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 : Modeling, Optimization, and Control of Dynamic Systems

Activity Report

2009

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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). Its evaluation was held this year (March, 2009) in the framework of Theme 3 of INRIA (Modeling, Optimization and Control of Dynamic Systems). The Evaluation Committee decided (October 17, 2009) to support ALIEN for the next 4 years. Note that ALIEN was also evaluated in the framework of AERES in Lille, AERES in Saclay, and AERES in Lille-LAGIS CNRS UMR 8146.

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 different places: Paris, 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. Of course, *algebraic tools, identification and estimation* are not recalled here since any member of ALIEN is concerned with.

	Upstream Researches	*Application Fields*
Saclay LIX	Computer algebra - Nonstandard analysis - Signal - Linear & nonlinear control - Delays	
Reims CReTIC	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)	Aeronautics - Magnetic bearings - Friction estimation - Networked control - Robotics
Nancy CRAN	Diagnosis - Control - Signal	Industrial processes - Signal & image processing

2.4. Highlights of the year

- Thierry Floquet defended his "Habilitation to supervise doctoral research" at 29 Oct, 2009 from Lille 1 Université des Sciences et Technologies [12].
- Patent pending in December 2008 with EDF on the control of hydroelectric projects.
- Confirmation of the importance of "model-free control" from various concrete examples [102], [43], [52], [91], [29], [88].
- New results in quantitative finance [35], [45], [46].
- Adaptation of the ALIEN techniques to hybrid systems [62], [63], [66] with switches.
- Confirmation of the ALIEN techniques to models with delay [15].
- Hints on multivariable differentiation, with applications to image and video processing.
- Plenary presentations by Michel Fliess and Cédric Join at SYSID09: "Model-free control and intelligent PID controllers: towards a possible trivialization of nonlinear control" [36], and at International Conference on Systems Theory: "Modeling, Analysis and Control: A mathematical proof of the existence of trends in financial time series" [35].

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.

[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 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

$$P \begin{pmatrix} \theta_1 \\ \vdots \\ \theta_r \end{pmatrix} = Q, \qquad (2)$$

where:

- θ_i, $1 \leq i \leq r$, 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 $t^\nu \frac{d^\mu \xi}{dt^\mu}$, $\mu, \nu \geq 0$, where ξ 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:

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

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 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.

[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.

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 [83].

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 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:

[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 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 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 $u = u_0 H$. 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 [75]. 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.

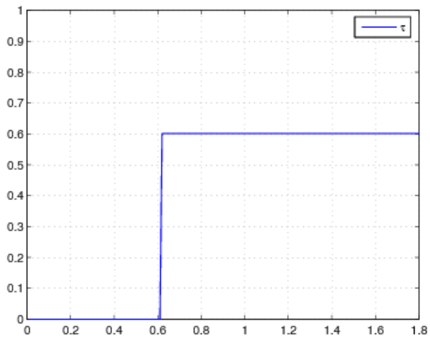

Figure 1. Delay τ identification from algorithm (15)

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 $t < \tau$.

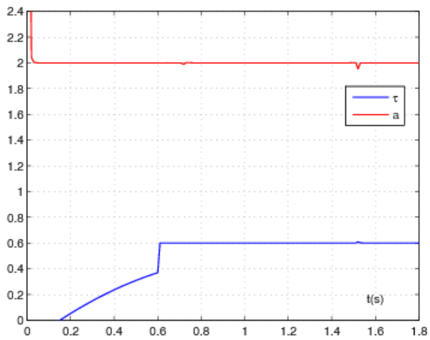

Figure 2. Simultaneous identification of a and τ from algorithm (16)

3.2. 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 [77], [79], [90], [89], [92], [93], 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 [95], [25], 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., $s^\mu \frac{d^\iota X_N}{ds^\iota}$, $\mu = 1, \cdots, N$, $0 \le \iota \le N$, 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 $0 \le t < \rho$. Approximate $x(t)$ in the interval $(0, \varepsilon)$, $0 < \varepsilon \le \rho$, 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., $X(s) = \sum_{\nu \ge 0} \frac{x^{(\nu)}(0)}{s^{\nu+1}}$. Denote by $[x^{(\nu)}(0)]_{e_N}(t)$, $0 \le \nu \le N$, 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 [87] 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 [101] are inherently connected with the developed algebraic numerical differentiators. A least-squares interpretation then naturally follows [94], [95] 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 [99]). 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 $n \ge 2$, 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. Application domains

The previous research report of ALIEN has already presented several applications of ALIEN techniques, related to control applications (closed loop identification, state reconstruction, unknown input observers, fault diagnosis, secure communication, delay identification, time-delay system and hybrid systems) and signal, image and video processing (compression, demodulation of signal, detection of abrupt changes and so on) with 3 patents [80], [82], [81].

