a left inversion problem\(^3\). This involves linear/nonlinear state models, including ordinary equations, systems with delays, hybrid systems with impulses or switches which still have to be exploited in the algebraic context. Power electronics is already one of the possible applications. Model-free techniques concerns the works initiated by ALIEN, which rely on the only information contained in the output signal and its derivatives. The corresponding algorithms rely on our algebraic annihilation viewpoint. One open question is: How to provide an objective comparison analysis between Model-based and Model-free estimation techniques? For this, we will only concentrate on Non-Asymptotic ones. This comparison will have to be based on the three Indicators 1 (time), 2 (complexity) and 3 (robustness).

\(^3\)Left invertibility deals with the question of recovering the full state of a system (“observation”) together with some of its inputs (“unknown input observers”), and also refers to algebraic structural conditions.
• Model-free control

Industry is keen of simple and powerful controllers: The tuning simplicity of the classical PID controller explains its omnipresence in industrial control, although its performances drop when working conditions change. The last challenge we consider is to define control techniques which, instead of using sophisticated models (the development of which may be expensive), use the information contained in the output signal and its estimated derivatives, which can be regarded as “signal-based” controllers. *Such design should take into account the Indicators 1 (time), 2 (complexity) and 3 (robustness).*

• Applications

Keeping in mind that we will remain focused at developing and applying fundamental methods for non-asymptotic estimation, we intend to deal with 4 main domains of application (see the lower part of Figure 1). The Lille context offers interesting opportunities in WSAN (wireless sensor and actuator networks and, more particularly, networked robots) at Inria, as well as nano/macro machining at ENSAM. A power electronics platform will be developed in ENSEA Cergy. Last, in contact with companies, several grants, patents and collaborations are expected from the applications of $i$–PID. Each of these four application domains was presented in the Non-A proposal:

- Networked robots, WSAN [Lille]
- Nano/macro machining [Lille]
- Multicell chopper [Lille and Cergy]
- $i$-PID for industry

In the present evaluation report, we choose to give a *particular focus on the first item* (Networked robots) which already received some development. It will be developed as the objective 4.

*The results concerning the other 3 applications fields will be dispatched into the 3 sections of theoretical objectives*, where they will be briefly presented.

• Resulting objectives of the period

In conclusion, the present report will successively present 4 objectives:

1. *More general annihilators*
2. *Non-asymptotic derivation and estimation*
3. *Model-free control*
4. *Focus on Networked robots*
2.4 Objective 1: General annihilators - Executive summary

2.4.1 Personnel - Objective 1

Members and Associate Members

- Mboup Mamadou, Prof. Univ. Reims, CReSTIC
- Perruquetti Wilfrid, Prof. EC Lille, LAGIS
- Ushirobira Rosane, Assist. Prof. U. Bourgogne, Inria secondment

Post-Doc Fellow:

- Estrada Antonio, Post-Doc. Inria

No Engineer, PhD student, nor External Collaborator on the objective.

2.4.2 Project-team positioning - Objective 1

One of the main achievements of our estimation approach is to provide closed form expressions for the desired parameters. These expressions follow from differential algebraic elimination. As originally introduced in the context of linear identifiability by M. Fliess and H. Sira-Ramírez in 2003\(^4\), the corresponding annihilators where taking the form of linear differential operators. During the last five years, some specific forms of annihilators have been considered further, leading to interesting results for numerical differentiation [MJF09, LGP11b] and more generally, to new tools in the control and the signal communities. The robustness properties of the estimators built within this algebraic framework are directly determined by the choice of the annihilators. Despite its importance, the underlying algebraic structure was however not investigated.

Note that the algebraic basis of our general problem has a longstanding history. In a few words, it concerns the annihilator of a left module on a ring, which is an ideal of the ring. In certain cases, when the ring satisfies some particular properties, such an annihilator can be nicely characterized. However, in the parameter estimation problem, for instance, no general characterization has been carried out taking into account the algebraic properties of the resulting structure (namely, the Weyl algebra structure endowed by the considered ring).

At the present time, there is no other Inria team working on this specific objective. A few research groups using an algebraic estimation approach can be mentioned: H. Sira-Ramírez (Mexico), J. Rudolph (Germany), V.F. Batlle (Spain), G. Fedele (Italy) and in France: E. Delaleau (Brest), B. D’Andrea-Novel (Mines de Paris).

Our task is to investigate algebraic properties of the systems — more precisely to answer the above presented open questions \(OQ1\) (Does a normal form exist for such annihilators?), \(OQ2\) (Does there exist an adequate basis representation of the annihilator in some adequate algebra?) and \(OQ3\) (Can the annihilator parameters be derived from efficient tuning rules?), in order to obtain general differential annihilators as explained in Objective 1. To illustrate this idea, let us start with an extremely simple example:

\[
\frac{dy(t)}{dt} = ay(t) + u(t) + \gamma_0, \tag{1}
\]

where \(a\) is an unknown parameter to be identified and \(y_0\) is an unknown, constant perturbation. Using the operational calculus (\(s\) is the Laplace variable), we get:

\[
sY(s) = aY(s) + U(s) + y_0 + \frac{\gamma_0}{s}
\]

where \( y_0 \) is the initial condition and \( Y(s) \) and \( U(s) \) are the Laplace transform of the signals \( y(t) \), \( u(t) \). Using the particular operator:

\[
s - 3 \frac{d}{ds} \in \mathbb{R}(s)\left[ \frac{d}{ds} \right],
\]

then, back to the time domain, one obtains:

\[
a = 2 \int_0^T d\lambda \int_0^\lambda y(t)dt - \int_0^T t y(t)dt + \int_0^T d\lambda \int_0^\lambda t u(t)dt - \int_0^T d\lambda \int_0^\lambda d\sigma \int_0^\sigma u(t)dt - \int_0^T d\lambda \int_0^\lambda d\sigma \int_0^\sigma y(t)dt.
\]

The proposed methods involve integral operators, but using more general convolution operators is an alternative to be analyzed (which is equivalent in our algebraic framework to look at more general sets with appropriate algebraic structure, for example the set of hyperfunctions introduced by Mikuzinski). It can be shown that such an annihilator is not unique and a natural question arises about the tuning of its parameters. Note that these operators are linear and, thus, are limited to linear objects (Linear ODE for example).

### 2.4.3 Scientific achievements - Objective 1

The annihilators considered so far belong to the ring \( \mathbb{R}(s)[d/ds] \) which can also be seen as a Weyl algebra. This has allowed us to give clear-cut answers to some of the questions raised above and a better understanding of the properties of the estimators. In particular, there exists a normal form for the annihilators (open question \( OQ1 \)), there exists an adequate basis representation of the annihilator in the Weyl algebra (open question \( OQ2 \)) and the annihilator parameters can be derived from efficient tuning rules \([UPMF11, UPMF12]\).

As a consequence, for a given set of undesired parameters in a linear ODE, we think we are about to find the minimal annihilator which generates all possible annihilators that remove the undesired parameters via some differential algebraic manipulations on the original ODE. These results made it possible to successfully apply our methods to two practical engineering situations:

- algebraic parameter estimation of a biased sinusoidal waveform signal from noisy data: it was considered the cases of one sinusoidal waveform signal \([UPMF12]\) and of three sinusoidal waveform signals \([UPMF11]\);
- application of our algebraic method for human posture estimation in the sagittal plane using the noisy signal coming from an accelerometer has been presented at the CDC’2012 \([PVM+12]\). Antonio Estrada is presently working on this topic of potentially high technological impact.

### 2.4.4 Collaborations - Objective 1

- Vincent Bonnet and Philippe Fraisse, Inria DEMAR and LIRMM Montpellier 2: we look at the estimation of the human posture in the sagittal plane using accelerometers \([PVM+12]\).
- Michel Fliess, CNRS Ecole polytechnique and AL.I.E.N. SAS, on algebraic annihilation ideas \([UPMF12]\);
- Alban Quadrat, DISCO (Inria Saclay-Île de France): our new algorithmic design of annihilators leads to some possible implementation in Maple: preliminary contacts with Alban started in 2012 in order to look at these aspects of formal computation, in relation to their Maple packages:
  - OreModules: A symbolic package for the study of linear (functional/control) systems over Ore algebras (by F. Chyzak, A. Quadrat and D. Robertz);
– Stafford: An OreModules package concerning Stafford’s theorems on Weyl algebras and their applications in systems theory (by A. Quadrat, D. Robertz).

- Hebertt Sira-Ramírez, CINVESTAV IPN Mexico City (Mx), about acceleration-based position sensor and other algebraic techniques.

2.4.5 External support - Objective 1

The main result during this period is a theoretical step and has mainly been supported by Rosane Ushirobira’s leave from October 2010 to September 2012: her salary was paid by U. Bourgogne, while Inria Lille paid U. Bourgogne for the teaching hours not carried out. From September 2012, she is on secondment at our team (remunerated by Inria Lille).

Since 15/10/12 this objective also benefits from the support of Inria with the post-doc of Antonio Estrada (Inria competitive funding).

2.4.6 Self assessment - Objective 1

[Strengths:] New exciting ideas that may lead to promising results. This part is very new, since the working plan for further development about the Weyl Algebra structure used to handle the annihilator was mentioned for the first time at the Non-A proposal submission (end of 2011).

[Weakness:] Too young activity, not much human power on this topic.

