INRIA

INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

# *Project-Team ALIEN*

# *ALgèbre pour Identification et Estimation Numériques*

*Lille - Nord Europe, Saclay - Île-de-France*

THEME NUM

Activity Report

2008

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# 2. Overall Objectives

## 2.1. History

After being initiated as a team **in 2004**, the project-team ALIEN was created in 2007, **July 1st** (see the 2006 activity report for the evolution from the initial group to the present one).

## 2.2. Objectives

The ALIEN project aims at designing new real-time estimation algorithms. Within the huge domain of estimation, ALIEN addresses the following, particular trends: software-based reconstruction of unmeasured variables (also called "observation"), filtering of noisy variables, estimation of the $n$-th order time derivatives of a signal, parametric estimation of a linear/nonlinear model (including delay and hybrid systems).

The novelty lies in the fact that ALIEN proposes algebra-based methods, leading to algorithms that are fast (real-time is aimed at), deterministic (noise is considered as a fast fluctuation), and non-asymptotic (finite-time convergence). This is why we think that ALIEN's studies are shedding a new light on the theoretical investigations around estimation and identification. As it was told, estimation is a huge area. This explains the variety of possible application fields, which both concern signal processing and real-time control. Several cooperations have already been launched on various concrete industrial problems with promising results.

Let us briefly mention some topics which will be studied in this project. In automatic control, we will be dealing with:

- identifiability and identification of uncertain parameters in the system equations, including delays;
- estimation of state variables, which are not measured;
- fault diagnosis and isolation;
- observer-based chaotic synchronization, with applications in cryptography and secure systems.

A major part of signal and image processing is concerned with noise removal, i.e. estimation. Its role in fundamental questions like signal modeling, detection, demodulation, restoration, (blind) equalization, etc, cannot be overestimated. Data compression, which is another key chapter of communication theory, may be understood as an approximation theory where well chosen characteristics have to be estimated. Decoding for error correcting codes may certainly also be considered as another part of estimation. We know moreover that any progress in estimation might lead to a better understanding in other fields like mathematical finance or biology.

## 2.3. Members complementarity

The members of the ALIEN project work in 3 different places: Paris, Lille 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. Of course, *algebraic tools, identification and estimation* are not recalled here since any member of ALIEN is concerned with.

| | *Upstream Researches* | *Application Fields* |
|---|---|---|
| Saclay<br>LIX | Computer algebra - Nonstandard analysis - Signal - Linear & nonlinear control - Delays | |
| Paris Descartes<br>CRIP5 | Signal - Numerical analysis | Denoising - Demodulation - Biomedical signal processing |
| Cergy<br>ECS | Nonlinear observers - Hybrid systems | Cryptography - Multi-cell chopper/converter |
| Lille<br>LIFL | Computer algebra | Dedicated software |
| Lille<br>ENSAM | Applied mathematics | High performance machining - Precision sensors, AFM[1] |
| Lille<br>LAGIS | Delay systems - Nonlinear control - Observers<br>(finite-time/unknown input) | Aeronautics - Magnetic bearings - Friction estimation - Networked control - Robotics |
| Nancy<br>CRAN | Diagnosis - Control - Signal | Industrial processes - Signal & image processing |

## 2.4. Highlights of the year

- A breakthrough paper [29] was accepted in the journal e-sta on “model-free control” or “intelligent PID controllers”. As a matter of fact, they rely on the outputs derivatives estimation rather than on the existence of a sophisticated model, whose parametrization usually takes a lot of time and energy in an industrial context.
- Organization of 2 international Workshops and of an invited session at IEEE MED’08 conference.
- Cooperations with EDF-CIH (2 contracts) and with PSA (1 contract).

# 3. Scientific Foundations

## 3.1. Fast parametric estimation and its applications

**Keywords:** *Computer Algebra*, *Control*, *Cryptography*, *Diagnosis*, *Dynamical Systems*, *Estimation*, *Fault-Tolerant Control*, *Identification*, *Image Processing*, *Robotics*, *Signal Processing*, *Video Processing*.

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 $\Theta$ of parameters,
- $n$ is a noise corrupting the observation.

---

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

Finding a "good" approximation of the components of $\Theta$ 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 projectis 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:

- $P$ 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 $t^\nu \frac{d^\mu \xi}{dt^\mu}$, $\mu, \nu \geq 0$, where $\xi$ is an input or output signal,
- the matrix $P$ is *generically* invertible, i.e. $\det(P) \neq 0$.

### 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 $t^\nu \frac{d^\mu \eta}{dt^\mu}$, $\mu, \nu \geq 0$, where $\eta$ is a perturbation or a noise.

#### 3.1.2.1. *Structured perturbations*

A perturbation $\pi$ 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.

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 $\Delta$ such that equation (3) becomes:

---

[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 $\mathbf{R}$ is not.

