INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Project-Team ALIEN

ALgèbre pour Identification et Estimation Numériques

Futurs

THEME NUM

Activity Report

2007

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2. Overall Objectives

2.1. History

After being initiated as a team **in 2004**, the project-team ALIEN was created this year (2007), **on July 1st**. Its previous activity report (2006) was explaining the evolution from the initial group to the present one, so we shall not bring it up again.

2.2. Objectives

ALIEN aims at designing new real-time estimation algorithms. Within the immense 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 derivatives of a signal, parametric estimation of a linear/nonlinear model (including delay systems).

The novelty rests 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 our 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 preliminary results.

2.3. Members complementarity

The members of the ALIEN project are distributed between 3 locations: 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 everybody in ALIEN is concerned with.

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

2.4. Highlights of the year

- Michel Fliess obtains the biennial Jacques-Louis Lions grand prize 2007 of the french Académie des Sciences.
- Breakthrough paper [43] was published in the conference IEEE MED. It opens a new way for the on-line estimation of the nth order derivatives of a signal, without computing the $(n-1)$th one.
- We have stimulating perspectives for nanobiology applications of ALIEN techniques: this project gathers biologists[2], physicists[3] and ALIEN's members. First results were already obtain for the imaging of a 27 nanometers virus.

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

[2] from CHRU & Univ. Lille II

[3] Specialists of Atomic Force Microscope from Laboratoire National de métrologie & d'Essais

3. Scientific Foundations

3.1. Parametric estimation and its application

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 observed 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.

Finding a "good" approximation of the components of Θ has been the subject of a huge literature in various fields of applied mathematics. Most of those researches have been done in a probabilistic setting, which necessitates a good knowledge of the statistical properties of n. Our project[4] is devoted to a new standpoint which does not require this knowledge and which is based on the following tools, which are of algebraic flavor:

- differential algebra[5], 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[6].

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.

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.

3.1.1. 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:

[4] Our works in this domain are already benefiting from: two *Actions Spécifiques* of the CNRS (RTP 24), one in control and the other in signal; one *Equipe Projet Multi-Laboratoire* of the CNRS (RTP 55), on control over networks; two *Math-STIC* programs from the CNRS.

[5] 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.

[6] 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.

$$\dot{y}(t) = ay(t) + u(t) + \gamma_0, \tag{2}$$

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 (2) reads:

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

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 :

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

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

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 $\nu > 0$,

$$s^{-\nu}\left[2s\widehat{y}(s) + s^2\widehat{y}'(s)\right] = s^{-\nu}\left[a(s\widehat{y}'(s) + \widehat{y}(s)) + s\widehat{u}'(s) + \widehat{u}(s)\right]. \tag{3}$$

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

$$a = \frac{2\int_0^T d\lambda \int_0^\lambda y(t)dt - \int_0^T ty(t)dt + \int_0^T d\lambda \int_0^\lambda tu(t)dt - \int_0^T d\lambda \int_0^\lambda d\sigma \int_0^\sigma u(t)dt}{\int_0^T d\lambda \int_0^\lambda d\sigma \int_0^\sigma y(t)dt - \int_0^T d\lambda \int_0^\lambda ty(t)dt} \tag{4}$$

Since $T > 0$ can be very small, estimation *via* (4) is very fast.

Note that equation (4) 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 (2), say:

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

it will be considered as fast fluctuating signal. The order ν in (3) determines the order of iterations in the integrals (3 integrals in (4)). 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 (4) in finite time;
- they are deterministic: no knowledge of the statistical properties of the noise n is required.

3.1.2. A second simple example, with delay

Now, let us consider the first order, linear system with constant input delay[8]:

[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 [54]. For further details, we suggest the reader to refer to it.

$$\dot{y}(t) + ay(t) = y(0)\delta + \gamma_0 H + bu(t-\tau). \tag{6}$$

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 now that 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:

$$\ddot{y} + a\dot{y} = \varphi_0 + \gamma_0\,\delta + b\,u_0\,\delta_\tau, \tag{7}$$

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):

$$\begin{array}{rcl} t^3\,[\ddot{y} + a\dot{y}] & = & \tau\,t^2\,[\ddot{y} + a\dot{y}], \\ bu_0\,t^3\delta_\tau & = & bu_0\,\tau\,t^2\delta_\tau. \end{array} \tag{8}$$

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

$$\tau = \frac{H^k(w_0 + a\,w_3)}{H^k(w_1 + a\,w_2)}, \qquad t > \tau, \tag{9}$$

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

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

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

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 denominator in the right hand side of (9) reaches a significant nonzero value.