[Opportunities:]
1. The Inria secondment of Rosane Ushirobira, Assistant Professor in Mathematics (algebra) from Université de Bourgogne (Dijon).
2. Possible connection with Alban Quadrat from DISCO for the future aspects of formal computation. We already discussed about using their Maple packages, in relation with our annihilation point of view.
3. Our “accelerometer-based position sensor” is developed in relation with a leader team in human robotics (DEMAR-LIRMM). Its success may open various technological issues.

[Threats:] Rosane’s departure would deprive us of her knowledge of Weyl’s algebras.
2.5 Objective 2: Non-asymptotic derivation and estimation -
Executive summary

2.5.1 Personnel - Objective 2

Members and Associate Members (including \textit{former ones})

- Barbot Jean-Pierre, Prof. ENSEA Cergy, ECS-lab (2006)
- Belkoura Lotfi, Prof. Lille 1 LAGIS
- Efimov Denis, CR1 Inria, LAGIS
- \textit{Fliess Michel, DR CNRS, LIX, Scientific leader of ALIEN}
- Floquet Thierry, CR1 CNRS, LAGIS
- Gibaru Olivier, Prof. ENSAM Lille
- Join Cédric, Assist.Prof. UHP Nancy, CRAN
- Mboup Mamadou, Prof. Univ. Reims, CReSTIC
- Perruquetti Wilfrid, Prof. EC Lille, LAGIS
- Richard Jean-Pierre, Prof. EC Lille, LAGIS
- Riachy Samer, Assist.Prof. ENSEA Cergy, ECS-lab
- \textit{Sédoglavic Alexandre, Assist.Prof. Lille 1, Member of ALIEN}
- Thiery Stéphane, Assist.Prof. ENSAM Lille
- Zheng Gang, CR1 Inria, LAGIS

PhD students (including \textit{former ones})

- Delpoux Romain \textit{PhD std, 01/10/09 to 22/11/12, now Post-Doc ATER Lille 1}
- Guerra Matteo, PhD std. EC Lille
- \textit{Ibn-Taarit Kaouther, PhD std 15/11/08 to 31/12/10}
- Liu Dayan, \textit{PhD std 01/09/08 to 17/10/11}
- Mincarelli Diego, PhD std. Inria
- Tiganj Zoran, \textit{PhD std, 01/09/08 to 08/11/11}

Post-Doc Fellows and Engineers (including \textit{former ones})

- \textit{Bejarano-Rodriguez Francisco, Post-Doc 01/10/10 to 30/09/11}
- Estrada Antonio, Post-Doc. Inria
- Polyakov Andrey, Post-Doc. Inria

External Collaborators on the objective

- Hetel Laurentiu, CR1 CNRS, LAGIS
- Kökösy Annemarie, Assist.Prof. ISEN Lille, LAGIS
- Kruszewski Alexandre, Assist.Prof. EC Lille, LAGIS
2.5.2 Project-team positioning - Objective 2

Let us recall that the estimation is related to identifiability/observability properties, which means that the quantities to be estimated (parameters or state variables) are functions of some known quantities (measurements and controls) and of a finite number of their successive time derivatives. Moreover, concerning observation, in many practical situations the quantity to be reconstructed is simply some derivative of the output (for example the velocity when the position is measured). Such problems can be efficiently solved using numerical differentiation, which should be robust with respect to measurement noise. The problem of numerical differentiation is ill-posed in the sense that a small error in measurement data can induce a large error in the approximated derivatives. Therefore, various numerical methods have been developed to obtain stable algorithms of estimation, variously sensitive to noise and uncertainties. They can be classified in two main groups:

**[Model-free approaches]** It is the group of methods, which do not use information about the model of a system in order to estimate its internal variables or parameters. Among them, it is worth mentioning:

- Digital filtering in signal processing for numerical differentiation. In France: S. Diop, F. Chaplais... Abroad, again we can only mention a few: J. Grizzle, M.A. Al-Alaoui, C.K. Chen, J.H. Lee, C.M. Rader, L.B Jackson, R.A. Roberts, C.T. Mullis...

**[Model-based approaches]** This branch of methods uses a-priori available information about a system structure in order to estimate the system state and the model parameters. Mainly, this group deals with the design of various observers:

- Observer design in the control literature: In France: G. Besançon, Y. Chitour, A. Glumineau, C. Moog and F. Plestan, P. Rouchon and Ph. Martin, H. Hamouri, S. Ibrir, J.P. Gauthier, L. Praly... Abroad, researchers are too numerous to be all mentioned, but let us mention a few: A. Astolfi, H.K. Khalil, S.V. Drakunov, A. Krener, N. Kazantzis and C. Kravaris, J. Li, C. Qian, F. Allgöwer, I.A.K. Kupka, M. Zeitz...
- Finite-time observers have been introduced by team members in 2008 and developed for more general classes in [MMP10]. Some intermediate and new results were obtained by other teams in particular by Y. Shen (China), X. Xia (South Africa).
- Continuous-time parameter adaptation laws which are, in fact, strongly related with the nonlinear observer theory (A. Astolfi, R. Ortega, R. Marino and P. Tomei...).

Each group of these methods has its own advantages and disadvantages, and the choice of a method for estimation in a concrete application depends on available information and restrictions.

Non-A is the host of an original method for derivative estimation, which is based on the algebraic annihilators [Mbo09, FJM10, Liu11, LGP12]. These techniques require few hypotheses (the main constraint is to assume structured perturbations, which can result from a realistic approximation, or that the noise is a fast-enough fluctuating signal).

In addition, the members of the group have developed various innovative solutions for finite-time estimation and derivation (model-based and model-free algorithms). Despite of the fact that there exists a strong worldwide competition in the field of estimation
theory (in which Non-A actively competes), it is probably the only team of Inria which is oriented on a group of theoretical methods for estimation/derivation with applications to various domains of science and technology.

2.5.3 Scientific achievements - Objective 2

The team is focused on Non-Asymptotic derivation/estimation techniques in order to answer on the fixed time response constraints. In many applications, the time convergence has to be well specified and achieved (for security reasons, for example, or simply to improve the productivity: e.g., robot catching a ball in full flight, control of a walking robot between two impacts, finite-time chaos synchronization in order to reconstruct the transmitted encrypted message, etc. It is also worth highlighting that such finite-time techniques are a possible way to extend in some cases the well known separation principle, which holds for linear systems but fails in some situations for nonlinear ones: in many cases, the finite-time stability framework facilitates the proof of convergence of observer based feedback control algorithms. In addition to that, this finite-time property is a way to provide some certification of the real-time control algorithm: for this, a detailed discretization effect study should be carried on.

The results obtained by Non-A belong to both groups of derivation and estimation approaches introduced above:

[Algebraic differentiation for mono- or multi-variate signal, applications to detection, diagnosis and observation] The PhD of Dayan Liu [Liu11] has achieved an important analysis of algebraic differentiators [LGP11a, LGP11b, LGP12] with a comparison of various other differentiation techniques (higher-order sliding mode differentiators and high gain observer-based differentiators). There, differentiation was considered with regard to the time variable (1−D signal [MJF09]), but our algorithms were also considered for multivariate numerical differentiation [RMR11], i.e. the estimation of partial derivatives of multidimensional (n−D) noisy signals (such as image, video...). Applications to neural spiking detection (on EEG signals) have been considered in the PhD thesis of Zoran Tiganj [TM12, TM11] as well as change-point detection in [FJM10]. Fault detection and isolation have been considered in [MAJH12]. Algebraic (on-line) differentiation has also been shown to be a tool for state and unknown inputs estimation in [BFPZ13] as well as tire-road forces [VDNFM11].

[Algebraic approach to parametric estimation] Algebraic differentiators/observers have been applied to the estimation of parameters or internal variables [Mbo09, MJF09, RMR11]. The PhD of Romain Delpoux [Dell2] included the algebraic identification for an active magnetic shaft. Considerable efforts have also been undertaken on open problems linked with the specific structure of the underlying models. Particularly, the two issues of 1) the delay estimation of continuous-time systems, and 2) the knowledge of the active mode of a switched system at any moment, have been tackled in a unified, algebraic framework in [BRF09], where a simultaneous delay and parameter identification of continuous-time systems with structured entries is proposed, followed by various works including the PhD [Ibn10] of Kaouther Ibn Taarit [ITBKR11, BFIT+11]. Note that we also developed robust control laws for systems with estimated delays in [HDRJ11]. The estimation of switching times was further developed in [TFBP11], as well as extensions to impulsive systems [BFPZ13].