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

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 necessitate a complete resetting of the notions of noises and perturbations. Besides some connections with physics, it might lead to quite new "epistemological" issues [73].

### 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 ALIEN 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 $\gamma_0$ is an unknown, constant perturbation. With the notations of operational calculus and $y_0 = y(0)$, equation (5) reads:

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

In order to eliminate the term $\gamma_0$, multiply first the two hand-sides of this equation by $s$ and, then, take their derivatives with respect to $s$ :

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

---

[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.

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

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 $\nu$ 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 ALIEN'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 $\delta$ 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 $\tau$. As previously, $\gamma_0$ is a constant perturbation, $a$, $b$, and $\tau$ are constant parameters. Consider also a step input $u = u_0 H$. A first order derivation yields:

---

[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 [60]. 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 $\delta_\tau$ 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 $\alpha$ 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 $\tau$ 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.

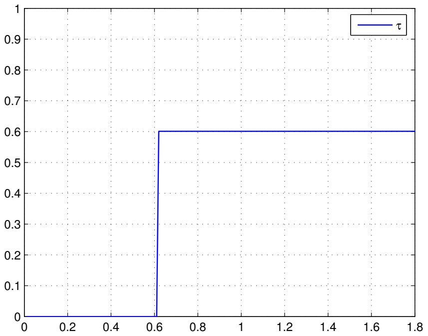

*Figure 1. Delay $\tau$ identification from algorithm (15)*

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 $\tau$ 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 $\tau$. 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 $t < \tau$.

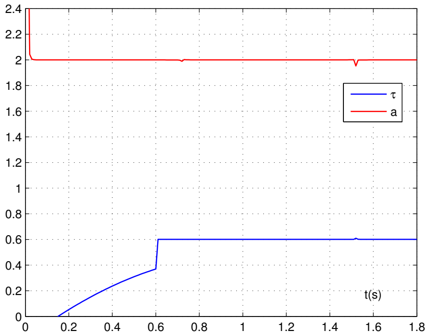

*Figure 2. Simultaneous identification of a and $\tau$ from algorithm (16)*

## 3.2. Numerical differentiation

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 [65], [67], [80], [79], [82], [83], and the references therein). 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 [87], [18], 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 $[x^{(\nu)}(0)]_{e_N}(t)$, $0 \leq \nu \leq N$, 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 [16] 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 [100] are inherently connected with the developed algebraic numerical differentiators. A least-squares interpretation then naturally follows [86], [87] and this leads to a key result: the algebraic numerical differentiation is as efficient as an appropriately chosen time delay is introduced. 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 [94]). 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.

# 4. Application Domains

## 4.1. Control applications

### *4.1.1. Closed loop identification*

In many practical situations, parameter identification has to be achieved in real time, i.e., in closed loop while the plant is working. This most important problem remains largely open, even for simple and elementary linear systems. Our method allows to achieve closed loop identification, even for nonlinear systems[10].

### *4.1.2. State reconstructors*

In many applications, the values of system variables, state variables especially, which cannot be directly measured have nevertheless to be determined. Classical means for doing this are, for linear systems:

- asymptotic observers,
- Kalman filters,

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[10] Some concrete laboratory examples have been successfully implemented at CINVESTAV, México.

which have enjoyed an immense popularity. Note however that:

- asymptotic observers are quite sensitive to mismatches and perturbations,
- Kalman filters are necessitating the solution of a Riccati equation, where the precise statistics of the noise has to be quite accurately known. It is moreover well known that the *extended Kalman filters* for nonlinear systems has never received a fully satisfactory justification.

For nonlinear systems the question has remained largely open in spite of a huge literature.

When those quantities are considered as unknown parameters, our previous techniques are applicable. We obtain *state reconstructors* which yield excellent estimates even with non-classic stochastic noises, with poorly known statistics.

Note that, in the case of a finite-time reconstructor, the separation principle holds for a large class of nonlinear systems, *i.e.* control and reconstruction can be achieved separately. This reduces the complexity at the global design level.

### 4.1.3. Unknown input observers

Another field of interest in the framework of state reconstruction is the design of so-called “unknown input observers”. The objective is to recover the value of the state in spite of the presence of unknown inputs. Some members of the project recently derived an observation algorithm that allows for the relaxation of some structural conditions usually assumed in most of the works related to unknown input observers [75], [74]. Such a method can be performed for a class of left invertible linear systems under the possibility to design finite time observers (or fast estimators). This method can be extended for a special class of nonlinear systems using differential geometric concepts [57]. Algebraic methods can be a powerful tool in this area: to derive structural conditions whether the aforementioned algorithm might work or not both for linear [69] and nonlinear systems [58], to numerically test these conditions and to quickly compute the required variables. There are several application domains. In ALIEN, we particularly focus on problems linked to the security and reliability of systems such as fault diagnosis and secure communication. Other results concern estimation of systems with unknown delay [97], [55], based on unknown-input observer techniques.