5. Software

5.1. Expanded Lie Point Symmetry

A software "Expanded Lie Point Symmetry", coded as a maple package, was developed by Alexandre Sedoglavic and François Ollivier [76], [100] allowing to reduce the number of parameter of parametric (ordinary) differential/difference/algebraic systems when the considered system have affine expanded Lie point symmetries. Given a model, ELPS allows to test its identifiability/observability and to reformulate the model if necessary.

6. New Results

6.1. Quantitative finance

Participants: Michel Fliess, Cédric Join.

We are settling a longstanding quarrel in quantitative finance by proving the existence of trends in financial time series thanks to a theorem due to P. Cartier and Y. Perrin, which is expressed in the language of nonstandard analysis [78]. Those trends, which might coexist with some altered random walk paradigm and efficient market hypothesis, seem nevertheless difficult to reconcile with the celebrated Black-Scholes model. In [35], we proved the existence of those trends for financial time series via nonstandard analysis. Moreover, a new model-free definition of the beta coefficient, which plays an important role in systematic risk management is proposed in [45]. This setting, which is based on the work [35], leads to convincing computer experiments which are easily implementable. These works allow us to define two new technical indicators for trading systems and risk management [46], where recent fast estimation techniques of algebraic flavor are used [25]. The first indicator tells us if the future price will be above or below the forecasted trend-line and the second one predicts abrupt changes.

6.2. Left invertibility and its applications

Participants: Jean-Pierre Barbot, Thierry Floquet, Gang Zheng, Lei Yu.

For secure communication based on chaos, we introduced a new class of chaotic hybrid delayed systems, which is at our opinion a real improvement with respect to the known plain text attack [67]. In the same way our theoretical improvement with respect to the left invertibility problem [21] has a great potential application in diagnostic, secure communication and identification. Moreover, we gave a new method to classify the way to chaos with respect to non smooth bifurcation [16] and some other preliminary results were given at the 2nd IFAC Chaos conferences [39]. Since normal form [17] can be used to analyze and classify systems with respect to control theory properties, we have used for the first time such normal form for studying whether a system is flat or not [40]. Some applications in power electronic [50] and Tire/road identification [65] were realized.

6.3. Model-free control

Participants: Michel Fliess, Cédric Join.

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 [84], [36]. 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) [91], stop-and-go automotive control strategy (in collaboration with the École des Mines de Paris and PSA) [102], [29], [43] 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, [88], [52]). Those ideas were also used to design so-called "intelligent" PID controllers [85], where the tuning of parameters becomes quite straightforward, even with highly nonlinear and/or time-varying systems [36].

6.4. Time-delay systems

Participants: Jean-Pierre Richard, Lotfi Belkoura, Kaouther Ibn Taarit.

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: "Online identification of systems with delayed inputs" [75]. Further works have extended this first result, in particular a paper in Automatica [15]. This paper also introduced structured entries, such as discontinuities, as another field of application for the same techniques. This first step now allows for the investigation of systems with switches and, in particular, systems with dry friction.

Among the many applications of time-delay systems, note they constitute a basic tool for modelling systems controlled over communication networks. During the year 2009, we improved and implemented our results on Master-Slave control with Internet-in-the-loop. The idea was to develop an observer that enables the Master to estimate the present state of the Slave despite the variable communication delays and packet losses coming from the network. This technique has now been implemented (remote control of a light mobile robot, with poor computation power, through Internet and Blutooth connections). The control algorithms have been improved so that the controller can adapt his gains to the available quality of service (QoS) of the network [55], [56], [57], [72].

6.5. Hybrid dynamical systems

Participants: Wilfrid Perruquetti, Lotfi Belkoura, Thierry Floquet, Yang Tian.

Concerning hybrid dynamical systems, during the year 2009, we firstly extended our previous work on the estimation of the switching signal and of the state for switching linear systems [86] to the perturbed case when the perturbation is structured that is when the perturbation is unknown but known to satisfy a certain differential equation (for example if the perturbation is constant then its time-derivative is zero) (see [47]). At the same time, we characterized singular inputs and/or perturbations for which the switched systems become undistinguishable.