Again, note the realization algorithm (9) 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 (8):

[9] In this document, in order to keep things simple, 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.

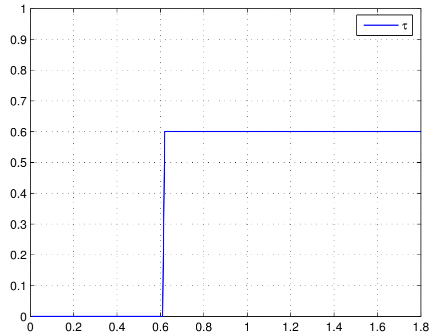

Figure 1. Delay τ identification from algorithm (9)

$$\tau(H^k w_1) + a\,\tau(H^k w_2) - a\,(H^k w_3) = H^k w_0, \tag{10}$$

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 $t < \tau$.

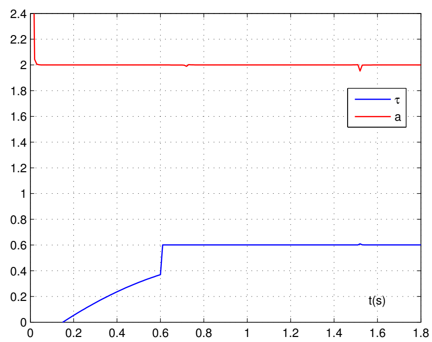

Figure 2. Simultaneous identification of a and τ from algorithm (10)

3.2. Fast estimation

3.2.1. 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

$$P \begin{pmatrix} \theta_1 \\ \vdots \\ \theta_r \end{pmatrix} = Q, \tag{11}$$

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 ξ is an input or output signal,
- the matrix P is *generically* invertible, i.e. $\det(P) \neq 0$.

3.2.2. How to deal with perturbations and noises?

With noisy measurements equation (11) becomes:

$$P \begin{pmatrix} \theta_1 \\ \vdots \\ \theta_r \end{pmatrix} = Q + R, \tag{12}$$

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.

3.2.2.1. 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.

By well known properties of the non-commutative ring of differential operators, we may multiply both sides of equation (12) by a suitable differential operator Δ such that equation (12) becomes:

$$\Delta P \begin{pmatrix} \theta_1 \\ \vdots \\ \theta_r \end{pmatrix} = \Delta Q + R', \tag{13}$$

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

3.2.2.2. 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.

3.2.2.3. Comments

Although the previous noise attenuation[10] may be fully explained *via* formula (13), its theoretical comparison[11] with today's literature[12] 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 [65].

3.2.3. Some hints on the calculations

The time derivatives of the input and output signals appearing in equations (11), (12), (13) may be suppressed in the two following ways which might be combined:

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

Obtaining the numerical values of the unknown parameters $\Theta = (\theta_1, \cdots, \theta_r)$ may be achieved by integrating both sides of the modified equation (13) during a very short time interval.

3.2.4. Time derivatives of noisy signals

Determining derivatives of various orders of a noisy time signal is a fundamental issue, which has been often tackled in signal processing as well as in automatic control. We have recently proposed a quite efficient solution which may be explained as follows:

- The coefficients of a polynomial time function are linearly identifiable. Their estimation can therefore be achieved as above.
- For an arbitrary analytic time function, apply the preceding calculations to a suitable truncated Taylor expansion.

3.2.5. Delay identification

As we have seen in the introductory example of subsection 3.1.2, 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) [54]. Further works will extend this first result within both the algebraic and distributional formalisms.

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

$$(P_1 + \tau P_2)\Theta = 0,$$

where the unknown delay τ and parameters $\Theta = (\theta_1, ..., \theta_r, 1)^T$ are identified as the constant pair eigenvalue/eigenvector. In case of delayed and piecewise constant inputs, 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. Numerical simulations as well as experimental results have shown the feasibility of the proposed technique.

