informatics mathematics

Activity Report 2011

Team NON-A

Non-Asymptotic estimation for online systems

RESEARCH CENTER
Lille - Nord Europe

THEME
Modeling, Optimization, and Control of Dynamic Systems

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Team NON-A

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Non-A follows the research team ALIEN which was stopped at the end of 2010.

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2. Overall Objectives

2.1. Objectives

For engineers, a wide variety of information is not directly obtained through measurement. Some parameters (constants of an electrical actuator, delay in a transmission, etc) or internal variables (robot's posture, torques applied to a robot, localization of a mobile, etc) 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 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. However, from a general point of view, the performance of an estimation algorithm can be characterized by three indicators:

- The computation time. Here, we mean the time needed for obtaining the estimation. Indeed, estimation algorithms should have as small as possible computation time in order provide fast, real-time, online estimation for processes with fast dynamics (for example, a challenging problem is to make an Atomic Force Microspcope work at GHz rates).
- 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.
- 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.

2.2. Members complementarity

The members of the Non-A project work in different places: Lille, Reims and Nancy; they share the algebraic tool and the non-asymptotic estimation goal, which constitute the natural kernel of the project. Each of them contributes to both theoretical and applied sides of the global project. The following table draws up a scheme of some of their specialities.

	Upstream Researches	*Application Fields*
Reims CReSTIC	Signal - Numerical analysis	Denoising - Demodulation - Biomedical signal processing
Cergy ECS	Nonlinear observers - Hybrid systems	Cryptography - Multi-cell chopper/converter
Lille ENSAM	Applied mathematics	High performance machining - Precision sensors, AFM[1]
Lille LAGIS	Delay systems - Nonlinear control - Observers (finite-time/unknown input)	Magnetic bearings - Friction estimation - Networked control - Robotics
Nancy CRAN	Diagnosis - Control - Signal	Industrial processes - Signal & image processing

2.3. Highlights

- The platform RobotCity has been inaugurated in April 2011 at Euratechnologies INRIA Lille;
- General public communication was achieved on cooperative robotics activities for disabled people for the project SYSIASS http://www.inria.fr/centre/lille/actualites/un-fauteuil-roulant-plus-intelligent.
- The survey paper on delay systems [109] is the ScienceDirect TOP 1 hottest article of Automatica since July 2009;
- Technology Partnership Award 2011 of research and innovation in the Val d'Oise: Aggregation Program SDI / ECS-Lab;
- National competition Award 2011 to assist the creation of innovative technology companies, category "EMERGENCE";
- Patent pending (FR11/51604) on the control of traffic flow;

3. Scientific Foundations

3.1. Fast parametric estimation and its applications

Parametric estimation may often be formalized as follows:

$$y = F(x, \Theta) + n, \tag{1}$$

where:

- the measured signal y is a functional F of the "true" signal x, which depends on a set Θ of parameters,
- n is a noise corrupting the observation.

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[1] Atomic Force Microscope, for which fast filtering is required

Finding a "good" approximation of the components of Θ has been the subject of a huge literature in various fields of applied mathematics. Most of those researches have been done in a probabilistic setting, which necessitates a good knowledge of the statistical properties of n. Our project is devoted to a new standpoint which does not require this knowledge and which is based on the following tools, which are of algebraic flavor:

- differential algebra[2], which plays with respect to differential equations a similar role to commutative algebra with respect to algebraic equations;
- module theory, i.e., linear algebra over rings which are not necessarily commutative;
- operational calculus which was the most classical tool among control and mechanical engineers[3].

3.1.1. Linear identifiability

In most problems appearing in linear control as well as in signal processing, the unknown parameters are *linearly identifiable*: standard elimination procedures are yielding the following matrix equation

$$P\begin{pmatrix}\theta_1\\ \vdots\\ \theta_r\end{pmatrix}=Q, \tag{2}$$

where:

- θ_i, $1\le i\le r$, represents unknown parameter,
- P is a $r\times r$ square matrix and Q is a $r\times 1$ column matrix,
- the entries of P and Q are finite linear combinations of terms of the form $t^\nu\frac{d^\mu\xi}{dt^\mu}$, $\mu,\nu\ge 0$, where ξ is an input or output signal,
- the matrix P is *generically* invertible, i.e., $\det(P)\ne 0$.

3.1.2. How to deal with perturbations and noises?

With noisy measurements equation (2) becomes:

$$P\begin{pmatrix}\theta_1\\ \vdots\\ \theta_r\end{pmatrix}=Q+R, \tag{3}$$

where R is a $r\times 1$ column matrix, whose entries are finite linear combination of terms of the form $t^\nu\frac{d^\mu\eta}{dt^\mu}$, $\mu,\nu\ge 0$, where η is a perturbation or a noise.

3.1.2.1. Structured perturbations

A perturbation π is said to be *structured* if, and only if, it is annihilated by a linear differential operator of the form $\sum_{\text{finite}} a_k(t)\frac{d^k}{dt^k}$, where $a_k(t)$ is a rational function of t, i.e., $\left(\sum_{\text{finite}} a_k(t)\frac{d^k}{dt^k}\right)\pi=0$. Note that many classical perturbations like a constant bias are annihilated by such an operator. An *unstructured* noise cannot be annihilated by a non-zero differential operator.

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[2] Differential algebra was introduced in nonlinear control theory by one of us almost twenty years ago for understanding some specific questions like input-output inversion. It allowed to recast the whole of nonlinear control into a more realistic light. The best example is of course the discovery of *flat* systems which are now quite popular in industry.

[3] Operational calculus is often formalized *via* the Laplace transform whereas the Fourier transform is today the cornerstone in estimation. Note that the one-sided Laplace transform is causal, but the Fourier transform over R is not.

By well known properties of the non-commutative ring of differential operators, we can multiply both sides of equation (3) by a suitable differential operator Δ such that equation (3) becomes:

$$\Delta P \begin{pmatrix} \theta_1 \\ \vdots \\ \theta_r \end{pmatrix} = \Delta Q + R', \tag{4}$$

where the entries of the $r \times 1$ column matrix R' are unstructured noises.

3.1.2.2. Attenuating unstructured noises

Unstructured noises are usually dealt with stochastic processes like white Gaussian noises. They are considered here as highly fluctuating phenomena, which may therefore be attenuated *via* low pass filters. Note that no precise knowledge of the statistical properties of the noises is required.