5Note that TROPICS (Laurent Hascoët, Inria Sophia Antipolis - Méditerranée) develops Automatic Differentiation tools, but from the point of view of software analysis. This differs from Non-A since our input is a signal coming from a process.
Many of our works have concerned the design of observers for complex systems: nonlinear, chaotic, delayed, hybrid, oscillatory systems, systems with unknown inputs. Our works on observability forms [ZBB09, BBBB09, YBBB11] contribute to the preliminary question of the observability. Finite-time observers are more particularly considered in [MMP10, DDFP11]. We also dealt with nonlinear observers with unknown inputs [BBF09, BFPZ13, BF10, RLGF12, MGGZ09], interval observers [EFR+12, ERCZ13, ERZ13, REZ12, SRZE13, ERZ12], observers for chaotic systems [ZB11, FBL12, ZBBB09] (with applications to synchronization), as well as hybrid systems [BGB10] (with application to multicell choppers). The PhD of Romain Delpoux [Del12] developed observer-based solutions for an efficient sensorless control of the stepper motor (i.e., without mechanical sensor, for the moment presented in ACC’12 [DBF12b] and SysId’12 [DBF12a]). Concerning observers for time-delay systems, we obtained general results for nonlinear time-delay systems [GdLB13, ZBB+11] and more particular ones for linear remote, networked-controlled systems with communication delays [KJF+12]. The recruitment of Denis Efimov drastically strengthened our skills in the area of oscillatory systems, with estimation of sinusoid signals [BEPZ12b, BEPZ12a], fault detection and isolation [EZ12]. Such questions also appear for vibrational control of industrial robots, with the machining applications considered in [OBG10]. Several finite-time solutions for estimation applying sliding-mode techniques have been obtained in [DFKP09b, DFPD09, DNFP09, FES11, GSF11].

Two classes of techniques are considered here. In what we call model-based techniques, the derivative estimation is regarded as an observation problem, which means the software-based reconstruction of unmeasured variables and, more generally, a left inversion problem. This involves various classes of state models (linear, nonlinear, delayed, switched, impulsive, chaotic, oscillatory...). Model-free techniques rely on the only information contained in the output signal and its derivatives. The corresponding algorithms rely on our algebraic annihilation viewpoint. As shown by our list of publications, both approaches lead to tractable estimators. The founding text of Non-A mentioned: “One open question is: How to provide an objective comparison analysis between Model-based and Model-free [Non-Asymptotic] estimation techniques? This comparison will have to be based on the three Indicators 1 (time), 2 (complexity) and 3 (robustness)”. We have mentioned the comparisons, achieved by Dayan Liu during his PhD [LGP11a, LGP11b, LGP12], among high-gain observer, sliding modes differentiator and Jacobi estimators. For a high-gain observer with well tuned parameters, the estimation errors in noise-free case are small. But large values for these parameters can produce large errors in the noisy case. Thus there should be some optimal tuning. The same was also observed for the two other approaches. We also noted that both algebraic differentiation and finite-time sliding mode differentiators constitute nice tools for improving state and unknown inputs estimation, as preliminary results show [BFPZ13]. However, a full comparative work has to be done, which is time and man power consuming (this may be a possible ADT subject for an engineer to implement and compare these techniques).

2.5.4 Collaborations - Objective 2

- Marc Bodson (Univ. of UTAH, Salt Lake City, USA) in the framework of the PhD of Romain Delpoux [Del12] on the observer-based control of stepper motors without mechanical sensor [DBF12b, DBF12a];

Note that this last application also corresponds to the framework of Wireless Sensor and Robot Networks to be presented as the Objective 4.
• Bernhard Beckermann, from Lille 1 University (lab. of Mathematics Paul Painlevé) for the co-supervision of the PhD thesis of Dayan Liu [Liu11] on numerical differentiation algorithms, including the comparison of the existing approaches;
• Alexy Bobtsov from Nat. Research Univ. LITMO, St Petersburg (Ru), on frequency estimation [BEPZ12b, BEPZ12a];
• Bernard Brogliato (BIPOP Inria Rhône-Alpes), Alain Glumineau (IRCCyN Nantes) and their teams, in the framework of ANR ChasLim (sliding modes);
• Emmanuel Brousseau of Cardiff University on application of new algebraic methods in tapping mode for AFM, collaboration with the National Laboratory of Metrology (LNE) located at Trappes [BKC+10];
• Mekki Ksouri, ENIT Tunis, Tunisia, on delay identification, with co-supervision of the PhD thesis of Kaouther Ibn Taarit [Ibn10];
• Ratko Magjarević, Univ. of Zagreb (Croatia) within the PHC Cogito, in relation with the PhD thesis of Zoran Tiganj [Tig11];
• Emmanuel Moulay from CNRS XLim Poitiers on finite-time estimation [MMP10];
• Yuri Orlov from CICESE, Ensenada, Mexico, on finite-time estimation of impulsive systems [BFIT+11, ZOPR11a, ZOPR11b];
• Alessandro Pisano, Univ. of Cagliari (It) in relation with the PhD thesis of Diego Mincarelli (PHC Galileo);
• Joachim Rudolph, from Saarland University (Germany) on algebraic techniques applied to magnetic devices: fault diagnosis [KMR12] and fast identification for closed-loop control [FFR10] (with co-supervision of a Master student in 2009);
• Sarah Spurgeon, Univ. of Kent (UK), on sliding mode observers [FES11, GSF11];
• Ali Zolghadri and his ARIA team of CNRS IMS, University Bordeaux I, on frequency estimation [BEPZ12b, BEPZ12a], interval state observers [EFR+12, ERZ13, REZ12] and fault-detection/diagnosis [EZ12, SRZE13].

2.5.5 External support - Objective 2

[PhD supports] These results where partially developed in the framework of various PhD theses supported by Ecole Centrale de Lille (Emmanuel Bernuau, Romain Delpoux), University of Lille 1 (Dayan Liu) and ENSAM (Marouenne Oueslati). Kaouther Ibn Taarit was partly supported by Tunisia and LAGIS-Lille 1. Zoran Tiganj was supported by Inria.

[CIFRE grants (at ENSEA)] Two PhD students with J.P. Barbot are working on finite-time estimation in the framework of CIFRE grants (PhD within industry, see http://www.amt.asso.fr/fr/espace_cifre/accueil.jsp), which shows the industry interest for these techniques: Leonardo Amet is with GS Maintenance (Champagne sur Seine) for power converter applications [AGB12]; Essaid Edjekouan started on February 2013 with SDI (Taverny) for mechatronics.

[ANR ChasLim] Jointly with BIPOP (Inria Rhône-Alpes), CNRS IRCCyN (Nantes), this ANR project runs from 1 Oct. 2011 until 30 Sept. 2015 and aims at developing a toolbox for synthesizing controllers and adequately simulating the obtained closed-loop systems. Andrey Polyakov is supported by ChasLim. More information at http://chaslim.gforge.inria.fr/

[FP7 NoE HYCON2] The work was partly supported by the FP7 Network of Excellence HYCON2.http://www.hycon2.eu/ and all our PhD students (whatever the objective) attend several modules of the associated EECI Graduate School on Control (European Embedded Control Institute) http://www.eeci-institute.eu/.
2.5.6 Self assessment - Objective 2

[Strengths:]
1. [Model-free] The obtained algebraic differentiators, according to our internal intensive testing / simulation campaigns and practical implementation experience demonstrate a rather good trade-off between the 3 above-defined indicators. The number of applications fields of these differentiators keeps enlarging.

2. [Model-based] The spreading of model-based control advances by the members of our group is confirmed by our production in the major journals, our participation to numerous TC/ IPC as well as national research networks.

[Weaknesses:]
1. [Model-free] It is still necessary to disseminate our approach on algebraic differentiators among a wider audience. In theoretical development a particular attention should be paid on the choice of structure of an algebraic differentiator (in relation with annihilation – Objective 1) and its tuning parameters, which play a central role in the numerical implementation and the noise error reduction. New differentiation schemes have to be developed taking into account various practical requirements and trade-offs.

2. [Model-based] The finite-time observers (emerged in [MMP10]) already attracted a lot of attention of scientific community the last years. New globally convergent finite-time and fixed-time observers have to be designed for uniformly observable nonlinear systems while relaxing the Lipschitz condition (on the nonlinear terms). A particular attention has to be paid to noise level reduction and parameter tuning.

[Opportunities:] Beyond finite-time, the fixed-time design aims at providing a required observation/control observation precision in a prescribed time (selected a priori) and independently of the initial state (fixed-time observation/control). Non-A is presently hosting a Post-Doc fellow, Andrey Polyakov, whose project is oriented towards this emerging research [Pol12]. Ongoing collaboration is already fruitful\footnote{A. Polyakov, D. Efimov, and W. Perruquetti. A Constructive Method for Finite Time and Fixed Time Stabilization with Application to Chattering-free Sliding Mode Control. provisionally accepted as a regular paper in the IEEE Transactions on Automatic Control.} and we are convinced there is a real opportunity for us to stabilize him at Lille... in finite or fixed time.

[Threats:] Theoretical research may lose its importance and become less supported by scientific institutions and state funding organizations (like ANR or NSF). A common focus on application-oriented investigations seems to be a right direction, since even a pure theoretical research may gain in its value by taking into account the real world constraints and requirements. However, “There is nothing more practical than a good theory” (Kurt Lewin, 1951).
2.6 Objective 3: Model-free control - Executive summary

2.6.1 Personnel - Objective 3

Members and Associate Members (including former ones)

- Belkoura Lotfi, Prof. Lille 1 LAGIS
- Fliess Michel, DR CNRS, LIX, Scientific leader of ALIEN
- Join Cédric, Assist.Prof. UHP Nancy, CRAN
- Riachy Samer, Assist.Prof. ENSEA Cergy, ECS-lab
- Thiery Stéphane, Assist.Prof. ENSAM Lille
- Zheng Gang, CR1 Inria, LAGIS

PhD students (including former ones)

- El Afou Youssef, PhD std. Lille 1/Univ. Meknes-Morocco
- Maalej Sonia, PhD std. Lille 1

External Collaborator on the objective

- Kruszewski Alexandre, Assist.Prof. EC Lille, LAGIS

2.6.2 Project-team positioning - Objective 3

Introduced by M. Fliess and C. Join (for good summarizes, see [FJ09b, FJR11]), the so-called Model-Free Control (MFC) has now a quite impressive list of successful, concrete applications in most diverse fields such as electronics, mechanics, automobile, hydroelectricity, traffic, finance...