### 4.1.4. Fault diagnosis

For a better understanding of complex industrial processes, fault diagnosis has recently become an important issue, which has been studied under various guises (See, e.g., M. Blanke, M. Kinnaert, J. Lunze, M. Staroswiecki, *Diagnosis and Fault-Tolerant Control*, Springer, 2003). In spite of this, the crucial problem of detecting and isolating a fault in closed loop for a possibly uncertain system remains largely open. Our estimation techniques enabled us to give a clear-cut answer, which is easily implementable.

A fault occurrence can lead to a reduction in performance or loss of important function in the plant. The quite particular problem to consider is the design of a fault-tolerant controller. Indeed, the number of possible faults, drastic changes in the system behavior and time of fault occurrence play a crucial role. However, ensuring that the performances of the system remain close to the nominal desired performance after a fault occurrence, represents a challenge, which we are now solving: for instance, we presented an invited paper for the *Festsschrift* of Prof. Dr.-Ing. M. Zeitz which took place in September 2005.

### 4.1.5. Fast observers for chaotic systems applied to cryptography

After Carroll and Pecora successfully synchronized two identical chaotic systems with different initial conditions [91], chaos synchronization has been intensively studied in various fields and in particular in secure communications (because chaotic system is extremely sensitive to its initial conditions and parameters). The idea is to use the output of the drive system to control the response system so that they oscillate in a synchronized manner. Different synchronization schemes have been applied such as system decomposition method [91], mutual coupling [68] or iteration method [66], [71].

Since the work [89], the synchronization has been regarded as a special case of observer design problem, i.e state reconstruction from measurements of an output variable under the assumption that the system structure and parameters are known. Many techniques issued from observation theory have been applied to the problem of synchronization: observers with linearizable dynamics [78], adaptive [76] or sliding mode observers [64], [70], generalized hamiltonian form based observers [99], etc.

Recently, significant results were obtained from both theoretical and practical aspects. In [58], we investigated the left invertibility problem for nonlinear systems was investigated from an algebraic point of view with a straightforward application to data secure transmission. The key issue here is to have an algebraic viewpoint for the state estimation problem associated with the chaotic encryption-decoding problem and to emphasize its use for the efficient and fast computation of accurate approximations of the successive time derivatives of the transmitted observable output signal received at the decoding end. Those methods can also be useful in new encryption algorithms that require fast estimation of the state variables and the masked message.

In [21] and [92], a new type of finite time observer for the synchronization of chaotic systems that can be put in Brunovsky canonical form up to output injection was introduced. The main contribution is that finite time observation is obtained using continuous output injections in a well chosen auxiliary dynamical system. The method is applied on the Chua's circuit.

In [27], delays were introduced in chaotic systems in order to improve the robustness of cryptosystems with respect to known plain text attacks. In order to enlarge the class of systems considered in data secure transmission, a grazing bifurcation analysis was proposed in [62] and an example of hybrid chaotic system was given. Finally, an analogical realization of data secure transmission was realized see http://www-ecs.ensea.fr/webdesign/ecspresent.html.

### *4.1.6. Delay identification*

As it has been seen in the introductory example of subsection 3.1.5, the framework of convolution equations can be used for fast identification issues and leads to computations analogous to the algebraic framework (multiplications by $t$ and integrations). This link was pointed out for the first time in our communication: “On-line identification of systems with delayed inputs” (Belkoura, Richard & Fliess 2006) [60]. Further works will extend this first result within both the algebraic and distributional formalisms.

In the case of systems with a single delay, we achieved the identification of both unknown parameters and the delay by using, as a starting point, an eigenvalue problem of the form:

$$(P_1 + \tau P_2)\Theta = 0, \tag{18}$$

where the unknown delay $\tau$ and the parameters $\Theta = (\theta_1, ..., \theta_r, 1)^T$ are identified as the constant pair eigenvalue/eigenvector. In case of delayed and piecewise constant inputs, the matrices $P_1$ and $P_2$ share the same structure as the above linear problem, while for general input and/or state delay, convolution products are required. The first contribution in this field concerns the extension of the ALIEN techniques to systems with structured entries (inputs or parameters), and for which retarded phenomena occur. As an example, equation (20) formulated in the time domain, is derived from the linear second order process (19) subject to nonzero initial conditions and structured delayed inputs $u_1$ and $u_2$.

$$s^2 y + a_1 s y + a_0 y = s y_0 + \dot{y}_0 + u_1 e^{-\tau_1 s}/s + u_2 e^{-\tau_2 s}/s, \tag{19}$$

$$t^3 (t - \tau_1)(t - \tau_2) \times [y^{(3)} + a_1 y^{(2)} + a_0 y^{(1)}] = 0. \tag{20}$$

From the latter equation, it is clear that the estimation problem is linear if only the parameters $a_i$ are to be estimated. In addition to the nonlinear structure, another specificity for the delays estimation is linked to the support of the entities derived from measurements. The simultaneous delay and parameters estimation can be reduced to a generalized eigenvalue problem [59]. The case of infinitely many delays can also be considered, using either a local estimation [60], or global estimators at the price of a change from non asymptotic estimators to asymptotic ones. Numerical simulations as well as experimental results have shown the feasibility of the proposed technique.