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

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

[12] Especially in signal processing.

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 one to achieve closed loop identification even for nonlinear systems[13].

4.1.2. State reconstructors

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,

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.

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 [67], [66]. Actually, it appears that 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 is being extended for a special class of nonlinear systems using differential geometric concepts. It is believed that 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 [60] and nonlinear systems, to numerically test these conditions and to quickly compute the required variables.

4.1.3. 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.

[13] Some concrete laboratory examples are working well at CINVESTAV, México.

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 change in 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.

4.2. Application 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[14],
3. compression, edge and motion detection of image and video signals[15].

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

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

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 the previous 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.

[14] This should be a US patent since it contains the corresponding mathematical apparatus.
[15] The extension to image and video processing will of course involve linear differential operators with respect to several indeterminates.

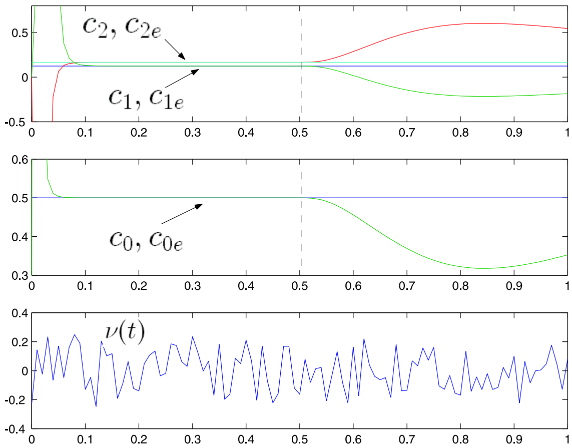

Figure 3. A sequence of noisy measured polynomial signals, generated by a noisy system, and their estimated parameter values

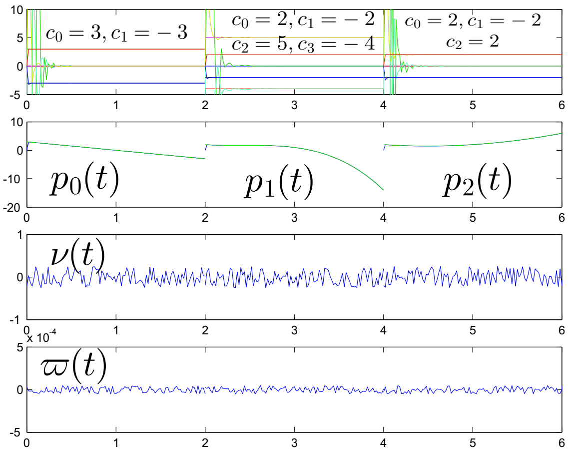

Figure 4. Identification of a discontinuity time in a perturbed time-polynomial signal parameter identification process.

4.3. ALIEN and the Strategic Plan

The COST proposition for the INRIA Strategic Plan 08-12 points out six national priorities.For most of them, ALIEN may contribute some direct or indirect advances. In each of the following items, we first cite (in *italic*) some words from the present wiki document. Then, we mention which could be the links with ALIEN.

4.3.1. Compute life for medicine, biology, and environment

and, more particularly: *Medical Robotics, Biomedical image processing at the cellular level*

BIOMEDICAL SIGNAL PROCESSING:

1. Fast signal processing for imaging via new AFM, Atomic Force Microscopes (being able to image viruses sized within 30-200 nanometers).
2. Fast signal processing for early detection of Epilepsy in EEG.

4.3.2. Compute and communicate everywhere

and, more particularly: *Software infrastructure for ambient intelligence and embedded systems*

SOFTWARE INFRASTRUCTURE FOR AMBIENT INTELLIGENCE & EMBEDDED SYSTEMS

1- Networked control and collaborating devices: Estimation of the unmeasured variables required for the global control and the safety (fast condition monitoring, fault diagnosis and control reconfiguration) of a network of collaborating devices.