MFC offers various advantages:
- it does not need any precise mathematical model,
- it presents a great conceptual simplicity and so, simplified parametrization,
- it exhibits a great robustness with respect to most various disturbances,
- and, very recently, MFC has been implemented on microchip, which makes it become a real alternative to the PID controller block.

Concept

Let us recall that the concept of MFC is to replace the model of the system, generally unknown, with the ultra-local model:

\[ y^{(ν)} = F + αu, \]

where

- the order \( ν ≥ 0 \) of derivation is a non-negative integer which is selected by the practitioner\(^8\);
- \( α ∈ \mathbb{R} \) is chosen by the practitioner such that \( αu \) and \( y^{(ν)} \) are of the same magnitude.

Some comments on \( F \) are in order:

- \( F \) is estimated via the measurements of \( u \) and \( y \);
- \( F \) subsumes not only the unknown structure of the system, but any perturbation;
- \( F \) is re-actualized in real-time, which means that what we call the ‘utra-local’ model (4) depicts the system’s behavior over a very short interval of time.

\(^8\)The existing examples show that \( ν \) may always be chosen quite low, i.e., 0, 1, or 2.
Intelligent controllers

Denote $e = y^* - y$, where $y^*$ is the desired output. Now, we close the loop with respect to Equation (4) via the intelligent controller:

$$u = -\frac{F - y^*(\nu) + \mathcal{C}(e)}{\alpha}.$$  \hfill (5)

Combining Equations (4) and (5) yields the functional equation:

$$e^{(\nu)} + \mathcal{C}(e) = 0.$$  

$\mathcal{C}$ should be selected so to impose the tracking error dynamic and to ensure the stability. Replacing $\mathcal{C}$ by usual proportional-integral-derivative controller $K_P e + K_I \int e + K_D \dot{e}$, we obtain the following intelligent proportional-integral-derivative controller, or i-PID:

$$u = -\frac{F - \dddot{y}^* + K_P e + K_I \int e + K_D \dot{e}}{\alpha},$$  \hfill (6)

where $K_P$, $K_I$, $K_D$ are the tuning gains. As explained in the Non-A founding text, estimation of $F$ is provided according to:

$$[F]_e = [y^{(\nu)}]_e - \alpha u,$$

where the derivative estimation $[y^{(\nu)}]_e$ is needed.

Using the results of Objective 2, we are able to estimate $F$ without differentiating the signal, according to our algebraic method for numerical differentiation [MJF09].

2.6.3 Scientific achievements - Objective 3

Results on the period

Besides the creation of AL.I.E.N. SAS (end 2011, see below), our results have been published in various domains, always associated to real-world experiments:

- control of shape-memory actuators (active spring) [GDB+11],
- car control: tire-road forces and maximum friction estimation [VDNFM11],
- control of DC/DC converters [MJF+10],
- power control of cascaded hydroelectrical dams, with EDF (Electricité de France) [JRF10, JRF10],
- control of a magnetic bearing [DMRF+12],
- traffic control, with DIRIF (Direction des Routes Île de France) [AFIJ12, AFIJ11, AFIJ11, FAIJ12].
- bank: risk management [FJ09c], option pricing and dynamic hedging [FJ09a], existence of trends in financial time series [FJ12].

International patents have been filed:

- with EDF [RLFJ10] on hydroelectrical dams, which was awarded the Innovation Prize 2010 from Ecole Polytechnique, in the “Patents” category;
- with DIRIF [AFJ11] on traffic control.

Latest results

- Based on usual stability margins, MFC has been analyzed and a new interpretation of its robustness is ready. A conference paper on this analysis has been submitted.
- According to its great simplicity and to its nature of a recursive algorithm, MFC is now implemented on microchip (like dsPIC, MFC clock rate 0.1ms). It makes it become a real alternative to PID controller block, this last still constituting the reference industrial controller. A conference paper on this subject is submitted.
2.6.4 Collaborations - Objective 3

Many people are interested by our concept, see below effective academic collaborations:

- Hassane Abouaissa, Univ. d’Artois, on traffic control,
- Brigitte d’Andréa-Novel, Ecole des Mines de Paris and Hugues Mounier, Univ. Paris Sud, on vehicle control [VDNFM11],
- Benachir Bouchikhi, Univ. of Meknes, Morocco,
- Emmanuel Delaleau, ISEN Brest, on shape-memory actuators [GDB+11],
- Jérôme De Miras, Univ. Technol. Compiègne, on magnetic actuators [DMRF+12],
- Frédéric Lafont, Université du Sud, Toulon, on greenhouse control
- Pierre Sicard and Ahmed Cheriti, Université du Québec à Trois-Rivières, on DC/DC converters [MJF+10],
- and various other colleagues working on MFC in Spain (V.F. Batlle), Italy (G. Fedele), Germany (J. Rudolph), Mexico (H. Sira-Ramírez)...

Most of activities on MFC are led in the framework of the AL.I.E.N.-SAS start-up (see below), but some works are also carried out in Lille:

- The PhD of Youssef El Afou, jointly prepared\(^9\) with the Meknes University and supported by a PHC Volubilis partnership, aims at showing how MFC applies to a greenhouse temperature control. Experimental results are encouraging and a paper is under preparation.
- The PhD of Sonia Maalej is concerned with the theoretical analysis of the robustness. It considers controller/estimator pairs, the stability and performances of which are guaranteed for the largest set of systems, with as less knowledge as possible.
- We are currently working on MFC for non-holonomic mobile robots (see page 23).

2.6.5 External support - Objective 3

[Start-up AL.I.E.N. SAS] Founded by Michel Fliess and Cédric Join, AL.I.E.N.-SAS exists from the end of 2011 and is domiciled at Nancy. It is helped by the “Incubateur Lorrain” and was awarded the “Prix OSEO, catégorie émergence” to support its creation.

[Contracts] Industrial contracts have been successfully concluded, where MFC plays a crucial rôle:

- EdF (Bourget-du-Lac): “Commande en puissance de barrages hydroélectriques en cascade” (power control of cascaded hydroelectric dams) [JRF10],
- DIRIF http://www.enroute.ile-de-france.developpement-durable.gouv.fr/: “commande des cycles de feux de 4 rampes d’accès de l’autoroute A4” (cycle control for the traffic lights of the 4 public ramps to the A4 highway),


Other contracts dealing with the problem of estimation have also been accomplished:

- EdF (Bourget-du-Lac): “Séparation des sources de puissance”,
- EdF (Bourget-du-Lac): “Estimation de débits entrants”,
- EdF (Mulhouse): “Modélisation de l’écoulement du Doubs”.

[PHC] Hubert Curien Partnership VOLEBILIS MA/09/211, Lotfi Belkoura and Benachir Bouchikhi (Univ.Meknes, Morocco) in relation with the PhD of Youssef El Afou.

\(^9\)PhD co-supervised by Lotfi Belkoura, Cédric Join and Benachir Bouchikhi.
2.6.6 Self assessment - Objective 3

[Strengths:] As previously explained and shown according to many industrial applications, the practical experimentation of MFC should be continued. It will be the case through start-up AL.I.E.N.-SAS which already received two awards.

[Weaknesses:] From a theoretical point of view, the MFC of delayed systems is a key case and needs some effort.

[Opportunities:] AL.I.E.N.-SAS has realized, thanks to VieDoc, an important market study and conclusions are clear: AL.I.E.N.-SAS is the only society to hold and control a such know-how. Through this society, Non-A has the opportunity to develop an important industrial activity.

[Threats]: Until now MFC met only industrial successes.

2.7 Focus on an applied Objective: Networked robots -
Executive summary

2.7.1 Personnel - Objective 4

Members and Associate Members

- Floquet Thierry, CR1 CNRS, LAGIS
- Perruquetti Wilfrid, Prof. EC Lille, LAGIS
- Richard Jean-Pierre, Prof. EC Lille, LAGIS
- Zheng Gang, CR1 Inria, LAGIS

PhD students (including former ones)

- Guerra Matteo, PhD std. EC Lille
- Sert Hugues, PhD std, 01/10/09 to 11/01/13

Post-Doc Fellows and Engineers (including former ones)

- *Lucie Jacquelin, Engineer, Inria ADT Sensas 15/10/2010 au 14/10/2012*
- Palos Ladeiro Jorge, Engineer, Inria
- Jin Xin, Engineer, EC Lille-Sysiass project
- Qiu Zhaopeng, Engineer, EC Lille-Sysiass project
- *Yangui Rahma, Engineer, 01/09/09 to 31/08/11*

External Collaborators on the objective

- Hetel Laurentiu, CR1 CNRS, LAGIS
- Kökösy Annemarie, Assist.Prof. ISEN Lille, LAGIS
- Kruszewski Alexandre, Assist.Prof. EC Lille, LAGIS
2.7.2 Project-team positioning - Objective 4

- **Global positioning**
  Integrating wireless sensor networks and multi-robot systems increases the potential of the sensors: Robots, in comparison, are resource-rich and can be involved in taking decisions and performing appropriate actions on themselves on sensors and/or the environment. In this area, our positioning can be done by reference to the FP7-ECO4 European project SEAL “Smart Efficient Component-based Cognitive sensor, Actuator and robot systems for everyday Life” that has been submitted on January, 15th 2013. This project concerns 3 teams in Inria Lille - Nord Europe (FUN, SequeL, Non-A) as well as partners from Greece, Serbia, Spain, Sweden and UK. It gathers wireless sensors networks, robotics, collaboration and cognition. To the best of our knowledge, SEAL is unique in addressing the main objective of developing a cognitive framework for artificial, heterogeneous, complex and multi-degree-of-freedom systems by exploiting the principles of control, optimization, component-based design, wireless networking, information processing, learning and distributed decision-making, to provide robotics systems able to evolve in an autonomous fashion and to dynamically adapt to dynamic environments.