### 4.1.7. Embedded systems and software

Among the numerous questions related to embedded systems, *control over networks* is a technology-driven problem for which the theory of systems with time delays can be helpful. Communication networks (Ethernet, wifi, Internet, CAN, etc.) have a huge impact on the flexibility and integration of control systems as remote controllers, wireless sensors, collaborative systems, etc. However, a network unavoidably introduces time delays in the control loops, which may put the stability and safety performances at risk[11]. Such delays are varying (jitter and packet dropouts) and the available efficient control techniques (predictor-based) take advantage of their knowledge. Two approaches have to be combined:

1. use delay identification algorithms [90], [61] and improve the control;
2. design control/estimation algorithms that can stand variations of the delay [98].

Note that the problem of non-uniform data sampling arising in real-time embedded controllers can also be regarded as a problem of systems with time-varying delay [77]. Indeed, a sampled signal $u_k = u(t_k)$ can be considered as a continuous signal with discontinuous delay:

$$u_k = u(t_k) = u(t - (t - t_k)) = u(t - h(t)), \quad \forall t \in [t_k, t_{k+1}[.$$

On these ideas, the control loop (between a Master and a remote Slave with poor computation power) presented in [98] has developed an observer that enable the Master to reconstruct the *present* state of the Slave despite the variable communication delays.

### 4.1.8. Robust control and estimation techniques for uncertain hybrid systems

Many systems encountered in practice exhibit switches between several subsystems, both as a result of controller design (such as switching supervisory control) and inherently by nature (such as a physical plant undergoing several operational modes); a walking robot during leg-impact and leg-swing modes, group of vehicles with various formations, reactions during chemical operations constitute some examples of hybrid switching systems. Among all the problems linked to switched systems, there are two main questions:

- The switching stabilizability: given a family of subsystems, how can the switching law be constructed in order to ensure the stability of the switched system (huge literature [102], [72], [101], [93])?
- The uniform stability: given a family of subsystems, which conditions on the vector fields ensure the stability of the switched system under any switching law (see [84], [85] and [88])?

In all the proposed results, a complete description of the subsystems is necessary for obtaining explicit stability conditions and control laws. Moreover, even if the description is complete, searching for a stable convex combination is a $NP-$hard problem, such as constructing a common Lyapunov function.

Using the ALIEN techniques, the control problem is tackled without a complete description of the subdynamics and even without knowing the switching signal.

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[11] See the recent book [95] (in French) by Richard and Divoux.

The proposed control design methodology is based on a new point of view: the system output on a small time window is approximated by a polynomial (w.r.t. time) which leads to some local model over this window. The obtained model relies on fast, i.e. real-time, estimations of derivatives for noisy signals. To this end, we consider switched systems without state jumps as a collection of ordinary differential equations (ODEs) which can be seen as differential relations between the input and output variables. During a short time window, those ODEs can be given by the elementary form $y^{(p)} = a(\cdot) + b(\cdot)u$, where the terms $a(\cdot)$ and $b(\cdot)$ depend on the input, output variables, their derivatives up to some finite order, and on the switching signal. Then, using fast on-line estimations of these two terms (as soon as $b(\cdot)$ is non zero) and eventually the successive derivatives of the output up to order $(p-1)$, one can obtain the desired tracking performances using either a PID controller or a kind of "state" feedback. one can use, for example, a control of the form:

$$[b(\cdot)]_{\mathrm{estim}}\, u = y_{\mathrm{ref}}^{(p)} - [a(\cdot)]_{\mathrm{estim}} - \sum_{i=-1}^{(p-1)} \alpha_i e_{y,i,\mathrm{estim}} \tag{21}$$

with $e_{y,i,\mathrm{estim}} = \left[y^{(i)}\right]_{\mathrm{estim}} - y_{\mathrm{ref}}^{(i)}$.

Recently, a new definition of observability was introduced in [81]. This definition is strongly linked to algebraic observability and, in this case, so-called "hybrid time trajectories" were considered. Under this new observability notion, some ALIEN observers for multi-cell chopper are under development.

## 4.2. Applications to signal, image and video processing

### 4.2.1. General presentation

Three patents are already pending in those topics:

1. compression of audio signals,
2. demodulation and its theoretical background[12],
3. compression, edge and motion detection of image and video signals[13].

It is therefore difficult in this report to give too much details.