4.3.3. Simulating, visualizing and interacting with the World

and, more particularly: *Autonomic methods for robust vision systems, as well as embedded vision systems and ad-hoc composition of distributed sensor networks.*

SOFTWARE INFRASTRUCTURE FOR AMBIENT INTELLIGENCE & EMBEDDED SYSTEMS, DISTRIBUTED ROBOT NETWORKS

1. Networked control and collaborating devices: Estimation of the unmeasured variables required for the global control and the safety (fast condition monitoring, fault diagnosis and control reconfiguration) of a network of collaborating devices.
2. Collaboration of autonomous robots: Design of computationally efficient algorithms working out the required information on the basis of the available sensors and available communication links between robots.

4.3.4. Modeling, Simulating, and Optimizing Complex Systems

and, more particularly: *Note that any technique providing fast and accurate derivatives estimates would also constitute a crucial step in diagnosis, fault tolerant control and signal processing.*

AUTOMATIC SIGNAL DIFFERENTIATION

Estimating the n-th order derivatives of a signal is one of the major trends of our project. A seminal paper was published by ALIEN in 2007: A revised look at numerical differentiation with an application to nonlinear feedback control, by M. Mboup, C. Join and M. Fliess. Such techniques already shown interesting results in several domains as: sensor improvement for vehicles (collaboration H. Mounier and PSA) or mechatronic systems (cart-pendulum at LAGIS).

4.3.5. Guaranteed secure computing

and, more particularly: *Security of Information Systems (Cryptology)*
as well as *Reliability and security: a mathematical approach.*

SECURITY AND RELIABILITY OF INFORMATION SYSTEMS

1. Cryptography: Fast observers for chaotic systems applied to cryptography.
2. Fault detection for diagnosis: Fast estimation of signal derivatives for fault detection (model-based finite-time observers, signal-based break detection) of uncertain systems.
3. Fault tolerant control: Robust control techniques for uncertain, hybrid systems (robustness w.r.t. switches) or networked control systems (robustness w.r.t. communication delays).

4.3.6. Embedded systems and software

and, more particularly: *Problèmes à cheval entre automatique et informatique – Conception et robustesse des lois de commande en boucle fermée prenant en compte les caractéristiques de l'architecture distribuée de contrôle: impact des latences, de la gigue, des bégaiements et pertes, avec contrôle de QoS.*.

NETWORKED CONTROL SYSTEMS However, a network unavoidably introduces time delays in the control loops, which may put the stability and safety performances at risk. Such delays are varying (jitter) and efficient control and estimation techniques (predictor-based) take advantage of their knowledge. The book [11] by J.P. Richard and T. Divoux, Hermes 2007 is devoted to that topic.

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 [47]). 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, could 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:

$$\mathrm{dx/dt} = (\mathrm{a} - \mathrm{bx})\mathrm{x} - \mathrm{cx}, \quad \mathrm{da/dt} = \mathrm{db/dt} = \mathrm{dc/dt} = 0, \quad \mathrm{dt/dt} = 1. \tag{14}$$

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 (14) using parameterization: $t = \mathbf{t}/(a-c), \ x = (a-c)\mathbf{x}/b$, 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 (14), 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 [38].

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.

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). 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.

6. New Results

6.1. Nanovirology

Participant: Olivier Gibaru [correspondant].

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 37C 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. Pierre SAUTER, soon-to-be recruited by INRIA Futurs in postdoc, 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!

6.2. Fast observers for chaotic systems applied to cryptography

Participant: Thierry Floquet [correspondant].

After Carroll and Pecora successfully synchronized two identical chaotic systems with different initial conditions [77], chaos synchronization has been intensively studied in various fields. In particular because chaotic system is extremely sensitive to its initial conditions and parameters, secure communications are a typical application field.

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 [77], mutual coupling [59] or iteration method [57], [63].

Since the work [76], 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 [69], adaptive [68] or sliding mode observers [55], [62], generalized Hamiltonian form based observers [81], etc.

Recently, significant results were obtained in both theoretical and practical aspects. In [35], 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 [45] and [27], we introduced a new type of finite time observers for the synchronization of chaotic systems that can be put in Brunovsky canonical form up to output injection. The main contribution is that finite time observation is obtained using continuous output injections. The method was applied on the Chua's circuit. In [33], 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 [37] 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.

6.3. Multi-cell chopper

Participant: Jean-Pierre Barbot [correspondant].