3.1.2.3. Comments

Although the previous noise attenuation[4] may be fully explained *via* formula (4), its theoretical comparison[5] with today's literature[6] has yet to be done. It will require a complete resetting of the notions of noises and perturbations. Besides some connections with physics, it might lead to quite new "epistemological" issues [80].

3.1.3. Some hints on the calculations

The time derivatives of the input and output signals appearing in equations (2), (3), (4) can be suppressed in the two following ways which might be combined:

- integrate both sides of the equation a sufficient number of times,
- take the convolution product of both sides by a suitable low pass filter.

The numerical values of the unknown parameters $\Theta = (\theta_1, \cdots, \theta_r)$ can be obtained by integrating both sides of the modified equation (4) during a very short time interval.

3.1.4. A first, very simple example

Let us illustrate on a very basic example, the grounding ideas of the algebraic approach, based on algebra. For this, consider the first order, linear system:

$$\dot{y}(t) = ay(t) + u(t) + \gamma_0, \tag{5}$$

where a is an unknown parameter to be identified and γ_0 is an unknown, constant perturbation. With the notations of operational calculus and $y_0 = y(0)$, equation (5) reads:

$$s\widehat{y}(s) = a\widehat{y}(s) + \widehat{u}(s) + y_0 + \frac{\gamma_0}{s} \tag{6}$$

where $\widehat{y}(s)$ represents Laplace transform.

In order to eliminate the term γ_0, multiply first the two hand-sides of this equation by s and, then, take their derivatives with respect to s:

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[4] It is reminiscent to what most practitioners in electronics are doing.

[5] Let us stress again that many computer simulations and several laboratory experiments have been already successfully achieved and can be quite favorably compared with the existing techniques.

[6] Especially in signal processing.

$$\frac{d}{ds}\left[s\left\{s\widehat{y}(s)=a\widehat{y}(s)+\widehat{u}(s)+y_0+\frac{\gamma_0}{s}\right\}\right] \tag{7}$$

$$\Rightarrow 2s\widehat{y}(s)+s^2\widehat{y}'(s)=a\left(s\widehat{y}'(s)+\widehat{y}(s)\right)+s\widehat{u}'(s)+\widehat{u}(s)+y_0. \tag{8}$$

Recall that $\widehat{y}'(s)\triangleq\frac{d\widehat{y}(s)}{ds}$ corresponds to $-ty(t)$. Assume $y_0=0$ for simplicity's sake[7]. Then, for any $\nu>0$,

$$s^{-\nu}\left[2s\widehat{y}(s)+s^2\widehat{y}'(s)\right]=s^{-\nu}\left[a(s\widehat{y}'(s)+\widehat{y}(s))+s\widehat{u}'(s)+\widehat{u}(s)\right]. \tag{9}$$

For $\nu=3$, we obtained the estimated value a:

$$a=\frac{2\int_0^T d\lambda\int_0^\lambda y(t)dt-\int_0^T ty(t)dt+\int_0^T d\lambda\int_0^\lambda tu(t)dt-\int_0^T d\lambda\int_0^\lambda d\sigma\int_0^\sigma u(t)dt}{\int_0^T d\lambda\int_0^\lambda d\sigma\int_0^\sigma y(t)dt-\int_0^T d\lambda\int_0^\lambda ty(t)dt} \tag{10}$$

Since $T>0$ can be very small, estimation *via* (10) is very fast.

Note that equation (10) represents an on-line algorithm that only involves two kinds of operations on u and y : (1) multiplications by t, and (2) integrations over a pre-selected time interval.

If we now consider an additional noise, of zero mean, in (5), say:

$$\dot{y}(t)=ay(t)+u(t)+\gamma_0+n(t), \tag{11}$$

it will be considered as fast fluctuating signal. The order ν in (9) determines the order of iterations in the integrals (3 integrals in (10)). Those iterated integrals are low-pass filters which are attenuating the fluctuations.

This example, even simple, clearly demonstrates how algebraic's techniques proceed:

- they are algebraic: operations on s-functions;
- they are non-asymptotic: parameter a is obtained from (10) in finite time;
- they are deterministic: no knowledge of the statistical properties of the noise n is required.

3.1.5. A second simple example, with delay

Consider the first order, linear system with constant input delay[8]:

$$\dot{y}(t)+ay(t)=y(0)\delta+\gamma_0 H+bu(t-\tau). \tag{12}$$

Here we use a distributional-like notation where δ denotes the Dirac impulse and H is its integral, i.e., the Heaviside function (unit step)[9]. Still for simplicity, we suppose that the parameter a is known. The parameter to be identified is now the delay τ. As previously, γ_0 is a constant perturbation, a, b, and τ are constant parameters. Consider also a step input $u=u_0H$. A first order derivation yields:

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[7] If $y_0\neq 0$ one has to take above derivatives of order 2 with respect to s, in order to eliminate the initial condition.

[8] This example is taken from [69]. For further details, we suggest the reader to refer to it.

[9] In this document, for the sake of simplicity, we make an abuse of the language since we merge in a single notation the Heaviside function H and the integration operator. To be rigorous, the iterated integration (k times) corresponds, in the operational domain, to a division by s^k, whereas the convolution with H (k times) corresponds to a division by $s^k/(k-1)!$. For $k=0$, there is no difference and $H*y$ realizes the integration of y. More generally, since we will always apply these operations to complete equations (left- and right-hand sides), the factor $(k-1)!$ makes no difference.

$$\ddot{y} + a\dot{y} = \varphi_0 + \gamma_0\, \delta + b\, u_0\, \delta_\tau, \tag{13}$$

where δ_τ denotes the delayed Dirac impulse and $\varphi_0 = (\dot{y}(0) + ay(0))\, \delta + y(0)\, \delta^{(1)}$, of order 1 and support $\{0\}$, contains the contributions of the initial conditions. According to Schwartz theorem, multiplication by a function α such that $\alpha(0) = \alpha'(0) = 0$, $\alpha(\tau) = 0$ yields interesting simplifications. For instance, choosing $\alpha(t) = t^3 - \tau\, t^2$ leads to the following equalities (to be understood in the distributional framework):

$$\begin{aligned} t^3\, [\ddot{y} + a\dot{y}] &= \tau\, t^2\, [\ddot{y} + a\dot{y}], \\ bu_0\, t^3 \delta_\tau &= bu_0\, \tau\, t^2 \delta_\tau. \end{aligned} \tag{14}$$