### 4.2.2. Detection of abrupt changes

Abrupt changes in a signal generally represent important information-bearing parameters. The presence of such transient phenomena in the electroencephalogram (EEG) records may reveal pathology in the brain activity. In such an instance, the detection and location of the change points may be critical for a correct diagnostic. As a first step towards a more general study of gap detection, we have considered a non-stationary piecewise polynomial signal. With our method, it is possible:

- to calculate the coefficients of the various polynomials in the presence of noises which might be non-Gaussian,
- to determine quite precisely the locations of the change points.

As an example, consider the estimation of the sequence

$$\begin{aligned} p_0(t) &= -3(t-t_0)+3, \\ p_1(t) &= -4(t-t_1)^3/6 + 5(t-t_1)^2/2 - 2(t-t_1)+2, \\ p_2(t) &= (t-t_2)^2 - 2(t-t_2)+2 \end{aligned} \tag{22}$$

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[12] This should be a US patent since it contains the corresponding mathematical apparatus.

[13] The extension to image and video processing will of course involve linear differential operators with respect to several indeterminates.

of unknown time polynomial signals measured by $y_i(t) = p_i(t) + \varpi(t)$ where $\varpi(t)$ is a zero mean value stochastic process constituted, at each time $t$, by a rectangularly distributed computer-generated random variable. Figure 3 shows the sequence of polynomials estimates, which are seen to converge quite fast to the ideal signal and the results of the constant parameter identification in the noisy environment. It should be pointed out that in these simulations, the instants $t_i$, at which the polynomial signal $p_i(t)$ changed into a new one $p_{i+1}(t)$, were known beforehand. It is not difficult to see that the proposed identification algorithm is also capable of depicting the instant at which the new polynomial signal arrives, when such discontinuity instants are randomly selected. Being unaware of the signal change, results in a noticeable drifting of the constant values of the parameters being currently identified. This allows for a simple and timely re-initialization of the estimation algorithm. Figure 4 depicts an example of the estimated parameters drift that occurs when a second order polynomial signal is suddenly changed to a different one.

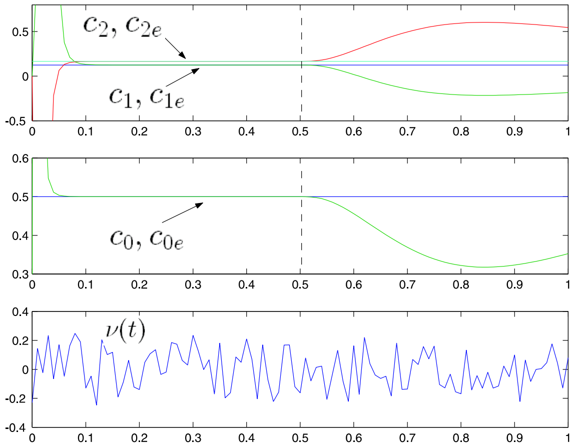

*Figure 3. A sequence of noisy measured polynomial signals, generated by a noisy system, and their estimated parameter values*

### 4.2.3. Nanovirology

The atomic force microscope (AFM) is unique in its capability to capture high-resolution images of biological samples. This capability will become more valuable to biological sciences if AFM additionally acquires an ability of high-speed imaging, because “direct and real-time visualization” is a straightforward and powerful means to understand biomolecular processes. With conventional AFMs, it takes more than a minute to capture an image, while biomolecular processes generally occur on a millisecond timescale or less. In order to fill this large gap, various efforts have been carried out in the past decade. Our objective is to apply the ALIEN methods so as to break the limitations and lead to the development of a truly useful high-speed AFM for virology with very good nanometer resolution.

We already got significant advances. The Coksakie virus $B4$ in its structural form at $37^oC$ has been imaged for the first time by atomic force microscopy (AFM). These virus particles were spread on glass substrates. They are roughly spherical, reasonably uniform, and have diameters of about 30 nanometers. This work which is managed by Olivier GIBARU, is done in collaboration with Didier HOBER director of the virology team of CHRU Lille (Univ. Lille 2) and Sébastien DUCOURTIEUX from the LNE. The research activity of the virology team concerns the involvement of the enterovirus in the disease of diabetes of kind one. The measure by AFM will allow us to improve the knowledge of enterovirus (30 nm) in particular their interactions with antibodies enabling the infection of human cells through an interaction (with a piece) of a protein called VP4

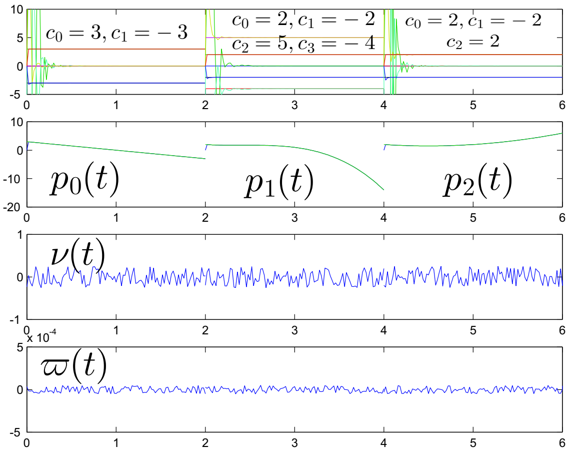

*Figure 4. Identification of a discontinuity time in a perturbed time-polynomial signal parameter identification process.*

of the virus capsid. In addition, it will be possible to visualize by AFM any viruses attached to various media for dealing with the nosocomial diseases. Pierre SAUTER, recruited by INRIA Lille - Nord Europe in post-doc, will allow us to optimize the process of creating viruses samples in order to improve the resolution of their details. These results are very encouraging!