Multi-cell choppers and converters (see http://www-ecs.ensea.fr/webdesign/ecspresent.html) are more and more popular in power electronic, due to three main reasons: (1) the possibility with the same switching component of covering a wide voltage scale; (2) the modularity and the flexibility introduced in the design of such choppers or converters; (3) the drastic decreasing of the dv over dt phenomenon.

Unfortunately, due to the complexity of the control (i.e. hybrid system, non universal input, etc.), many of industrial applications are considered in the vicinity of a given, /static/ requested behavior. The algebraic techniques could be considered so as to design observer-based control algorithms that can deal for more general /dynamic/ behavior. Application domains of such a breakthrough are for instance: Railway traction, Active filter for networks, etc.

Recently, a new definition of observability was introduced in [41]. This definition is strongly linked to algebraic observability but, in this case, so-called “hybrid time trajectory” was considered. Under this new observability notion, some ALIEN observers for multi-cell chopper are under development.

6.4. Robust control techniques for uncertain hybrid systems

Participant: Wilfrid Perruquetti [correspondant].

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, two main questions are:

- 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 [84], [64], [83], [78], [79])?
- The uniform stability: given a family of subsystems, which conditions on vector fields are ensuring the stability of the switched system under any switching law (see [74], [75] and [27])?

But 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 sub-dynamics and even without knowing the switching signal.

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 may be given 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. Now 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 popular PID or a kind of "state" feedback, one can use, for example, a control of the form $e_{y,i,\mathrm{estim}} = \left[y^{(i)}\right]_{\mathrm{estim}} - y_{\mathrm{ref}}^{(i)}$:

$$[b(\cdot)]_{\mathrm{estim}}\, u = y_{\mathrm{ref}}^{(p)} - [a(\cdot)]_{\mathrm{estim}} - \sum_{i=-1}^{(p-1)} \alpha_i e_{y,i,\mathrm{estim}} \tag{15}$$

6.5. Embedded systems and software

Participant: Jean-Pierre Richard [correspondant].

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[16]. 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 [25], [36] and improve the control;
2. design control/estimation algorithms that can stand variations of the delay [31].

Several other results concerned estimation of systems with unknown delay [48], based on unknown-input observer techniques.

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 [21].

Indeed, a sampled signal $u_k = u(t_k)$ can be regarded 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 groundings, the control loop (between a Master and a remote Slave with poor computation power) presented in [31][17] has developed an observer that enable the Master to reconstruct the *present* state of the Slave despite the variable communication delays. The link from Master to Slave was including of a buffer. The next step of this research will be to make the control loop free of any buffer, so to speed up the allowable dynamics. Packet loss were also considered but may be treated in a still better way.

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

[17] also published in ACC'06

6.6. Numerical differentiation

Participants: Mamadou Mboup [correspondant], Cédric Join [correspondant].

Numerical differentiation, i.e., the derivatives estimation of noisy time signals, is an important but difficult ill-posed theoretical problem. It has attracted a lot of attention in many fields of engineering and applied mathematics (see, e.g. in the recent control literature [56], [58], [71], [70], [72], [73], 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 [43], we revise the problem through our algebraic approach. 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 [82] are inherently connected with the developed algebraic numerical differentiators. A least-squares interpretation then naturally follows [51], [43] 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 upon introducing delayed signals in a control loop. Note however that since the delay is known *a priori*, it is always possible to devise a control law which compensates for its effects (see [80]). 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 expresses 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.

6.7. Delay estimation

Participant: Lotfi Belkoura [correspondant].

The first contribution 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 (17) formulated in the time domain, is derived from the linear second order process (16) subject to nonzero initial conditions and structured delayed inputs u_1 and u_2.

$$s^2y + a_1sy + a_0y = sy_0 + \dot{y}_0 + u_1e^{-\tau_1 s}/s + u_2e^{-\tau_2 s}/s, \tag{16}$$

$$t^3(t-\tau_1)(t-\tau_2) \times [y^{(3)} + a_1y^{(2)} + a_0y^{(1)}] = 0. \tag{17}$$

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 [53]. The case of infinitely many delays can also be considered, using either a local estimation [54], or global estimators at the price of a change from non asymptotic estimators to asymptotic ones.