Secondly, since the knowledge of the switching function plays a central role in observation and control of switched systems, we have developed, within the framework of ALIEN techniques (by using some algebraic manipulations), new algorithms in order to estimate in "real-time" the switching time sequence of some classes of switched linear systems with the knowledge of the continuous state only (see [47], [62], [63]).

6.6. Multi-dimensional differentiation

Participants: Samer Riachy, Mamadou Mboup, Jean-Pierre Richard.

Multivariate signals are involved in all branches of physics. To name a few, they can be in digital images and videos, telecommunication, geology, archeology and econometrics. Estimating partial derivatives of multi-dimensional signals is an old ill-posed problem. Using multivariate Taylor series expansion, multivariate Laplace transform and adequate algebraic manipulations we obtain very efficient partial derivatives estimators [97], [96], [98]. In fact those estimators correspond to orthogonal projection in a Jacobi basis i.e., a least squares minimization. In addition they can be implemented as finite impulse digital filters. We combine somehow optimization and fast computation. Applications in image processing namely motion detection are in progress.

6.7. Detection of abrupt changes in electro-physiological signals

Participants: Mamadou Mboup, Lotfi Belkoura, Zoran Tiganj.

Decoding the neural information is one of the most important problems in neuroscience. As it is well known, this information is conveyed by the spike train of electrical discharges, called action potential. One of the difficulties stems from the impossibility, in general, to record the activity of a single neuron but only a mixture activity of all neurons in a measured region. Imperative requirement for the neural information decoding is the ability of action potential detection and sorting (finding out which action potentials are fired by the same neuron).

To make the detection and sorting easier, recording systems usually consist of several electrodes. Each electrode receives the action potentials from all the surrounding neurons. The contribution from a single neuron depends on its distance from the electrode and on the type of the tissue that the action potentials go through.

Recently, we proposed a new method for action potentials detection [64], in which we show how a new algebraic technique for numerical differentiation presented in subsection 3.2 can lead to a very good performances in neural spike detection as compared to existing methods. We also combine the proposed method with ICA in order to obtain spike sorting.

6.8. Atomic force microscope

Participants: Olivier Gibaru, Wilfrid Perruquetti, Dayan Liu, Stéphane Thiery.

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 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.

Recently, we applied the non asymptotic algebraic methods developed in ALIEN to improve the measurement accuracy and the dynamic of AFM [58]. This improvement allows us to improve the measurements in liquid of biological structures such as the virus capsid. This work was done in collaboration with the French National Laboratory (LNE) located in Trappes. Indeed, this laboratory has an AFM with an open electronic system which allows us to implement our methods and our algorithms. The results are very encouraging.

6.9. Multi-axes control systems for machining

Participants: Olivier Gibaru, Marouene Oueslati.

Nowadays, the adaptation of industrial robots to carry out high-speed machining operations is strongly required by the manufacturing industry. This new technology of machining process demands the improvement of the overall performances of robots in order to achieve an accuracy level close to that realized by machine-tools. In [28], we present a method of trajectory planning adapted for continuous machining by robot. Our methodology is based on a parametric interpolation of the geometry in the operational space. FIR filters properties are exploited to generate the tool feedrate with limited jerk. This planning method is validated experimentally on an industrial robot for machining. The geometric trajectories of the end-effector of the robot are based on quintic C^2-continuous splines. These splines are calculated according to a new method where we minimize the L^1 norm of second order derivative of the quintic spline. This method prevents the Gibb's phenomenon. This optimization is a nonlinear problem. It is solved by the use of an efficient local strategy which allows us to calculate exactly all the algebraic solutions. The details of this new method are given in [27].

All these systems have to be identified or observed. For this, we need to estimate the derivatives up to a finite order of the output of these systems. So, we currently study the optimal parameters to be used so as to define real time derivative estimators with a minimum time-delay and a minimum noisy contribution part. In [58] an analysis of the error due to a corrupting noise is conducted for a new affine derivative estimator. Some upper-bounds on this error are given. A convincing simulation example gives an estimation of the state variable of a nonlinear system when the measured output is noisy.

7. Contracts and Grants with Industry

7.1. EDF contracts

Two contracts (from 2008 till november 2009) with EDF-CIH (Centre d'Ingénierie Hydraulique) to study control and estimation problems in hydroelectrical dams. The first one is concerned with the fast identification of parameters and delays for such a process and the second one is the design of model-free control strategy for the water level regulation. The third contract with EDF is in the final phase of signature.