# 5. Software

## 5.1. Expanded Lie Point Symmetry

**Keywords:** *observability/identifiability*, *simplification*, *system of parametric ordinary differential/difference equations*.

**Participants:** Alexandre Sedoglavic [correspondant], François Ollivier.

ELPS is a pilot implementation (coded as a maple package) that allows to reduce the number of parameter of parametric (ordinary) differential/difference/algebraic systems when the considered system have affine expanded Lie point symmetries (see http://wwww.lifl.fr/~sedoglav/Software and [96]). Given a model, ELPS allows to test its identifiability/observability and to reformulate the model if necessary.

Before analysing a parametric model described by a differential/difference system, it is useful to reduce the number of relevant parameters that determine the dynamics. Usually, presentation of this kind of simplification relies on rules of thumbs (for example, the knowledge of units in which is expressed the problem when dimensional analysis is used) and thus, can not be implemented easily. However, these reductions are generally based on the existence of Lie point symmetries of the considered problem. The package ELPS uses this strategy in order to reformulate the considered model if it is not observable/identifiable and thus simplify further computations. Example: let us consider the classical Verhulst's model:

$$\mathrm{dx/dt} = (\mathrm{a} - \mathrm{bx})\mathrm{x} - \mathrm{cx}, \quad \mathrm{da/dt} = \mathrm{db/dt} = \mathrm{dc/dt} = 0, \quad \mathrm{dt/dt} = 1. \tag{23}$$

with output $y = btx$. The package ELPS determines that there is a 4-dimensional Lie group of transformations that act on this model but leave its solutions set and its output invariant. Using these informations and assuming that $a \neq c$ and $b \neq 0$, the code gives automatically a representation of the flow $(t, x)$ of (23) using parametrization: $t = \mathbf{t}/(a-c),\ \ x = (a-c)\mathbf{x}/b$, where $(\mathbf{t}, \mathbf{x})$ is the flow of the following *simpler* differential equation $\mathrm{d}\mathbf{x}/\mathrm{d}\mathbf{t} = (1-\mathbf{x})\mathbf{x},\ \ \mathrm{y} = \mathbf{t}\mathbf{x}$. In this formulation of (23), parameters $a$ and $c$ were lumped together into $a-c$ and its state variables $x$ and $t$ were *nondimensionalise*. The complexity of the whole process is polynomial time with respect to input's size and is based on the result [63].

**observability** — In control theory, *observability* is a measure for how well internal states of a system can be inferred by knowledge of its external outputs.

**identifiability** — When a process is described a by differential equations, the validation of a model implies to be able to compute a set of parameters allowing to product a theoretical behavior corresponding to experimental data. Before any identification of the parameters, a preliminary issue is to study *identifiability* which means that there is a unique set of parameters corresponding to a given behavior of the system.

# 6. New Results

## 6.1. State and parameter estimation in finite dimensional systems

**Participant:** Michel Fliess [correspondant].

The techniques developed in our project result in fast closed-loop state estimation [16], [46], [47] and fast closed-loop parameter estimation [28], [54], [52], for large classes of linear and nonlinear systems. The fact that we can achieve such results in closed loop seems to be new because most of the above points were until now open problems and subject to a huge literature. Other results concern closed-loop perturbation attenuation with application to the cart-pendulum problem [23], [24], closed-loop state estimation with unknown inputs with application to cryptography [26], [27], [21], or fast parametric estimation for macroscopic traffic flow model [32], [51]. Some successful applications were also achieved in the automotive industry in collaboration with the team led by Prof. B. d'Andréa-Novel at the École des Mines de Paris [31], [48].

## 6.2. Numerical differentiation

**Participant:** Mamadou Mboup [correspondant].

New results in this field concern image processing if derivation is not considered with regard to time but to space ($2-$D derivation in [44]). Those techniques are also now applied to mathematical finance (in particular to the forecast of foreign exchange rates [36]). They also concern control since the corresponding algorithms constitute the basis for the "model-free" control techniques.

## 6.3. Model-free control

**Participant:** Cédric Join [correspondant].

The great difficulty to obtain a simple but sufficiently accurate model for most concrete industrial systems has prompted us to look at model-free control [29]. This very elementary model, which is valid during a very short time window and continuously updated, has already met some success with several concrete situations: throttle control for IC engines (with APPEDGE and PSA) [30], stop-and-go automotive control strategy (in collaboration with the École des Mines de Paris and PSA) [49], hydroelectrical dams modeling and control (in collaboration with EDF, contract and patent under progress), shape memory actuators (collaboration with the team directed by Prof. E. Delaleau at the École Nationale des Ingénieurs de Brest, [39]). Those ideas were also used to design so-called "intelligent" PID controllers [35].