  Collaborative robotics has experienced a little over ten years a considerable development in the world and particularly in the US, partly under the DARPA management. Most of these US projects can be classified into two categories, dealing with: 1) a collaboration of robots\(^{10}\); 2) or deployment of networks / sensors\(^{11}\). At the European Research Area, approximately 85 projects were performed in robotics during subsequent calls of ICT, only 15 of them involve collaboration robot / robot\(^{12}\) and the nearest 7 ones do not consider the network deployment (sensors are fixed with known positions, which simplifies the robot/sensor interaction). Note also that, concerning the global point of view of SEAL, it is aimed at considering cognition aspects. Among the few European actions gathering robotics and cognition, most are centered around the single robot\(^{13}\) and not on the emerging global behavior of a fleet of robots and sensors. Only 4 projects\(^{14}\) analyze cognitive collaborative models but without considering communication and relocation issues.

  Recently two projects have been launched dealing with the intersection of these two areas: 1) At EPFL (Laboratory of Intelligent Systems), the SMAVNET Project (Swarming Micro Air Vehicle Network) aims at developing swarms of flying robots that can be deployed in disaster areas to rapidly create communication networks for rescuers. 2) At MIT (Distributed Robotics Laboratory), the project “Deployment and Optimization of Wireless ad-hoc Communication Networks” develops a platform for autonomous deployment of a mobile communication backbone, which can provide networking capability to other robotic agents, sensor networks, or people). In comparison with these projects, SEAL is

\(^{10}\) Univ. of Pennsylvania; Univ. Southern California; Advanced Robotics System (ARS) - JRP / ARFL; Basic UXO Gathering System (BUGS) - AFRL; Distributed Robotics (DR) - DARPA / MTO; Software for Distributed Robotics (SDR) - DARPA / IPTO; MOBOTS (Rodney Brooks).

\(^{11}\) Man-Portable Networked Sensor System (MPNSS) - SPAWAR; Autonomous Mobile Communication Relays (CDMA) - DARPA / IPTO.

\(^{12}\) 2 projects deal with micro robots (REPLICATOR and MICRON), 4 concern underwater UAVs (MORPH, Co3 AUVs, CoCoRo and NOPTILUS), 2 are devoted to flying robots (sFLY and COMETS), the rest 7 project investigate various research/application problems for ground mobile robots. Among them, 5 projects (ARCAS, MARTHA, IWARD, DustBot and ROBOSWARM) deal with a fixed asset of sensors for transportation, area cleaning, construction or patrolling. Finally, only 2 addressed the aspects of sensor placing and adaptation (URUS and GUARDIANS).

\(^{13}\) COGX http://cogx.eu/, ROBOT-CUB http://www.robotcub.org/, PACO-PLUS, in which cognitive approaches are used to make the robot self-understand and self-extend its abilities

more fundamental and it is oriented on a combined investigation of cognitive networks of sensors, data knowledge processing and mobile robots, while the latter two projects were considering only the robotics.

- **Autonomous groups of mobile robots**
  The self deployment of autonomous groups of mobile robots in an unknown environment (including different kinds of static or moving obstacles, as other moving vehicles or robots) involves localization, path planning and robust control problems. Both the control and signal aspects of our researches are expected to solve some problems coming from — or taking advantage of — such collaboration frameworks, which includes the following aspects:

  1. *Path planning based on optimal collaborative control problem;*
  2. *Localization using as few as possible landmarks and exteroceptive information by means of derivative estimates;*
  3. *Robust, autonomous, energy-aware controllers based on either model-free or model-based techniques.*

2.7.3 Scientific achievements - Objective 4

1) **Path planning based on optimal collaborative control problem:**
   Our preliminary works on coordinated control of non-holonomic robot swarms\textsuperscript{15} \cite{DPK09,DFKP09a} have opened new feasible ways of optimizing, on-line, a collaborative path planning as well as their local control\textsuperscript{16}.

   During the period, these algorithms have been applied to the coordinated control of groups of mobile robots: An illustrative platform exhibited at EuraTechnologie(plateau Inria in Lille city) \url{http://www.inria.fr/centre/lille/innovation/plateau-inria} has been designed within the framework of Non-A. They are now being extended to medical devices (such as wheelchairs) within the European project SYSIASS, in collaboration with partners from hospital settings (\url{http://www.sysiass.eu}).

   Moreover, our pool of engineers is currently regrouping all our published results as a package of the open source ROS, see presentation of the SLIM software page\textsuperscript{26}.

2) **Localization using as few as possible landmarks and exteroceptive information by means of derivative estimates:**
   In the framework of the PhD of Hugues Sert \cite{Ser13}, we applied the differential algebra to two main issues of wheeled mobile robotics, localization and navigation \cite{SPK12}. Our localization algorithm presented at ICRA 2011 \cite{SKP11} can be worked out with one single landmark instead of 3, usually.

   The first issue was to be able to tell where the robot is in its environment. We assume that we have a number of landmarks in space whose coordinates are known in this area. Depending on the number of landmarks, it is possible or not to localize the robot. This notion of localizability has been defined and studied in the algebraic framework. We show that this framework is more interesting than the geometric one in the sense that it does not only allow for studying localizability, but also for designing state estimators which reconstruct the posture of the robot. This study was conducted in a five-case study concerning four of the five classes of wheeled mobile robots. The second problem studied is that of a robot decentralized swarm navigation in a complex environment. This work presents an architecture that can be used in a wide class of problems and enjoying the

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\textsuperscript{15} PhD of M. Defoort, 2007, \url{http://tel.archives-ouvertes.fr/tel-00196529}

\textsuperscript{16} For instance, the following paper has has been cited 65 times: Defoort, Floquet, Kókésy, Perruquetti: Sliding-mode formation control for cooperative autonomous mobile robots, IEEE Trans. on Industrial Electronics, 55(11), 3944-3953, 2008
benefits of both discrete and continuous approaches. Indeed, high-level block strategy specifies the goal, constraints and parameters as well as the cost function; A low-level block computes a trajectory which minimizes the cost function in accordance with the objective and the problem constraints. This minimization is done on a sliding window, so it is possible to take into account changes in the environment or mission during navigation.

3) Robust, autonomous, energy-aware controllers based on either model-free or model-based techniques:
[Model-based techniques:] WSAN are composed of embedded systems interconnected through unreliable communications networks. Robustness and optimization issues are to be considered in relation to usual control performance (see above), but also w.r.t. the perturbations created by this additional dynamics coming from the communication medium. We have addressed various networked situations: network-in-the-loop control (how to face the unreliability of the network?), sparse sampling control (how to reduce the number of output-data packets sent by the sensors?). These advances were achieved with ‘external colleagues’ from our LAGIS team SyNeR and use Lyapunov-based approaches (ensuring asymptotic convergence). Our main two results were: 1) to ensure the robustness w.r.t. asynchronously sampled data, packets dropouts, transmission delays... [HKPR11, KJF+12] and 2) to actively control the sampling interval so to enlarge it and avoid too frequent sensor transmissions [FHRP12].
[Model-free control:] Another ongoing study concerns the adaptation of our model-free control techniques to general non-holonomic mobile robots. For such models, one parameter of the local model has to switch according to the information from the system.

2.7.4 Collaborations - Objective 4
- FUN, Inria Project-Team at Lille (Future Ubiquitous Networks, Nathalie Mitton).
- and more generally in the framework of the CIA, FIT and SENSAS programs (see below).
- ISEN Lille (A. Kökösy is also a member of our LAGIS team), the Kent Univ., Essex Univ. as members of the Interreg IV A 2 Mers Seas Zeeën - SYSIASS.

2.7.5 External support - Objective 4

2010-2012 RobotCity] was exhibited for the first time during the opening ceremony held on April 6th, 2011, see http://team.inria.fr/non-a/RobotCity (other video at http://chercheurs.lille.inria.fr/~jrichard/manips.htm)

2010-2013 SYSIASS InterReg IV-A Two Seas 6-020-FR: Autonomous and Intelligent Healthcare System. SYSIASS aims at assisting patient’s mobility and securing the provision of communication services. An exemplar of the corresponding technology would be an intelligent wheelchair that is able to provide mobility to the patient and allows healthcare providers to transport patients to desired locations in a clinical or domestic environment. See http://www.sysiass.eu

2010-2014 CPER CIA, “Campus Intelligence Ambiante”, is a program supported by the Government, Regional Council and European FEDER, which our collaboration with the team FUN belongs to. We also start a collaboration on the Equipex platform FIT (see ‘opportunities’ at the end of this part).
2010-2014 ADT SENSAS: Our developments on WSRN take place in this national network SENSAS (SENSor network ApplicationS), which proposes robotic applications (package SENSROB) based on wireless sensor and actuator network nodes provided from the work done around SENSLAB and SENSTOOLS projects. It involves 8 Inria project-teams, see http://sensas.gforge.inria.fr/.