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 2008-2009 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".
- Model-free control: collaborations with Professor Brigitte D'Andréa-Novel at Mines ParisTech and Professor Emmanuel Delaleau at ENIB.
- 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.

8.3. European actions

8.3.1. Collaboration with Saarlandes Universität, Germany

Thierry Floquet and Pr. Joachim Rudolph, from Saarlandes Universität, co-supervised a Master student in spring 2009. Since October 2009, they have been co-supervising a PhD student on the problem of fast identication and closed-loop control for magnetic shaft.

8.4. International actions

8.4.1. International collaborations

- Collaboration with Professors Emilia Fridman (Tel Aviv University) and Joao Manoel Gomes da Silva (UFRGS, Porto Allegre, Brasil) on time-delay systems.
- Co-supervision (French "co-tutelle") of the PhD thesis of Mrs Ibn Taarit with Professor Mekki Ksouri, ENIT Tunis, Tunisia, on pseudo-spetra for delay identification.
- Collaborations with Professor Guiseppe Fedele from University of Calabria, Italy, on "Model-free control".
- Programme Hubert Curien VOLUBILIS (Maroc, Integrated Action MA/09/211) between LAGIS (Université Lille1), ALIEN INRIA and Laboratory of Electronic, Information and Biotechnology of Department of Science at University Moulay Ismail of Meknès.

9. Dissemination

9.1. Scientific Community

9.1.1. Organization of Workshops and invited sessions

- Olivier Gibaru co-organized Workshop "Approximation, Geometry and Images" at ARTS ET METIERS ParisTech with SMAI-AFA (the Society of Industrial and Applied Mathematics), November 13, 2009, Paris, France.
- Invited session on Workshop "Multidimensional (nD) Systems" June, 2009, Greece. Speakers: Daniel Alpay and Mamadou Mboup.

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 was, until July 2009, 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*.
- Mamadou Mboup is currently Associate Editor of *African Diaspora Journal of Mathematics*.

9.1.3. Program Committees

- Jean-Pierre Barbot was vice-chair of the international program committee of The IFAC Conference: Chaos 09 Queen Mary, University of London, June 22nd-24th, 2009.
- Mamadou Mboup was in committee of IEEE International Workshop on Machine learning for Signal Processing, 2009
- JD-JN-MACS 2009: The members of ALIEN attended the 3èmes Journées Nationales du GDR MACS, à Angers, France.
- 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 1.3 - 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.
- CIFA 2010: Jean-Pierre Richard is the president of international program committee and the chairman of session "emergent domains". Wilfrid Perruquetti is the chairman of session "hybrid dynamic systems". Michel Fliess, Jean-Pierre Barbot, Mamadou Mboup, Lotfi Belkoura and Thierry Floquet are involved in the international program committee.

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

- From 2007 till Septembre 2009, Wilfrid Perruquetti was a representative of the DGRI (Direction Générale de la Recherche et de l'Innovation) from the French Ministry of Education and Research. Wilfrid Perruquetti is an expert for the evaluation of projects submitted to ANR, ARC (Australian Research Council).
- 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 and AERES.
- Thierry Floquet is an expert for the evaluation of projects submitted to Israel Science Foundation.
- Lotfi Belkoura is heading the Master "AG2i: Automatique, Génie Informatique et Image", University of Lille 1 and École Centrale de Lille.
- Jean-Pierre Richard is heading the 3rd year professional training "Research" of the École Centrale de Lille.
- The team members are also involved in numerous examination committees of theses and Habilitations, in France and abroad.

9.2. Theses and Habilitations

Thierry Floquet. *Commande et observation à structure variable des systèmes non linéaires*. HDR from Lille 1 Université des Sciences et Technologies, $29th$ October 2009 .

- Reviewers:
  - Bernard Brogliato, Research director INRIA Rhône-Alpes.
  - Mohamed Darouach, Professor, CRAN, Université H. Poincaré, Nancy I.
  - Hebertt Sira-Ramirez, Research director of CINVESTAV, Mexico.
- Examiners:
  - Michel Fliess, Research director CNRS, LIX, École Polytechnique.
  - Jean-Pierre Richard, Professor, LAGIS, École Centrale de Lille.
  - Joachim Rudolph, Professor, Universität des Saarlandes, Saarbrücken, Germany.
  - Marcel Staroswiecki, Professor, Université de Lille I.
- Director: Wilfrid Perruquetti, Professor, LAGIS, École Centrale de Lille.