## 6.4. Delay estimation

**Participant:** Lotfi Belkoura [correspondant].

A new contribution is concerned with delay estimation in the more general case of unstructured entries [14], [61]. Combined with the ALIEN project techniques, the delay estimation problem is tackled using the well known properties of the convolution product [33]. The following example illustrated this approach on an elementary retarded integrator:

$$\left\{\begin{array}{l} \dot{y} = \delta_\tau * ku \\ (t-\tau)\dot{y} = \delta_\tau * ktu \end{array}\right. \quad \Rightarrow \quad \tau = \frac{ty * u - y * tu - \int_0^t u * y}{u * y}. \tag{24}$$

EDF-CIH (Centre d'Ingénierie Hydraulique) is interested in using those methods for delay estimation in hydroelectrical dams and a contract was signed in 2008.

## 6.5. Embedded systems and software

**Participant:** Jean-Pierre Richard [correspondant].

Our results on linear systems with delay recently found other applications in networked control systems [95], in particular for Ethernet/Internet-in-the-loop control [41], [40], [45].

## 6.6. Robust control techniques for uncertain hybrid systems

**Participant:** Wilfrid Perruquetti [correspondant].

In [37], previous works on real-time estimation, via algebraic techniques, were extended to the recovering of the switching signal and of the state for switching linear systems. Singular inputs for which the switched systems become undistinguishable were also characterized.

## 6.7. Change-point detection

**Participant:** Mamadou Mboup [correspondant].

Change-point detection and estimation is an important topic in many fields stemming from signal processing to econometrics, where our techniques allow an efficient online detection even if the signal to be analyzed is corrupted by quite strong noises [22]. The main applications are concerned with the analysis of neurophysiological signals (Fast signal processing for early detection of Epilepsy in EEG, PhD Thesis of Z. Tiganj), with image processing (ongoing joint work [42] on robust curvature extrema detection) and with signals stemming from oil industry (Schlumberger).

## 6.8. Nanovirology

**Participant:** Olivier Gibaru [correspondant].

Recent developments deal with the algebraic estimation of the parameters of noisy sinusoidal signals and the analysis of the estimation [43].

A collaboration on the problems of fast estimation and closed-loop control for AFM has been initiated with IEMN (Institut d'Electronique de Microélectronique et de Nanotechnologie) and IRCICA (Institut de Recherche sur les Composants logiciels et matériels pour l'Information et la Communication Avancée) .

# 7. Contracts and Grants with Industry

## 7.1. DGA Grant

This grant—started at LIX/École polytechnique in November 2006—aims at developing the knowledge belonging to the research field of Network Centric Warfare that constitutes the core of modern defense systems. This project is constituted by 3 parts: *Systèmes complexes distribués mobiles sécurisés*, *Réseaux mobiles sécurisés* and *Signal*. The team-project ALIEN is involved in this last part: the grant supported the F. Woittennek post-doctoral stay and the applications of ALIEN estimation's techniques to this project.

## 7.2. EDF contracts

Two contracts were signed in 2008 with EDF-CIH to study control and estimation problems in hydroelectrical dams. The first one is the design of model-free control strategy for the water level regulation and the second one is concerned with the fast identification of parameters and delays for such a process.

## 7.3. Collaboration with PSA

Contract on the control of throttles with PSA through APPEDGE.

## 7.4. Collaboration with Schneider

Contract on the control of electric devices with Schneider through APPEDGE.

# 8. Other Grants and Activities

## 8.1. Regional actions

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

## 8.2. National actions

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".

## 8.3. European actions

### *8.3.1. PAI (Integrated Action Program) with T.U. Dresden, Germany*

A magnetic shaft benchmark in the LAGIS, Lille, in collaboration with Pr. Joachim Rudolph from the Technical University of Dresden. The first experimental tests were conducted in February 2007 and J. Rudolph visited us from $1^{rst}$ to 31 March 2008 in order to develop and apply fast identification techniques on this benchmark.

## 8.4. International actions

### *8.4.1. INRIA–STIC Tunisia Project*

INRIA grant for the cooperation with Tunisia (2005-2008).

# 9. Dissemination

## 9.1. Scientific Community

### 9.1.1. Organization of Workshops and invited sessions

- Workshop “Closed loop identification and estimation techniques in linear and nonlinear control” at the IEEE MED’08 conference (1 day, June 2008, Ajaccio). Speakers: Michel Fliess, Cédric Join, Wilfrid Perruquetti, Joachim Rudolph.
- Workshop on "Identification and Model-Free Control", at the Johannes Kepler University Linz, Austria on December 12-13 2008. Speakers: Michel Fliess, Cédric Join.
- Invited session on fast algebraic estimation at IEEE MED’08 conference.
- Jean-Pierre Barbot was co-organizer of the first Inter-GDR on Automatic and Chaos meeting, 17 and 18 December 2008 ENSEA, Cergy-Pontoise.