The delay τ becomes available from $k \geq 1$ successive integrations (represented by the operator H), as follows:

$$\tau = \frac{H^k(w_0 + a\, w_3)}{H^k(w_1 + a\, w_2)}, \qquad t > \tau, \tag{15}$$

where the w_i are defined, using the notation $z_i = t^i\, y$, by:

$$\begin{aligned} w_0 &= t^3\, y^{(2)} = -6\, z_1 + 6\, z_2^{(1)} - z_3^{(2)}, \\ w_1 &= t^2\, y^{(2)} = -2\, z_0 + 4\, z_1^{(1)} - z_2^{(2)}, \\ w_2 &= t^2\, y^{(1)} = 2\, z_1 - z_2^{(1)}, \\ w_3 &= t^3\, y^{(1)} = 3\, z_2 - z_3^{(1)}. \end{aligned}$$

These coefficients show that $k \geq 2$ integrations are avoiding any derivation in the delay identification.

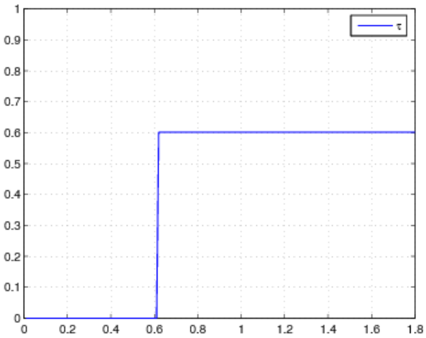

Figure 1. Delay τ identification from algorithm (15)

Figure 1 gives a numerical simulation with $k = 2$ integrations and $a = 2, b = 1, \tau = 0.6$, $y(0) = 0.3, \gamma_0 = 2, u_0 = 1$. Due to the non identifiability over $(0, \tau)$, the delay τ is set to zero until the numerator or the denominator in the right hand side of (15) reaches a significant nonzero value.

Again, note the realization algorithm (15) involves two kinds of operators: (1) integrations and (2) multiplications by t.

It relies on the measurement of y and on the knowledge of a. If a is also unknown, the same approach can be utilized for a simultaneous identification of a and τ. The following relation is derived from (14):

$$\tau(H^k w_1) + a\,\tau(H^k w_2) - a\,(H^k w_3) = H^k w_0, \tag{16}$$

and a linear system with unknown parameters $(\tau, a\,\tau, a)$ is obtained by using different integration orders:

$$\begin{pmatrix} H^2 w_1 & H^2 w_2 & H^2 w_3 \\ H^3 w_1 & H^3 w_2 & H^3 w_3 \\ H^4 w_1 & H^4 w_2 & H^4 w_3 \end{pmatrix} \begin{pmatrix} \widehat{\tau} \\ \widehat{a\tau} \\ -\widehat{a} \end{pmatrix} = \begin{pmatrix} H^2 w_0 \\ H^3 w_0 \\ H^4 w_0 \end{pmatrix}.$$

The resulting numerical simulations are shown in Figure 2. For identifiability reasons, the obtained linear system may be not consistent for $t < \tau$.

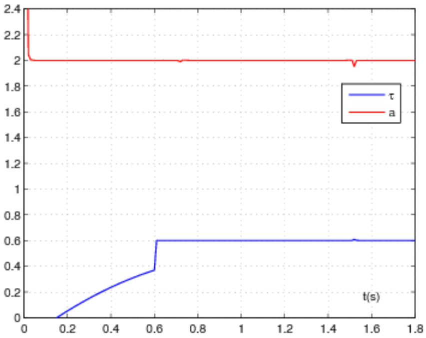

Figure 2. Simultaneous identification of a and τ from algorithm (16)

3.2. Finite time estimation of derivatives

Numerical differentiation, i.e., determining the time derivatives of various orders of a noisy time signal, is an important but difficult ill-posed theoretical problem. This fundamental issue has attracted a lot of attention in many fields of engineering and applied mathematics (see, e.g. in the recent control literature [70], [71], [91], [90], [97], [98], and the references therein).

3.2.1. Model-free techniques for numerical differentiation

A common way of estimating the derivatives of a signal is to resort to a least squares fitting and then take the derivatives of the resulting function. In [101], [99], this problem was revised through our algebraic approach. The approach can be briefly explained as follows:

- The coefficients of a polynomial time function are linearly identifiable. Their estimation can therefore be achieved as above. Indeed, consider the real-valued polynomial function $x_N(t) = \sum_{\nu=0}^{N} x^{(\nu)}(0)\frac{t^\nu}{\nu!} \in \mathbb{R}[t]$, $t \geq 0$, of degree N. Rewrite it in the well known notations of operational calculus:

$$X_N(s) = \sum_{\nu=0}^{N} \frac{x^{(\nu)}(0)}{s^{\nu+1}}$$

Here, we use $\frac{d}{ds}$, which corresponds in the time domain to the multiplication by $-t$. Multiply both sides by $\frac{d^\alpha}{ds^\alpha} s^{N+1}$, $\alpha = 0, 1, \cdots, N$. The quantities $x^{(\nu)}(0)$, $\nu = 0, 1, \cdots, N$ are given by the triangular system of linear equations:

$$\frac{d^\alpha s^{N+1} X_N}{ds^\alpha} = \frac{d^\alpha}{ds^\alpha} \left(\sum_{\nu=0}^{N} x^{(\nu)}(0) s^{N-\nu} \right) \tag{17}$$

The time derivatives, i.e., $s^\mu \frac{d^\iota X_N}{ds^\iota}$, $\mu = 1, \cdots, N, 0 \leq \iota \leq N$, are removed by multiplying both sides of Equation (17) by $s^{-\overline{N}}$, $\overline{N} > N$.