The team members were also involved in numerous examination committees.

9.3. Visitors

- Yuri Orlov, Research director at CISES, Ensenada, Mexico, June 2009, invited École Centrale de Lille.
- Daniel Alpay, Professor, Ben-Gurion University of the Negev, Septembre 2009, financially supported by Université de Ben Gurion, Israël.
- Mekki Ksouri, Professor, ENIT, Tunis, invited by Université Lille1.
- Hebertt Sira-Ramirez, Research director of CINVESTAV, Mexico, October 26-30, 2009, invited by École Centrale de Lille.
- Horst Schulte, Professor, University of Applied Sciences, Berlin, December 9-10, 2009, invited by École Centrale de Lille.

9.4. Participation to conferences, seminars

- Workshop of Control Theory: On the Way to New Application Fields. Oberwolfach, Germany, February 22-28, 2009. (Michel Fliess).
- ICA09: 8th International Conference of Independent Component Analysis and Signal Separation. Paraty, Brazil, March 15-18, 2009. (Mamadou Mboup).
- International Conference on Systems Theory: Modeling, Analysis and Control. Fes, Morocco, May 25-28, 2009. (Michel Fliess and Lotfi Belkoura).
- ACC09: IEEE American Control Conference. St. Louis, Missouri, USA, June 10-12, 2009. (Jean-Pierre Barbot).
- Chaos09: 2nd IFAC Conference on Analysis and Control of Chaotic Systems. London, UK, June 22-24, 2009. (Jean-Pierre Barbot).
- NDS09: 6th International Workshop on Multidimensional (nD) Systems. Thessaloniki, Greece, from June 29 to July 1, 2009. (Mamadou Mboup).
- SYSID09: 15th IFAC Symposium on System Identification. Saint-Malo, France, July 6-8, 2009. (Michel Fliess, Cédric Join and Thierry Floquet).
- ECC09: 10th European Control Conferences. Budapest, Hungary, August 23-26, 2009. (Michel Fliess).
- ADHS09: 3rd IFAC Conference on Analysis and Design of Hybrid Systems. Zaragoza, Spain, September 16-18, 2009. (Wilfrid Perruquetti and Thierry Floquet).
- COGIS09: Cognitive Systems with Interactive Sensors. Paris, France, November 16-18, 2009. (Michel Fliess).
- Sixième workshop RECAP, Réseaux de Capteurs et Actuateurs. Grenoble, France, November 24-26, 2009. (Wilfrid Perruquetti).
- CDC09: 48th IEEE Conference on Decision and Control and 28th Chinese Control Conference. Shanghai, China, December 16-18, 2009. (Wilfrid Perruquetti, Olivier Gibaru, Gang Zheng, Dayan Liu and Yang Tian).
- Colloque DYCOEC, Journées du GDR DYCOEC (GDR 2984). Rouen, France, December 14-16, 2009. (Jean-Pierre Barbot).

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

- Jean-Pierre Richard was the organizer, with Prof. M. Ksouri (ENIT, Tunis), of a one-week school on "Mathematics for Research and Development", March 21-27, 2009, Djerba. This event was organized after the first one (December 2007) and was supported by INRIA and other institutions from Tunisia. As a result of both events, a 400-pages book (http://syner.ec-lille.fr/~richard/ouvrages.htm) was published and distributed to the attending students of the second school, and is now for sale in Tunisia at the price of 7 TDN (less that 5 euros). The lecturers were : A. Achour (Fac.Sc. Tunis), L. Belkoura (ALIEN, Univ. Lille 1), M. Dambrine (Univ. Valenciennes), M. Ksouri (ENIT Tunis), H. Mounier (Univ. Paris Sud), J.-P. Richard (ALIEN, EC Lille), J. Rudolph (T.U. Dresden), W. Perruquetti (ALIEN, EC Lille)
- 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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Major publications by the team in recent years

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[2] L. BELKOURA, J.-P. RICHARD, M. FLIESS. *Parameters estimation of systems with delayed and structured entries*, in "Automatica", vol. 45, n^o 5, 2009, p. 1117-1125, http://hal.inria.fr/inria-00343801/fr/.

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Year Publications

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[12] T. FLOQUET. *Commande et observation à structure variable des systèmes non linéaires*, Lille 1 Université de Sciences et Technologies, 29, Oct 2009, HDR.

Articles in International Peer-Reviewed Journal

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International Peer-Reviewed Conference/Proceedings

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