2012-2014 ADT SLIM. Software Library for cooperative Multi-robots is one of the “Actions de Développement Technologique” that Inria supports in Lille, see p.26.

2.7.6 Self assessment - Objective 4

[Strengths:] Networked robots is one key application of Non-A. We have successfully applied our theoretical results to the localization and control of non-holonomic mobile robots. By estimating velocities (for which other techniques do not apply), our non-asymptotical estimation techniques offer a comparable localization result with respect to conventional localization method, with less landmarks or sensors. The algebraic differentiator has also been used to identify the different types of those robots. As well, the MFC technique (model-free control) is being applied to control non-holonomic mobile robots. Moreover, there was 5 projects on this topic during the last 4 years. Those two aspects (theoretical research and implementation project) are to be highlighted and continued.

[Weaknesses:]
1. Beyond the success of our academic activities, now we feel ready for wider collaborations with industries which, despite preliminary contacts, still need to be created.
2. Even if we are well recognized in the ‘control’ community, our presence in the ‘robotics’ community is rather new, we still have to improve our visibility, for instance by increasing our participation to the major conferences ICRA [SKP11] and IROS [SPK+12].

[Opportunities:]
1. This activity is a part of the challenge Internet of Things of the Inria strategic plan at Lille Nord Europe. It benefits from the construction of the EQUIPEX platform FIT (http://www.inria.fr/en/centre/lille/news/equipex, Future Internet of Things) won by the team FUN and planning the collaboration between thousands of sensors and hundreds of robots. Indeed, future ubiquitous services require to conjugate information and action, such as in wireless sensor and actuator networks. In what concerns the many informatics aspects of wireless sensors and networks, various skills are present at Inria Lille. Fewer control/estimation skills are present. We think we can be the necessary “control and robotics ingredient” for the success of this strategic challenge.
2. Another opportunity comes from the fact that our former PhD student working in collaborative robotics, Hugues Sert, is now in charge of R&D for a small company, EOS innovation (Evry) http://www.eos-innovation.eu/eos. Depending on the success of this company, a promising collaboration in may start with our group on this topic.

[Threats:] No identified threat.

17 (except SequeL by Philippe Preux that considers complementary components in sequential learning and sensor fusion, and Orchestron by Rodolphe Sepulchre, devoted to brain rythms).
3 Knowledge dissemination

3.1 Publications

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(*) HDR Habilitation à diriger des Recherches

(**) Conference with a program committee

(†) Note that three other PhD co-supervised by members of Non-A have been defended in the framework of the LAGIS team: W.J. Jiang 2009, Z. Bo 2012, C. Fiter 2012.

Two major journals in the field and, for each, the number of papers coauthored by members of Non-A that have been accepted during the evaluation period:

- 6 Automatica (2.829)
- 9 IEEE Transactions on Automatic Control (2.110)

Other journals:

- 1 SIAM Journal on Control and Optimization (1.518)
- 2 Systems & Control Letters (1.222)
- 3 International Journal of Robust and Nonlinear Control (1.554)
- 2 IEEE Transactions on Control Systems Technology (1.766)
- 2 IEEE Transactions on Industrial Electronics (5.160)
- 1 IEEE Signal Processing Letters (1.388)
- 3 Control Engineering Practice (1.481)
- 4 International Journal of Control (0.977)
- 1 Chaos, Solitons & Fractals (1.222)
- 3 IET Control Theory & Applications (0.990)
- 6 Nonlinear Analysis: Hybrid Systems (new journal, no impact index by ISI yet)
- 1 Applied and Computational Harmonic Analysis (3.452)
- 2 Numerical Algorithms (1.042)
- 1 Robotics and Autonomous Systems (1.056)
- 1 Robotica (1.032)
- ...

Major conferences in the field and, for each, the number of papers coauthored by members of Non-A that have been accepted during the evaluation period:

- 21 CDC, IEEE Conference on Decision and Control
- 5 SYSID, IFAC Conference on Systems Identification \(^{18}\)
- 1 ICRA, IEEE International Conference on Robotics and Automation

\(^{18}\)(SYSID is organized every three years, here 2009 and 2012)
3.2 Software

- **SLIM:** *Software Library for cooperative Multi-robots* (more details in the next section page 26): Within SLIM, our pool of engineers is currently regrouping all our published results as a package of the open source ROS. It is targeted at all potential users (experienced or not, scientific or not).

- **Neural Spike Sorting:** Matlab program implementing the spike sorting method presented in J. Neural Eng. 9 (2012) Z. Tiganj and M. Mboup [TM12].

- In the general annihilators context, *Maple* programs are implemented for computations in the Weyl algebra, using the package *Ore algebra*.

NB: Today, it is not planned to circulate the last two softwares but we keep it for internal use.

3.3 Valorization and technology transfer (Socio-economic impact and transfer)

- **Collaborative robots in Lille:** The ADT SLIM: ‘Software Library for cooperative Multi-robots’ is one of the ADTs 19 Inria supports in Lille (2 years, 2013-2014). SLIM aims at combining all algorithms developed by Non-A (localization, path planning and robust control) and offering a simple and complete software library for the cooperation of multi-robots. The targeted software library will allow *all users* (experienced or not, scientific or not) to easily reuse and establish their own scenario of application. It is developed under the open-source ROS (Robotic Operation System20) http://www.ros.org/wiki/. Among several other open-source systems (Robotics Developer Studio by Microsoft, NAOQi by Aldebaran Robotics, URBI by Gostai), ROS was chosen mainly for two reasons: ROS can integrate code from other project (Player/Stage, OpenCV...), contrarily to its above competitors; ROS is a *de facto* standard in robotics and Inria teams use this architecture (*e-Motion, FUN, PRIMA...*) as well as the national Equipex FIT, the ADT SENSAS...

- **Model-Free Control in Nancy:** By the end of 2011, Michel Fliess and Cédric Join created the start-up AL.I.E.N.-SAS, domiciled at Nancy. This start-up is helped by the “Incubateur Lorrain” and was awarded the “Prix OSEO, catégorie émergence” to support its creation (see below).

- **CIFRE grants at ENSEA:** Two PhD students with J.P. Barbot are working on finite-time estimation in the framework of CIFRE grants (PhD within industry, see http://www.amrt.asso.fr/fr/espaces/cifre/accueil.jsp), which shows the industry interest for these techniques: Leonardo Amet is with GS Maintenance (Champagne sur Seine) for power converter applications [AGB12]; Essaid Edjekouan started on February 2013 with SDI (Taverny) for mechatronics.

- **GM R&D Center:** since 2002, Denis Efimov is in charge of control projects for General Motors R&D Center in Warren, USA (hybrid systems and IC engines).

- **Nanotechnologies at ENSAM:** we expect to improve the speed performances of AFMs (Atomic Force Microscopes) and apply it to nano-machining (collaboration of O. Gibaru and S. Thiery with Cardiff Univ. [BKC+ 10]).

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19 ADT: ‘Actions de Développement Technologique’
20 Licensed under an open source, BSD license, ROS provides libraries and tools to help software developers create robot applications: hardware abstraction, device drivers, libraries, visualizers, message-passing, package management, and more.
3.4 Teaching

All members of the team teach at various levels in universities (Lille, Nancy, Reims) and engineering schools (EC Lille, ENSAM Lille, ENSEA Cergy, ISEN Lille):

- 192h/y - Barbot Jean-Pierre, Prof. ENSEA Cergy
- 192h/y - Belkoura Lotfi, Prof. Lille 1
- 25h/y - Efimov Denis, CR1 Inria
- 18h/y - Floquet Thierry, CR1 CNRS
- 192h/y - Gibaru Olivier, Prof. ENSAM Lille
- 192h/y - Join Cédric, Ass.Prof. Univ. Nancy
- 192h/y - Mboup Mamadou, Prof. Univ. Reims
- 86h/y - Perruquetti Wilfrid, Prof. EC Lille
- 192h/y - Riachy Samer, Ass.Prof. ENSEA Cergy
- 192h/y - Richard Jean-Pierre, Prof. EC Lille
- 192h/y - Thiery Stéphane, Ass.Prof. ENSAM Lille
- 25h/y - Zheng Gang, CR1 Inria

In particular, at Master Thesis level:

- Lotfi Belkoura is in charge of the Master Thesis training in control ‘SMaRT’ (autonomous systems and field busses) of Université Lille 1 and Ecole Centrale de Lille. This Master has been awarded as one of the “Pépites 2013 de la Fac” (Top 400 French University training, over 11000) by Le Nouvel Observateur (31 January 2013). Non-A is quite invested in this training since L. Belkoura, T. Floquet, W. Perruquetti and J.P. Richard are all carrying out teaching activities there.
- Jean-Pierre Richard is in charge of the ‘Filière Recherche’, École Centrale de Lille, which is a dedicated training for the last year students preparing a Master 2.
- Jean-Pierre Barbot has been in charge (until 2011) of the Master Thesis training in control of the University of Tlemcen, Algeria.