- For an arbitrary analytic time function, apply the preceding calculations to a suitable truncated Taylor expansion. Consider a real-valued analytic time function defined by the convergent power series $x(t) = \sum_{\nu=0}^{\infty} x^{(\nu)}(0) \frac{t^\nu}{\nu!}$, where $0 \leq t < \rho$. Approximate $x(t)$ in the interval $(0, \varepsilon)$, $0 < \varepsilon \leq \rho$, by its truncated Taylor expansion $x_N(t) = \sum_{\nu=0}^{N} x^{(\nu)}(0) \frac{t^\nu}{\nu!}$ of order N. Introduce the operational analogue of $x(t)$, i.e., $X(s) = \sum_{\nu \geq 0} \frac{x^{(\nu)}(0)}{s^{\nu+1}}$. Denote by $\left[x^{(\nu)}(0)\right]_{e_N}(t)$, $0 \leq \nu \leq N$, the numerical estimate of $x^{(\nu)}(0)$, which is obtained by replacing $X_N(s)$ by $X(s)$ in Eq. (17). It can be shown [85] that a good estimate is obtained in this way.

Thus, using elementary differential algebraic operations, we derive explicit formulae yielding point-wise derivative estimation for each given order. Interesting enough, it turns out that the Jacobi orthogonal polynomials [112] are inherently connected with the developed algebraic numerical differentiators. A least-squares interpretation then naturally follows [100], [101] and this leads to a key result: the algebraic numerical differentiation is as efficient as an appropriately chosen time delay. Though, such a delay may not be tolerable in some real-time applications. Moreover, instability generally occurs when introducing delayed signals in a control loop. Note however that since the delay is known *a priori*, it is always possible to derive a control law which compensates for its effects (see [110]). A second key feature of the algebraic numerical differentiators is its very low complexity which allows for a real-time implementation. Indeed, the n^{th} order derivative estimate (that can be directly managed for $n \geq 2$, without using n cascaded estimators) is expressed as the output of the linear time-invariant filter, with finite support impulse response $h_{\kappa,\mu,n,r}(\cdot)$. Implementing such a stable and causal filter is easy and simple. This is achieved either in continuous-time or in discrete-time when only discrete-time samples of the observation are available. In the latter case, we obtain a tapped delay line digital filter by considering any numerical integration method with equally-spaced abscissas.

3.2.2. Model-based estimation of derivatives

If we consider that the derivatives to be estimated are unmeasured states of the process that generates the signal, differentiation techniques can be regarded as left invertibility algorithms. In this sense, the previous algebraic estimation achieves a “model-free” left inversion. Now, when such a model is available, the *finite-time observers*, relying on higher order sliding modes [105] and homogeneity properties [106], [102], also represent possible non-asymptotic algorithms for differentiation[10]. Using such model-based techniques appears to be complementary[11] and we already obtained left-inversion results for several classes of models: linear systems [87], nonlinear systems [68], delay systems [2] and hybrid systems [96].

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[10] Usually, observer design yields asymptotic convergence of the estimation error dynamics. The main advantages of such a technique in the case of linear systems are simplicity of design, estimation with a filtering action and global stability property. Nevertheless, the filtering property is not ensured for nonlinear systems and the stability property is generally obtained only locally. For these reasons, in the case of nonlinear systems, finite-time observers and estimators have been proposed in the literature [98], [106], [107], [86]...

[11] The choice between the two approaches will be done after comparison with respect to the indicators 1, 2, 3, and taking into account the application (for instance, the system bandwidth, system dimension), the kind of discontinuity, the observer in the control loop or not...

4. Application Domains

4.1. Application domains

Unlike the traditional methods, the estimators we defined are "non-asymptotic": solutions are provided by explicit formulae. They result in relatively simple and fast algorithms. In this sense, rather than being a project linked to a specific domain of application, we can say that the present project Non-A is a method-driven project. However, one must not forget that applicability remains a guideline in all our research. As it was told, estimation is a huge area, which explains the variety of possible application fields our new methods address. Figure 3 illustrates the connections between our techniques and the possible applications.

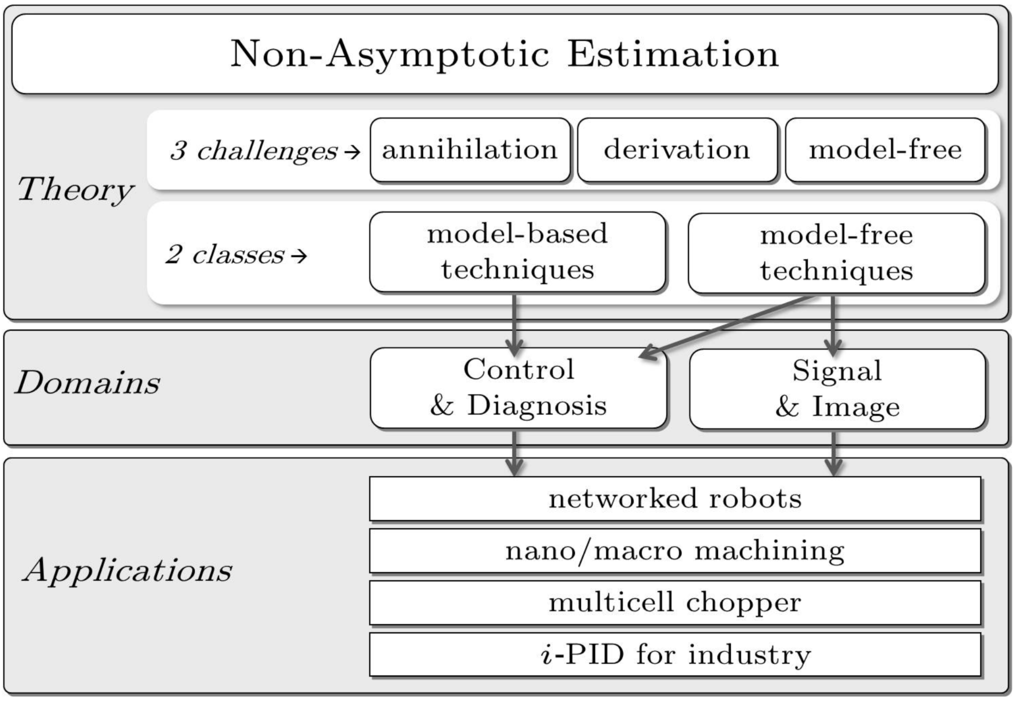

Figure 3. Non-A is a method-driven project, centered around non-asymptotic estimation techniques (i.e., providing estimates in finite-time), and connected to applications.