### 9.1.2. Editorial boards

- Jean-Pierre Barbot is currently Associate Editor of *IEEE Transactions on Circuits and Systems II*.
- Michel Fliess is currently Associate Editor of *Forum Mathematicum* and *Journal of Dynamical and Control Systems*.
- Thierry Floquet is currently Associate Editor of *e-sta*.
- Wilfrid Perruquetti is currently Editor in chief of *e-sta* (e-revue Sciences et Technologie de l’Automatique).
- Jean-Pierre Richard is currently Associate Editor of *Int. J. of Systems Science*.

### 9.1.3. Program Committees

- IFAC Technical Committees: The members of ALIEN 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 1.5 Networked Systems, TC 2.2 Linear Control Systems, TC 2.3 Nonlinear Control Systems, TC 2.5 Robust Control.
- Jean-Pierre Barbot is vice-chair of the international program committee of The IFAC Conference: CHAOS 09 Queen Mary, University of London, June 22nd-24th, 2009.

### 9.1.4. Reviews

The members of ALIEN 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, 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 Modelling and Simulation, Journal of the Franklin Institute, ...

### 9.1.5. Scientific and administrative responsibilities

- Since 2007, Wilfrid Perruquetti has been appointed as a representative of the DGRI (Direction Générale de la Recherche et de l’Innovation) from the French Ministry of Education and Research.
- Jean-Pierre Richard is president of the GRAISyHM, federation from the French government.
- Jean-Pierre Richard is an expert for the evaluation of projects submitted to ANR, CNRS, DGRI.

## 9.2. Theses and Habilitations

Riachy, Samer. *Contribution à l'estimation et la commande de systèmes mécaniques sous-actionnés*. PhD from the École Centrale de Lille, $1st$ December 2008 Research grant Ministry of research, 2005-2008. Reviewers: Canudas-de-Witt, C. (Research Scientist CNRS, Univ. Grenoble, Glumineau, A. (Pr. École Centrale de Nantes). Examiners: d'Andréa-Novel, B. (Pr. École des Mines de Paris), Delaleau, E. (Pr. École Nationale d'Ingénieurs de Brest), and Perruquetti, W. (Pr. École Centrale de Lille). Directors: Richard, J.P. (Pr. École Centrale de Lille), Floquet, T. (Research Scientist CNRS, LAGIS).

The team members were also involved in numerous examination committees.

## 9.3. Stays and Invitations

- Jean-Pierre Barbot was nominated as a Visiting Professor at Northumbria University in 2008.
- From 12th to 26th November 2008, T. Floquet worked at the Technical University of Dresden (Germany) with Pr. J. Rudolph on the fast algebraic identification of nonlinear systems applied to magnetic shafts.
- Mamadou Mboup was invited at the University of Sao Paulo and the University of Campinas in Brazil, from October 22nd to November 1st 2008. This invitation enters within the framework of a FAPESP/CNRS project.
- W. Perruquetti was invited in April 2008 by the French embassy in Japan to prepare the First France-Japan Research Workshop on Human-Robot Interaction[14]. During this first stay he visited, in a week, more than 20 robotics laboratories in Japan in order to prepare the workshop. Then, in October, he was invited to give a talk on the ALIEN techniques at the First France-Japan Research Workshop in Sendai, Japan. The outcome of this meeting is the reinforcement of some cooperation (especially with Keio University), and new contacts were established with Prof. Nakamura and the JRL.

## 9.4. Visitors

- Joachim Rudolph, Professor, Technical University of Dresden (Germany), March 2008, invited by École Centrale de Lille.
- Guiseppe Fedele, Professor, University of Calabria (Italy), September-November 2008 financially supported by his own country.
- Sonia Rezk, PhD student in Tunisia under the joint guidance of C. Join (ALIEN) and S. El Asmi, Professor at Supcom, Tunis, July 2008, financially supported by INRIA-ALIEN.

## 9.5. 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 | Advanced control and communications | Master | Univ. Cergy-Pontoise |
| Barbot | Process Control | Master | Univ. Tlemcen, Algeria |
| Fliess | Advanced control | Master | École polytechnique, Tunis |
| Gibaru | Applied Mathematics | Master | USTL-UVHC-ULCO |
| Mboup | Advanced Signal Processing | Master | Univ.Paris 5, ENIT-Tunis |
| Perruquetti | Nonlinear control | 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 |

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[14] see http://www.lirmm.fr/FJWHRI08/Home.html

- Lotfi Belkoura is in charge of the Master Thesis training in control of USTL 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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