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<thead>
<tr>
<th>Name</th>
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<td>Barbot (–2011)</td>
<td>Advanced control and communications</td>
<td>Univ. Cergy-Pontoise</td>
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<td>Barbot</td>
<td>Process Control</td>
<td>Univ. Tlemcen, Algeria</td>
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<tr>
<td>Floquet</td>
<td>Robotics</td>
<td>MR SMaRT Lille 1 - EC Lille</td>
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<td>Gibaru</td>
<td>Applied Mathematics</td>
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<td>Mboup (–2011)</td>
<td>Advanced Signal Processing</td>
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<td>Belkoura</td>
<td>An introduction to distributions</td>
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</tr>
</tbody>
</table>

**Book:** With Tunisian, French and German colleagues, we also organized a series of two Schools ‘Mathematics for R&D’ in Djerba, Tunisia (2008 and 2009) ending with the edition of a dedicated book\(^{21}\)

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3.5 General audience actions

**SYSIASS**, Press Releases at [http://www.sysiass.eu/?page_id=518](http://www.sysiass.eu/?page_id=518), in particular:


**RobotCity**, launched on 2011 together with an interview of Wilfrid Perruquetti [https://team.inria.fr/non-a/RobotCity/](https://team.inria.fr/non-a/RobotCity/), see also:

[http://www.youtube.com/watch?v=U2Y1eGpMi2k](http://www.youtube.com/watch?v=U2Y1eGpMi2k)
[http://www.inria.fr/centre/lille/innovation/plateau-inria](http://www.inria.fr/centre/lille/innovation/plateau-inria)

**Control applications**, various videos at
[http://researchers.lille.inria.fr/jrichard/Mes_sites_Web_English/manips.htm](http://researchers.lille.inria.fr/jrichard/Mes_sites_Web_English/manips.htm)

in particular: ‘smartuator’ (shape-memory actuator), ‘robotcity2’ and ‘inverted pendulum’.

3.6 Visibility

**Editorial Boards of Journals**


**Plenary Talks:**

- (2009) SysId’2009, 15th IFAC Symp. on Systems Identification (St Malo, France) [FJ09b] (M. Fliess, C. Join)
- (2009) 6th CNRS workshop RECAP (Grenoble, France) [http://evariste.org/mail/recap.7Nov09.txt.html](http://evariste.org/mail/recap.7Nov09.txt.html) (W. Perruquetti)

28
• (2011) (Semi-plenary) Workshop “Toward a Society of Robots”, Centro Piaggio (21-22 June 2011, Pisa, Italy) (W. Perruquetti)

Awards & Highlights:
• (2010) AL.I.E.N.-SAS was awarded the “Prix OSEO, catégorie émergence”
• (2010) A patent with EDF [RLFJ10] was awarded the Innovation Prize 2010 from École Polytechnique
• (2011) The paper [FHPR11] was awarded the ‘Meilleur article jeune chercheur’ at the French conference 8e MSR http://www.lifl.fr/msr11/
• (2011) The program ‘Agrégation’ of ECS Lab was awarded the Prix du partenariat Technologique 2011 du Val d’Oise http://www.vonews.fr/article_13725
• (2013) The Master SMaRT was awarded one of the French “Pépites 2013 de la Fac” (Top 400 French University training, over 11000) by Le Nouvel Observateur (31 January 2013)
• (2009-2013) Since 2009, our survey paper on time delay systems22 is ranked as the ScienceDirect TOP 1 hottest article of Automatica http://top25.sciencedirect.com/subject/engineering/12/journal/automatica/00051098/archive/40/

Miscellaneous:
• IPC Chair (and organization) of ICSCS’12 (IEEE), Lille, France, Aug. 2012, 1st Int. Conf. on Systems & Computer Science (L. Belkoura, J.P. Richard) http://www-lagis.univ-lille1.fr/ICSCS2012/
• IPC Associate Editorship for 9 IFAC/IEEE conferences23 (D. Efimov, J.P. Richard)
• IPC Membership: over 35 other participations to IPCs of IFAC or IEEE international conferences (J.P. Barbot, L. Belkoura, M. Mboup, W. Perruquetti, J.P. Richard)
• IFAC TCs: participation to 6 IFAC Technical Committees: TC 1.2, Adaptive and Learning Systems; TC-1.3 Discrete and Hybrid Systems; TC1.5 Networked Systems; TC2.2 Linear Systems; TC-2.3 Nonlinear Control Systems; TC-2.5 Robust Control (J.P. Barbot, T. Floquet, M. Mboup, W. Perruquetti, J.P. Richard))
• Invitations: various invitations in France and abroad: Czech Rep. (T.U. Prague), Italy (Calgiari Univ.), Japan (Keio Univ.), US (General Motors), Saudi Arabia (KAUST), Tunisia (ENIT Tunis)
• PhD committees: participation to various PhD committees in France, India, Italy, Mexico, Russia, South Africa, Spain, Tunisia

• Expert activities: various other expertise activities appointed by French institutions (ANR, CNRS, DGRI/MEI, DGESIP...) and abroad: Australia (Australian Research Council), Israel (Tel Aviv Univ.), Romania (Nat. Council for Research & Devel.), USA (General Motors, Southern Illinois Univ.)

• National Council of the French University (CNU): Section 61 - Control & Signal (T. Floquet, G. Zheng) and Section 25 - Mathematics (R. Ushirobira, also vice-president in the permanent committee (CP-CNU) for the Group 5, gathering sections 25 - Maths, 26 - Applied Maths. and 27 - Informatics)

• J.P. Barbot was the Director of the laboratory ECS-Lab (EA3649, Electronics and Control Systems Lab) until Feb.2013

• W. Perruquetti held, over the period, various national (AERES, ANR, DGRI...) and Regional (Doctoral School, GRRT²⁴, Inria...) responsibilities and, in particular, for the ANR (French Agency for Research): since 2012, he is the Scientific head of the Maths-STIC division the R2E department²⁵ and, since 2010, Scientific officer for the ANR - SIMI 3 committee²⁶

• J.P. Richard held, over the period, various national responsibilities (expert AERES, DGRI/MEI, DGESIP, Gov. board of CNRS GDR 717 MACS²⁷...) and, in particular, he was the President of the GRAISyHM, Regional Federation of Control and Man-Machine systems (about 200 people, 11 Institutes from North of France) http://www.univ-valenciennes.fr/graisyhm/ and served in several other regional/local committees.

²⁴Group for Research in Transport, Regional Council
²⁵Recherches exploratoires et émergentes : “département Blanc” (annual budget 25 MEuros)
²⁶Automatique - Productique - Robotique - Signal Image - Micro Nano (annual budget 8MEuros)
²⁷http://www.univ-valenciennes.fr/gdr-macs/
4 Funding

4.1 Funding external to Inria

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</tr>
<tr>
<td>PhD ISEN and ENSAM</td>
<td>24.000</td>
<td>72.000</td>
<td>72.000</td>
<td>72.000</td>
</tr>
<tr>
<td>Post-Doc ANR CHASLIM (Inria)</td>
<td></td>
<td></td>
<td></td>
<td>36.000</td>
</tr>
<tr>
<td>Post-Doc/Eng. InterReg SYSIASS (EC Lille)</td>
<td></td>
<td></td>
<td>11.722</td>
<td>41.696</td>
</tr>
<tr>
<td>Post-Doc CPER CIA (Inria)</td>
<td></td>
<td></td>
<td>40.728</td>
<td></td>
</tr>
<tr>
<td><strong>Other external funding</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>112.728</td>
<td>156.000</td>
<td>203.142</td>
<td>302.533</td>
</tr>
</tbody>
</table>

\(^a\) competitive programs by the Ministries of Foreign Affairs and of Higher Education & Research.

NB: the above table only concerns the supports managed by the partners institutes (EC Lille, Lille 1, CNRS and Inria Lille.

4.2 Inria competitive funding

<table>
<thead>
<tr>
<th>(k euros)</th>
<th>year1</th>
<th>year2</th>
<th>year3</th>
<th>year4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inria Research Initiatives</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ARC (^1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AE (^2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Associated teams</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Scholarships</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internship</td>
<td>2.731</td>
<td></td>
<td>3.164</td>
<td></td>
</tr>
<tr>
<td>PhD (^3)</td>
<td>33.946</td>
<td>42.040</td>
<td>59.777</td>
<td>42.296</td>
</tr>
<tr>
<td>Post Doc (^4)</td>
<td>3.898</td>
<td>42.466</td>
<td>35.098</td>
<td>9.817</td>
</tr>
<tr>
<td><strong>Technological development</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AI (^5)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADT (^6) (AI)</td>
<td>2.110</td>
<td>52.559</td>
<td>45.395</td>
<td>81.262</td>
</tr>
<tr>
<td>ODL (^7)</td>
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<tr>
<td><strong>Other Inria competitive funding</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>39.954</td>
<td>139.976</td>
<td>140.270</td>
<td>136.539</td>
</tr>
</tbody>
</table>

\(^1\) Inria Cooperative Research Initiative (ARC = Action de Recherche Cooperative).
\(^2\) Large-scale Initiative Action (AE = Action d’Envergure nationale).
\(^3\) Inria doctoral research contract (CORDI-S, doctorat Inria sur subvention).
National initiatives

- **[ANR ChasLim 2011-2015]** Jointly with BIPOP (Inria Rhône-Alpes), CNRS IRCCyN (Nantes), this ANR project runs from 1 Oct. 2011 until 30 Sept. 2015 and aims at developing a toolbox for synthesizing controllers and adequately simulating the obtained closed-loop systems. Andrey Polyakov is supported by ChasLim. More information at [http://chaslim.gforge.inria.fr/](http://chaslim.gforge.inria.fr/)

- **[CPER CIA 2010-2014]** The “Campus Intelligence Ambiante” is a program supported by the Government, Regional Council and European FEDER, which our collaboration with the team FUN belongs to. We also start a collaboration on the Equipex platform FIT (see ‘opportunities’ at the end of this part).