During these first few years, our techniques have already generated 3 patents [77], [79], [78]. It shows their efficiency in various industrial domains, including (see the previous reports):

- Vehicle control (engine throttle [94], lateral and longitudinal velocities [73], stop-and-go [114], tire/road contact condition [118]) with PSA, APEDGE, Mines-ParisTech, INRIA IMARA, Universidad Carlos III (Madrid), Université Paris Sud;
- Hydroelectric power plants [93], [92] with EDF-CIH (patent pending FR0858532);
- Shape memory actuators [89] with Université de Bretagne Occidentale and ANR MAFESMA;
- Magnetic actuators with Univ. des Saarlandes;
- Power Electronics [103] with Univ. du Québec à Trois-Rivières;
- Aircraft identification [113] with ONERA DCSD;

- Secured communications (chaos-based cryptography [111], [120], [119], CPM demodulation [104]) with CINVESTAV Mexico, Math.Dept. Tlemcen Univ. Algeria and PRISME ENSI-Bourges.
- Image and video processing (denoising [83], edge detection [95]) with INRIA QGAR, compression [84], compressive sensing [116], [117] with CINVESTAV Mexico and Whuan Univ., China.
- More recently, financial engineering [76] with MEREOR Investment Management and Advisory SAS.

5. New Results

5.1. Model-free control

Participants: Cédric Join, Riachy Samer, Lotfi Belkoura.

After the successful implementation of model-free control [75], [81] for several concrete situations:

- Throttle control for IC engines (with APPEDGE and PSA) [94];
- Stop-and-go automotive control strategy (in collaboration with the École des Mines de Paris and PSA) [72], [114], [115];
- Hydroelectrical dams modeling and control (in collaboration with EDF) [92], [93];
- Shape memory actuators (collaboration with the team directed by Prof. E. Delaleau at the École Nationale des Ingénieurs de Brest [88], [89]);
- Model-free control involves the design of the so-called "intelligent" PID controllers [75], [82], and a mathematical explanation via "intelligent" PID controllers of the strange ubiquity of PIDs has been developed in [74], and the simulations confirm the superiority of the new intelligent feedback design;
- Application of model-free control method to set Delta hedging [76];
- Model-free control of "Planar Vertical Take-Off and Landing" (PVTOL) aircraft [108];
- Model-free control for power converters [103];
- The longitudinal control of the electrical vehicle by using model-free control technique [73];
- Model-free control for automatic water level regularization [93] and [92];
- [49] simplifies several aspects of the practical implementation of the newly introduced model-free control and of the corresponding intelligent PID controllers. Four examples with their computer simulations permit to test our techniques.

More achievements have been made in 2011, listed as follows:

- Shape Memory Alloys (SMA) are more and more integrated in engineering applications. These materials with their shape memory effect permit to simplify mechanisms and to reduce the size of actuators. Most of successful control strategies applied to SMA actuator are not often suitable for industrial applications. In [17], an application of the new framework of model-free control to a SMA spring based actuator was proposed. This control strategy is based on new results on fast derivatives estimation of noisy signals, its main advantages are: its simplicity and its robustness. Experimental results and comparisons with PI control are exposed that demonstrate the efficiency of this new control strategy.
- The regulation of freeway traffic flow, which is a complex nonlinear system, is achieved via the newly introduced model-free control in [39] and [64]. Several computer simulations are validating our control strategy, which is easy to implement and shows good robustness properties with respect to perturbations;
- After numerous successful applications, [36] has revisited some points of model-free control. The numerical differentiation of noisy signals may be replaced by a real time parameter identification which is much simpler. The strange ubiquity of classic PIDs is explained as well as the almost universal utilization of ultra-local models of order 1.We show that even with a partially known model the utilization of an intelligent PI controller remains profitable.
- The Ph.D. work of Y. El Afou allowed for experimental results on climate control in greenhouse.

5.2. Algebraic technique for estimation, differentiation and its applications

Participants: Cédric Join, Mamadou Mboup, Wilfrid Perruquetti, Lotfi Belkoura, Olivier Gibaru, Zoran Tiganj, Dayan Liu.

Elementary techniques from operational calculus, differential algebra, and noncommutative algebra lead to a new algebraic approach for estimation and detection. It is investigated in various areas of applied sciences and engineering. The following lists only some applications:

- [28] presents a partial derivatives estimation method for multidimensional signals. On a small interval the signal is represented by a truncated Taylor expansion. Then the application of multivariate Laplace transform together with adequate algebraic manipulations enabled us to express the desired partial derivative of any order as a function of iterated integrals of the noisy signal. Several recurrence relations and structural properties were provided. An interpretation of the estimators as least square minimization is also done by expressing the estimators in an orthogonal basis constituted by Jacobi polynomials. This projection enabled us not only to show a spacial shifting inherent to a specific class of estimators but also to synthesize a new class of estimators minimizing the truncation remainder of the Taylor local model. We provided also another class of estimators minimizing the noise influence. Finally we provided a numerical implementation scheme in the form of a finite impulse digital filters.
- A fast identification algorithm is proposed in [20] for systems with delayed inputs. It is based on a non-asymptotic distributional estimation technique initiated in the framework of systems without delay. Such a technique leads to simple realization schemes, involving integrators, multipliers and piecewise polynomial or exponential time functions. Thus, it allows for a real time implementation.
- A new approach to estimate vehicle tire forces and road maximum adherence is presented in [30]. Contrarily to most of previous works on this subject, it is not an asymptotic observer based estimation, but a combination of elementary diagnosis tools and new algebraic techniques for filtering and estimating derivatives of noisy signals. In a first step, instantaneous friction and lateral forces will be computed within this framework. Then, extended braking stiffness concept is exploited to detect which braking efforts allow to distinguish a road type from another. A weighted Dugoff model is used during these “distinguishable" intervals to estimate the maximum friction coefficient. Very promising results have been obtained in noisy simulations and real experimentations for most of driving situations.
- [27] proposes a diagnosis approach of sensor and actuator modeled as structured signals acting on a particular class of uncertain linear dynamical systems. The main advantage of this approach is that it is possible under certain assumptions, to detect, isolate and identify faults using only input and output measurements without having to identify model parameters. The method is based on the generation and analysis of analytical redundancy relations and exploits the fact that a structured signal satisfies a differential equation. The decision rule is based entirely on the temporal behaviour of the estimates of some fault characteristics.
- Numerical causal derivative estimators from noisy data are essential for real time applications especially for control applications or fluid simulation so as to address the new paradigms in solid modeling and video compression. By using an analytical point of view, [23] revisited the nth order algebraic derivative estimators. Thanks to a given noise level and a well-suitable integration length window, we analyzed the derivative estimator error;
- Recent algebraic parametric estimation techniques provide an estimate of the derivatives by using iterated integrals of a noisy observation signal. These algebraic parametric differentiation techniques give derivative estimations which contain two sources of errors: the bias term error and the noise error contribution. In order to reduce these errors, [25] extends the parameter domains used in the estimators, and studies some error bounds which depend on these parameters. This allows us to minimize these errors. It is shown that a compromise choice of these parameters implies an “optimized" error among the noise error contribution, the bias term error and the time delay.