The second contribution concerns the delay estimation in the more general case of unstructured entries [36]. Combined with the ALIEN project techniques, the delay estimation problem is tackled using the well known properties of the convolution product. The following example illustrated this approach on a elementary retarded integrator:

$$\begin{cases} \dot{y} = \delta_\tau * ku \\ (t-\tau)\dot{y} = \delta_\tau * ktu \end{cases} \quad \Rightarrow \quad \tau = \frac{ty * u - y * tu - \int_0^t u * y}{u * y}.$$

7. Contracts and Grants with Industry

7.1. DGA Grant

This grant—started at LIX/École polytechnique in November 2006—aims at developing knowledges 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 complexe distribué mobiles sécurisé*, *Réseaux mobiles sécurisés* and *Signal*. The team-project ALIEN is involved in this last part: the grant supports the F. Woittennek post-doctoral stay and the application of ALIEN estimation's techniques to this project.

8. Other Grants and Activities

8.1. Regional actions

8.1.1. Invited stay of Prof. Serguey Drakunov (Tulane University, USA)

From 1rst June to 31rst December 2007, Region Nord Pas de Calais invited S. Drakunov as a Senior Researcher at Ecole Centrale de Lille. His expertise in automotive area includes designing nonlinear control for complex vehicle dynamics. The joint research program we started takes place in the CISIT[18] program of the CPER and concerns braking control systems and frictions estimation. Pr. Drakunov participated to the DARPA Grand Challenge within the Team Gray (website at http://www.graymatterinc.com/teamgray/devteam.shtml), which team belonged to the semi-finalists of this competition which, this year, was devoted to Urban autonomous vehicles (http://www.darpa.mil/grandchallenge/index.asp). Publications are under preparation and include the control of nonhonolomic systems with delay (coming from the steering model).

8.1.2. Fête de la Science 2007

During 3 days (11-13 October), several thousands of children were able to fight our inverted pendulum (PhD thesis of S. Riachy) dressed up in an equilibrist robot, which was part of the play demonstrations presented of "Sciences O Park" within the "Fête de la Science 2007". http://sciencesopark.fr/programme/tout-public

8.2. National actions

We are still participating to 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 Group "Identification" and Technical Group "Time Delay Systems".

8.2.1. CPER Grant Automatique et Systèmes Homme-Machine : applications aux transports

Thematic research on Automatic control and Man – Machine systems with Application to Transport. This grant ended in November 2007. It took place in the framework of the CPER program "TAT Technologies Avancées pour les Transports" (Advanced Technologies for Transport) and was supported by Regional Council of Nord Pas de Calais, French Ministry of Research.

This program addressed a fundamental research with applications to transport systems. This includes works devoted to observation of nonlinear systems and delay systems, as well as their application to vehicle control. The global allocated ceiling was 1894 kEurs (including a 1497 kEurs subvention from Region & FEDER) for the GRAISyHM teams (GRAISyHM is a Federation of Automatic control labs in North France). Within this global ceiling, 46 kEuros were concerning SyNeR LAGIS team (37 kEuros subvention from French Ministry — RU).

[18]International Campus on Safety and Intermodality of Transports, grant CPER 2007-2012, previously ST2. The LAGIS is one of the a founder members of this project.

8.3. European actions

8.3.1. Robocoop

"Robocoop : cooperative strategies within tele-operated formations".

This Arcir ("Action de recherche concertée d'initiative régionale") will be closed in December 2007.

It received a global funding of 142 KEurs (european fund FEDER was supporting 71 KEurs, the remaining being supported by the region Nord Pas-de-Calais).

This project developed techniques belonging to the research field of automatic control that took into account co-operation issues and the delays due to communications between the robots. The obtained results were demonstrated on two test benches: mobile robots Miabot and mobile robots Pekee. The implementation of two manipulators is now in progress. In this last case, ALIEN techniques may help for reconstructing the mechanical efforcts coming from the environment.

8.3.2. TAT 3.1 TRACTECO (AS 2005-2007)

The program TRACTECO "Action Spécifique TRACTECO : Méthodes de commande, d'observation et d'identification de systèmes non linéaires avec application aux paliers magnétiques" Applied research on Control, observation and identification of nonlinear systems with application to magnetic bearings will also end in December 2007.