- **[PHC Volubilis 2010-2013]** VOLUBILIS MA/09/211 is a Hubert Curien Partnership dealing with a greenhouse temperature control, jointly with Univ. of Meknes, Morocco (in relation with the PhD of Youssef El Afou).

- **[PHC Galileo 2011-2012]** This Hubert Curien Partnership GALILEO 26076ZJ deals with estimation techniques for embedded switching systems with applications to the security of embedded systems, jointly with Univ. of Cagliari, Italy (in relation with the PhD thesis of Diego Mincarelli).

- **[PHC Cogito 2010-2012]** Mamadou Mboup won this Hubert Curien Partnership with Univ. of Zagreb, Croatia (Prof. Ratko Magjarević) for works on neurophysiologic signal detection (in relation with the PhD thesis of Zoran Tiganj). Support: 2.5k euros/y, not mentioned above because not in Lille.

European projects

- **[FP7 NoE HYCON2 2010-2013]** This FP7 Network of Excellence, started in September 2010, is a four-year project coordinated by the CNRS (F. Lamnabhi-Lagarrigue) with the partnership of Inria and many European institutes. It aims at establishing a long-term integration in the strategic field of control of complex, large-scale, and networked dynamical systems. Its associated EECI Graduate School on Control is regularly attended by our PhD students. [HYCON2.http://www.hycon2.eu/](http://www.hycon2.eu/)

- **[InterReg SYSIASS 2010-2013]** This InterReg IV-A Two Seas 6-020-FR on Autonomous and Intelligent Healthcare System, aims at assisting patient’s mobility and securing the provision of communication services. It was worked on an intelligent powered wheelchair for clinical or domestic environment. It involves ISEN Lille, EC Lille, Kent Univ., Essex Univ. and several partners from hospital settings. [http://www.sysiass.eu](http://www.sysiass.eu)

Industrial contracts

Contracts of AL.I.E.N. SAS on model-free control:

- EdF (Bourget-du-Lac): “Commande en puissance de barrages hydroélectriques en cascade” (power control of cascaded hydroelectrical dams),
- DIRIF: “Commande des cycles de feux de 4 rampes d’accès de l’autoroute A4” (cycle control for the traffic lights of the 4 public ramps to the A4 highway),
Contracts of AL.I.E.N. SAS on algebraic estimation:

- EdF (Bourget-du-Lac): “Séparation des sources de puissance”,
- EdF (Bourget-du-Lac): “Estimation de débits entrants”,
- EdF (Mulhouse): “Modélisation de l’écoulement du Doubs”.

No ARCs, no AE, no other funding

Associated teams and other international projects

We contribute (no funding) to a GDRi DELSYS (CNRS internat. group on Delay Systems) [https://dri-dae.cnrs-dir.fr/IMG/pdf/GDRI_DELSYS_2012-2.pdf], associated with the IFAC Workshop on Time-Delay Systems and, now, with a new book series ‘Advances in Delays and Dynamics at Springer’ coordinated by S.I. Niculescu from CNRS and DISCO.

5 Objectives for the next four years

Non-A has been created in July 2012, so our objectives remain unchanged:

Theory:
- More general annihilators
- Non-asymptotic derivation and estimation
- Model-free control

Applications:
- Networked robots, WSAN [Lille]
- Nano/macro machining [Lille]
- Multicell chopper [Lille and Cergy]
- i-PID for industry [Nancy, AL.I.E.N. SAS]
6 Bibliography of the project-team

Abstract of selected publications (downloadable from the evaluation website)

1. Objective 1 – Annihilators and Weyl Algebra [UPMF12]
   Weyl algebra applied to robust estimation of the amplitude, frequency and phase of a biased and noisy sum of two complex exponential sinusoidal signals. The estimation is obtained within a fraction of the signal period. The methods that are popular today do not seem able to achieve such performances. The approach is illustrated by several computer simulations.

2. Objective 2 – Algebraic Differentiation [MJF09]
   Numerical differentiation in noisy environment is revised through our algebraic approach. Elementary differential-algebraic operations yield explicit formulas of the point-wise derivatives of chosen orders. These expressions are composed of iterated integrals filtering the noisy observation signal. The introduction of delayed estimates affords significant improvement. An implementation in terms of a classical FIR digital filter is given.

3. Objective 2 – Algebraic Differentiation for $n-D$ Signal [RMR11]
   A generalization of the above $1-D$ result for $n-D$ signals. Multivariate numerical differentiation concerns the estimation of partial derivatives of multidimensional noisy signals. Again, the desired partial derivative is expressed as a function of iterated integrals of the signal. A family of estimators for each partial derivative of any order is given. Numerical implementation can be achieved via FIR digital filters.

4. Objective 2 – Algebraic identification of Delay (or Switched) Systems [BRF09]
   On-line identification of continuous-time systems with structured entries, which may consist in inputs, perturbations or piecewise polynomial (time varying) parameters. Such signals can be easily annihilated, yielding a non asymptotic estimation of the unknown coefficients. Application to delayed and switching hybrid systems are proposed, with numerical simulations and experimental results on a delay process.

5. Objective 2 – Algebraic Estimation of Impulsive Systems [BFIT+11]:
   On-line identification of continuous-time systems subject to impulsive terms. Using a distribution framework, we annihilate singular terms corresponding to the impulses. An on-line estimation of unknown parameters is provided, regardless of the switching times nor impulse rules, followed by numerical simulations of physical processes.
6. Objective 2 – Model-based, Finite-Time observers [MMP10]
http://hal.inria.fr/hal-00455790

A global finite-time observer is designed for nonlinear systems which are uniformly observable and globally Lipschitz. This result is based on a high-gain approach combined with recent advances on finite-time stability using Lyapunov function and homogeneity concepts.

7. Objective 2 – Model-based, Finite-Time estimation [BEPZ12b]
http://hal.inria.fr/hal-00664105

Parametric estimation of harmonic signals is achieved in the presence of noise and computational constraints, via an algorithm for frequency and bias estimation. A switching algorithm is able to filter the measurement high-frequency noise and to ensure the required minimal accuracy in a finite time.

8. Objective 2 – Use of Non-Asymptotic differentiation techniques [BFPZ13]
http://hal.inria.fr/hal-00753706

The strong observability/detectability of a general class of singular linear systems with unknown inputs are tackled. Algebraic NSC of observability/detectability are given. A formula expresses the state as high order derivative of a function of the output. Finite-time differentiation techniques are applied to solve it concretely.

9. Objective 3 – Model-Free Control [RLFJ10]

This is the legal text (written in French) of a patent concerning the water level control for an hydroelectric dam, with several Figures describing the process. A scientific presentation can also be found in [JRF10].

10. Objective 4 – Robots localization: algebra vs EKF [SPK+12]
http://hal.inria.fr/hal-00720198

Our ICRA’2011 paper [SKP11] described a single-landmark-based localization algorithm for mobile robots of the unicycle type. Here, a sensibility study leads to a new fusion algorithm in the multi-landmark case. Simulations and experimentations compare our algebra-based techniques with the well known EKF method.
6.1 Doctoral dissertations and “Habilitation” theses


6.2 Patents


6.3 Articles in referred journals


### 6.4 Book chapters


6.5 Publications in conferences and workshops


Emmanuel Bernuau, Wilfrid Perruquet, Denis Efimov, and Emmanuel Moulay. Finite-time output stabilization of the double integrator. In CDC’12, 51st IEEE Conference on Decision and Control, Maui, Hawaii, USA, December 2012.


Michel Fliess, Cédric Join, and Samer Riachy. Revisiting some practical issues in the implementation of model-free control. In IFAC’11, 18th IFAC World Congress, Milano, Italy, August 2011.


Malek Ghanes, Olivier Bethoux, Mickaël Hilairet, and Jean-Pierre Barbot. Validation expérimentale d’une commande aux perturbations singulières d’un système pile à combustible/super capacités. In CIFA, Grenoble, France, July 2012.


Srinath Govindaswamy, Thierry Floquet, and Sarah Spurgeon, K. Discrete time Output Feedback Sliding Mode Control for Uncertain Systems. In IFAC’11, 18th IFAC World Congress, Milano, Italy, 2011.


Samer Riachy, Michel Fliess, and Cédric Join. High-order sliding modes and intelligent PID controllers: First steps toward a practical comparison. In IFAC’11, 18th IFAC World Congress, Milano, Italy, August 2011.

Samer Riachy, Mamadou Mboup, and Jean-Pierre Richard. Numerical differentiation on irregular grids. In IFAC’11, 18th IFAC World Congress, Milano, Italy, August 2011.


6.6 Publications in French, or in national conferences