- The numerical differentiation by integration method based on Jacobi polynomials originally introduced by Mboup, Fliess and Join is revisited in [24] for the central case where the used integration window is centered.
- [59] proposed new algebraic techniques to estimate the amplitude, frequency and phase of a biased and noisy sinusoidal signal. The methods which are popular today seem unable to obtain a robust estimation of those parameters within a fraction of the signal's period. The efficiency of our approach is illustrated by several computer simulations;
- A “practical" comparison between high-order sliding modes and the recently introduced model-free control is made in [56]. The perfect knowledge of the relative degree of the output variable, which is a standard assumption for sliding modes, is assumed. The comparisons are based on two concrete case-studies and on numerous computer simulations. The smoothness of the input variables, the robustness with respect to noises and the straightforward extendibility of the model-free controllers to MIMO systems are highlighted.
- [43] and [66] present a parameter estimation algorithm for a magnetic bearing. Such process are inherently unstable systems with strongly nonlinear dynamics. A simplified model of the magnetic bearing is developed, which enables to obtain a linear expression with respect to the unknown parameters. These parameters are measurable with difficulties, and may slightly vary over time. The expression of the estimates is written as a function of integrals of the inputs and outputs of the system. The simulations and the experiments show a fast and robust on-line identification
- Estimators of the frequency, amplitude and phase of a noisy sinusoidal signal with time-varying amplitude by using the algebraic parametric techniques is studied in [52], in which a similar strategy to estimate these parameters by using modulating functions method is applied. The convergence of the noise error part due to a large class of noises is studied to show the robustness and the stability of these methods. We also show that the estimators obtained by modulating functions method are robust to "large" sampling period and to non zero-mean noises.
- In the framework of the SYSIASS project, a single landmark based localization algorithm for non-holonomic mobile robots is studied in [58]. In the case of a unicycle robot model, the localization problem is equivalent to the system observability. Based on this observation, the proposed localization method consists in finding a vector function which depends on the measurement vector and its derivatives, for which a numerical differentiation method is used in [58].

5.3. Observability and observer design for nonlinear systems

Participants: Jean-Pierre Barbot, Wilfrid Perruquetti, Lotfi Belkoura, Thierry Floquet, Gang Zheng.

Observability analysis and observer design are important issues in the field of control theory. Some recent results are listed below:

- [32] investigates the observability and observer design for a class of single output switched systems with high frequency switching, where classical observers cannot be applied directly since the high frequency switching signals are not derivable. By assuming that these signals are integrable in the less restrictive way, and defining a new output, this study shows that algebraic observer can be adopted to estimate the states of the studied switched systems. Although the main idea is explained via normal forms, it can be easily extended to treat generic switched systems with high frequency switching.
- Observability of a class of switched systems with Zeno phenomenon or high switching frequency is treated in [31]. Particularly, three observability forms are proposed and the observability for each form with knowledge of filtered switching signal is analyzed. Meanwhile, sufficient and necessary conditions for the existence of a diffeomorphism to transform a class of switched systems into one of such forms are presented.

- A triangular canonical form for a class of 0-flat nonlinear systems is studied in [13]. Necessary and sufficient geometrical conditions are given in order to guarantee the existence of a local diffeomorphism to transform the studied nonlinear systems into the proposed 0-flat canonical form, which enables us to compute the flat output as well.
- A fault tolerant control for induction motors based on backstepping strategy is designed in [44]. The proposed approach permits to compensate both the rotor resistance variations and the load torque disturbance. Moreover, to avoid the use of speed and flux sensors, a second order sliding mode observer is used to estimate the flux and the speed. The designed observer converges in a finite time and gives a good estimate of flux and speed even in the presence of rotor resistance variations and load torque disturbance.
- [42] studies the observability problem of a general class of singular linear systems with unknown inputs. It is shown that, under some assumptions, the problem is equivalent to study the observability of a standard linear system with unknown inputs satisfying algebraic constraints. We obtain necessary and sufficient conditions for observability in terms of the zeros of the system matrix.
- [53] is concerned with the study of observability properties of systems without inputs via homogeneous approximations. This approximation is induced by a filtration on the space of observation. A corresponding filtration on a Lie algebra of vector fields is defined and allows to construct the approximation that preserve observability properties. An explicit construction is given in [53].

5.4. Time-delay systems

Participants: Jean-Pierre Richard, Jean-Pierre Barbot, Thierry Floquet, Gang Zheng, Denis Efimov, Wilfrid Perruquetti.

- [22] considers a networked control loop, where the plant is a "slave" part, and the remote controller and observer constitute the “master". Since the performance of Networked Control Systems (NCS) depends on the Quality of Service (QoS) available from the network, it is worth to design a controller that takes into account qualitative information on the QoS in realtime. The goal of the design is to provide a controller that guarantees two things: 1) high performances (here expressed by exponential decay rates) when the QoS remains globally the same; 2) global stability when the QoS changes. In order to guarantee the global stability, the controller will switch by respecting a dwell time constraint. The dwell time parameters are obtained by using the switched system theories and the obtained conditions are Linear Matrix Inequalities (LMI).
- Causal and non-causal observabilities are discussed in [33] for nonlinear time-delay systems with unknown inputs. Using the theory of non-commutative rings and the algebraic framework, the nonlinear time-delay system is transformed into a suitable canonical form to solve the problem. A necessary and sufficient condition is given to guarantee the existence of a change of coordinates leading to such a form.
- The notion of homogeneity is extended to the time-delay nonlinear systems in [45]. It is shown that under some conditions the stability of homogeneous functional systems on a sphere implies the global stability of the system. The notion of local homogeneity is introduced, the relations between stability of the locally approximating dynamics and the original time-delay system are established.
- [38] addresses the problem of the position/force tracking in tele-operation system and proposes a haptic proxy control scheme, in which communication delays are assumed to be both time-varying and asymmetric, and the response of the synchronization and the transparency are improved. The control design is performed using Linear Matrix Inequality (LMI) optimization based on Lyapunov-Krasovskii functionals (LKF) and H_1 control theory.
- Stability and synchronization of systems with time-varying delays is studied in [37], in which a novel control scheme with position/velocity information channel on the basis of Lyapunov-Krasovskii functional (LKF) and H_1 control theory by using Linear Matrix Inequality (LMI) is proposed. The proposed solution is efficient for different working conditions, such as abrupt motion and wall contact illustrated by various simulations.

- Embedded systems can benefit from all results on variable sampling for delayed systems [18], [19] and [47].

6. Contracts and Grants with Industry

6.1. Projects

- Project SYSIASS http://www.sysiass.eu/;
  - Subject: Autonomous and Intelligent Healthcare System;
  - Partners: ISEN de Lille, Ecole Centrale de Lille, University of Kent, University of Essex, East Kent Hospitals University NHS Foundation Trust, Groupement Hospitalier de l'Institut Catholique de Lille;
  - Duration: 2010 - 2013;
  - Support: FEDER;
- Project CHASLIM http://chaslim.gforge.inria.fr/;
  - Subject: Sliding mode control;
  - Partners: INRIA Grenoble-Rhône Alpes, INRIA Lille-Nord Europe, Ecole Centrale de Nantes;
  - Duration: 2011-2014;
  - Support: ANR;
- Project HYCON2http://www.hycon2.eu/;
  - Subject: Networked control systems;
  - Partners: See http://www.hycon2.eu/?page=5&PHPSESSID=c185e278a6cab0a35c8dea0970c5723d
  - Duration: 2010-2015;
  - Support: FP7;
- Project SENSAS http://sensas.gforge.inria.fr/wiki/doku.php;
  - Subject: Sensor network Applications;
  - Partners: INRIA Grenoble-Rhône Alpes, INRIA Lille-Nord Europe, INRIA Sophia Antipolis-Méditerranée, INRIA Nancy-Grand Est;
  - Duration: 2010-2014;
  - Support: ANR;

6.2. Contracts with Industry

- New contract with EDF on the prediction of inflow into the Rhine;
- Contract with DIRIF (Direction Interdépartementale des Routes d'Île-de-France) to control the highway access problem.
- Imminent creation of a cooperation with SAS in December 2011.

7. Partnerships and Cooperations

7.1. Regional Initiatives

- Grant from GRAISyHM (Groupement de Recherche en Automatisation Intégrée et Systèmes Homme-Machine, governmental Federation and Regional Council) on networked control (results connected with delay systems), with LAGIS and LAMIH (CNRS-UVHC Valenciennes).

7.2. National Initiatives

- We are involved in several technical groups of the GDR MACS (CNRS, "Modélisation, Analyse de Conduite des Systèmes dynamiques", see http://www.univ-valenciennes.fr/GDR-MACS), in particular: Technical Groups "Identification", "Time Delay Systems", "Hybrid Systems" and "Control in Electrical Engineering".
- Model-free control: collaborations with Professor Brigitte D'Andréa-Novel at Mines ParisTech and Professor Emmanuel Delaleau at ENIB (Brest).
- Atomic Force Microscope (AFM): application of new algebraic methods in tapping mode for AFM, collaboration with the National Laboratory of Metrology (LNE) located at Trappes.

7.3. European Initiatives

- Collaboration with Sarah Spurgeon of University of Kent on Sliding mode control;
- Collaboration with Emmanuel Brousseau of Cardiff University for the project: "on nano mechanical machining of 3D nano structures by AFM".

7.4. International Initiatives

- Collaboration with Professors Emilia Fridman (Tel Aviv University) and Joao Manoel Gomes da Silva (UFRGS, Porto Allegre, Brasil) on time-delay systems.
- Collaboration with Professor Hong Sun (Whuan University, China) for co-supervising the PhD thesis of Lei Yu on Compressive sensing.
- Collaborations with Professor Guiseppe Fedele from University of Calabria, Italy, on "Model-free control".
- Programme Hubert Curien GALILEE for scientific exchange between LAGIS and University of Cagliari, Italy;
- Programme Hubert Curien VOLUBILIS (Maroc, Integrated Action MA/09/211) between LAGIS (Université Lille1), Non-A/INRIA and Laboratory of Electronic, Information and Biotechnology of Department of Science at University Moulay Ismail of Meknès;
- Programme Hubert Curien COGITO for scientific exchange between University of Reims Champagne Ardenne, Non-A and University of Zagreb.

8. Dissemination

8.1. Animation of the scientific community

8.1.1. Editorial boards

- Jean-Pierre Richard is currently Associate Editor of *Int. J. of Systems Science*.
- Mamadou Mboup is currently Managing Editor of *African Diaspora Journal of Mathematics* and Associate Editor of *EURASIP Journal on Advances in Signal Processing*.
- Thierry Floquet is currently Associate Editor of *Nonlinear Analysis : Hybrid Systems* and *e-sta*.

8.1.2. Program Committees

- IFAC Technical Committees: The members of Non-A are participating to several technical committees of the IFAC (International Federation of Automatic Control, see the TC list on http://www.ifac-control.org/areas): TC 1.3 - Discrete Event and Hybrid Systems, TC 1.5 Networked Systems, TC 2.2 Linear Control Systems, TC 2.3 Nonlinear Control Systems, TC 2.5 Robust Control.
- Jean-Pierre Richard was in the International Program Committee of several IEEE and IFAC conferences: IEEE Mediterranean Conference on Control and Automation, 2011; IEEE SmArt COmmunications & Network technologies applied on Autonomous Systems, 2011; IEEE International Symposium on Programming and Systems, 2011; IEEE International Conference on Communications, 2011; Journées Doctorales Modélisation Analyse et Conduite des Systèmes dynamiques, 2011; Journées Identification Modélisation Expérimentale, 2011;
- Cédric Joint was in committee of Conférence Méditerranéenne sur l'Ingénierie sûre des Systèmes complexes, 2011;
- Lotfi Belkoura was in committee of Journées Identification Modélisation Expérimentale, 2011;
- Gang Zheng was in committee of IEEE International Conference on Intelligent Control and Information Processing, 2011;
- Mamadou Mboup was in the Program committee of IEEE International Workshop on Machine Learning for Signal Processing 2011;
- Jean-Pierre Barobt was in evaluation committee of PES-(61 section of CNU).

8.1.3. Scientific and administrative responsibilities

- Jean-Pierre Richard is president of the GRAISyHM, federation from the French government. He is an expert for the evaluation of projects submitted to ANR, CNRS, DGRI and AERES, and heading the 3rd year professional training "Research" of the École Centrale de Lille;
- Wilfrid Perruquetti is the scientific head of ANR program Blanc SIMI3, and is heading the 3rd year professional training "ISD: Information System and Decision" of the École Centrale de Lille; He is an expert for ANR, AERES and ARC (Australian Research Council);
- Mamadou Mboup is heading the group SYSCOM - CReSTIC, University of Reims Champagne-Ardenne;
- Lotfi Belkoura is heading the Master "AG2i: Automatique, Génie Informatique et Image", University of Lille 1 and École Centrale de Lille. This Master, after a national evaluation (A), is presently "SMaRT: Systèmes, Machines autonomes et Réseaux de Terrain";
- Thierry Floquet is an expert for the evaluation of projects submitted to ANR and Israel Science Foundation, and a member of Conseil National des Universités, 61ème Section. He is as well the head of the groupe SyNeR of LAGIS laboratory;
- Cédric Join is heading the AII-ASRI, IUT Nancy-Brabois;
- The team members are also involved in numerous examination committees of theses and Habilitations, in France and abroad.

8.1.4. Stay

- Thierry Floquet: 2-week stay in University of Cagliari, Italy, with Dr. Alessandro Pisano.

8.1.5. Visitors

- Emilia Fridman, Professor of Tel Aviv University, Israel, June 2011, supported by École Centrale de Lille;
- Marc Bodson, Professor of University of Utah, USA, June 2011, supported by École Centrale de Lille;

- Benachir Bouchikhi, Professor of University Moulay Ismail of Meknès, supported by “Partenariat Hubert Curien Volubilis";
- Hisaya Fujioka, Associate Professor of Kyoto University, September 2011, supported by Kyoto University.

8.1.6. Participation to conferences

- IFAC World Congress, 2011, Italy (Jean-Pierre Richard, Jean-Pierre Barbot, Wilfrid Perruquetti, Mamadou Mboup, Gang Zheng, Denis Efimov, Samer Riachy);
- International Workshop in honour of Prof. Giorgio Bartolini Retirement, 2011, Italy (Wilfrid Perruquetti, Jean-Pierre Barobt);
- IEEE Conference on Decision and Control, 2011, USA (Wilfrid Perruquetti, Jean-Pierre Barbot);
- IEEE Chinese Conference on Control and Decision, 2011, China (Gang Zheng);
- Journées Nationales de la Recherche en Robotique, 2011, France (Wilfrid Perruquetti);
- Summer School on Robotics and Automation, 2011, Alger (Wilfrid Perruquetti);
- Conférence Méditerranéenne sur l’Ingénierie sûre des Systèmes complexes, 2011, Maroc (Cédric Join);
- Summer school on Automatic control, 2011, Romania (Lotfi BelKoura);
- Journée d’Identification et de Modélisation Expérimentale, 2011, France (Lotfi Belkoura);
- IEEE International Workshop on Machine Learning for Signal Processing, 2011, China (Mamadou Mboup);
- Colloque on Signal and Image Processing, 2011, France (Mamadou Mboup).

8.1.7. Reviews

The members of Non-A are reviewers for most of the journal of the control and signal communities: IEEE Transactions on Automatic Control, IEEE Transactions on Systems and Control Technologies, IEEE Transactions on Industrial Electronics, IEEE Transactions on Signal Processing, Automatica, SIAM Journal on Control and Optimization, Journal of Computation and Applied Mathematics, Systems & Control Letters, International Journal of Control, International Journal of Robust and Nonlinear Control, International Journal of Systems Science, Journal Européen des Systèmes Automatisés, IET Control Theory & Applications, Fuzzy Sets and Systems, Mathematics and Computers in Simulation, International Journal of Modeling and Simulation, Journal of the Franklin Institute, ...

8.1.8. Theses and Habilitations

- Dayan Liu, "Analyse d’Erreurs d’Estimateurs des Dérivées de Signaux Bruités et Applications", October 17, 2011;
- Zoran Tiganj, "On the pertinence of a numerical transmission model for neural information", November 8, 2011.

8.2. Teaching

The members of the team teach at different level in universities and engineering schools and, in particular, at Master Thesis level:

Name	*Course title*	*Level*	*Institution*
Barbot	Process Control	Master	Univ. Tlemcen, Algeria
Gibaru	Applied Mathematics	Master	USTL-UVHC-ULCO
Mboup	Advanced Signal Processing	Master	Univ.Paris 5, ENIT-Tunis
Perruquetti	Nonlinear control	Master	EC Lille
Perruquetti	Robotics	Master AG2i	EC Lille - USTL
Richard	Mathematical tools for nonlinear systems	Master AG2i	EC Lille - USTL
Richard	Dynamical systems	Research training	EC Lille
Belkoura	An introduction to distributions	Master AG2i	EC Lille - USTL

- Jean-Pierre Richard is in charge of the professional training "Research" of Ecole Centrale de Lille since 2003 (training for last-year students of EC Lille who are preparing a research career). (http://www.ec-lille.fr/85787934/0/fiche___pagelibre/).
- Wilfrid Perruquetti is in charge of the professional training "ISD: Information System and Decision" of Ecole Centrale de Lille since 2010 (http://www.ec-lille.fr/syst_auto/0/fiche___formation/).
- Lotfi Belkoura is in charge of the SMART Master Thesis training in control of University of Lille 1 and Ecole Centrale de Lille.
- Jean-Pierre Barbot is in charge of the Master Thesis training in control of the University of Tlemcen, Algeria.

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