This grant of 45 Keurs took place in the CPER[19] program framework of the program "TAT Technologies Avancées pour les Transports" (Advanced Technologies for Transport) Regional Council of Nord Pas de Calais, French Ministry of Research, European Community (FEDER).

This program was also helped by financial support of Foundation École Centrale de Lille and Bonus Qualité Recherche of École Centrale de Lille. These fundings allowed us to buy the magnetic bearing system and a D-space card. Several classical algorithms have been checked on this material. Now our mean objective is to design fast estimation algebraic methods for improving their control abilities. This research is developed in collaboration with J. Rudolph from the University of Dresden, Germany.

8.3.3. PAI (Integrated Action Program) with T.U. Dresden, Germany.

The LAGIS team has just developed a magnetic shaft benchmark in Lille in collaboration with Dr. Joachim Rudolph from the Technical University of Dresden (see 8.3.2). The first experimental tests were conducted in February 2007 and J. Rudolph visited us from 1rst to 31 March 2007 in order to develop and apply fast identification techniques on this benchmark.

8.4. International actions

8.4.1. INRIA–STIC Tunisia Project

This project involved École Polytechnique Tunis, SUPCOM Tunis, École des mines de Paris and ALIEN. This program started in 2006 and was reconducted for 2007. It allowed joined researches and teaching (visits of M. Fliess, C. Join and P. Rouchon in Tunis) and student exchanges between From Tunisia to France. A joint conference paper with C. Join was submitted.

8.4.2. Winter School on Mathematics for Research and Development, Djerba, Tunisia

From 15th to 18th December 2007, J.P. Richard (ALIEN) and M. Ksouri (ENIT Tunis) are organizing a Winter School on Mathematics for Research and Development ("Les Mathématiques en R&D"), giving a wide place to the spreading of algebra-based results for dynamic systems analysis and control. The invited speakers are: A. Achour (Fac. Sc. Tunis), L. Belkoura (ALIEN), M. Dambrine (Univ. Valenciennes), H. Mounier (Univ. Paris Sud 11), J.P. Richard (ALIEN), J. Rudolph (T.U. Dresden) and W. Perruquetti (ALIEN). This school is addressing an audience of Tunisian Teachers and Researchers, PhD and Master Students, as well as Engineers.

[19] Contrat de Projet État Région — State Region project Grant

8.4.3. 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.

9. Dissemination

9.1. Jacques-Louis Lions grand prize

The biennial Jacques-Louis Lions prize of the french Académie des Sciences was created in 2003 to reward a scientist for a series of works of extremely high value in applied mathematics, carried out in the fields in which Jacques-Louis Lions worked: partial derivative equations, control theory, numerical analysis, scientific computation and their applications. The 2007 grand prize winner, Michel Fliess, is Director of Research at CNRS and Scientific Leader on the team-project ALIEN.

9.2. Theses

- Bourdais, Romain. *Une contribution à la modélisation et à la commande des systèmes non linéaires à commutation*. Reviewers: Daafouz, J. (Pr. ENSEM), Join, C. (Ass. Pr. Univ. Henri Poincaré), Guéguen, H. (Pr. SUPELEC). Examiners: Demongodin, I. (Pr. Univ. Paul Césane) and Floquet, T. (Research Scientist, CNRS LAGIS). Directors: Perruquetti, W. (Pr. École Centrale de Lille) and Yim, P. (Pr. École Centrale de Lille).
- Defoort Michael. *Contribution à la planification et à la commande pour les robots mobiles coopératifs*. “ Contribution to the path planning and tracking of cooperative mobile robots”. PhD from the École centrale de Lille, 22 October 2007 Research grant Ministry of research, 2004-2007 (LAGIS) Directors : W. Perruquetti, T. Floquet, A. Kokosy (LAGIS) Chairman of the Jury: M. Fliess Reviewers: P. Fraisse (LIRMM), H. Mounier (IEF), S. Spurgeon (Univ. Leicester, UK) Examiners: S. Drakunov (Embry-Riddle Aeronautical Univ., USA) PhD prepared in the framework of the LAGIS.
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9.3. Visits and stays

- From 15th to 20th April 2007, C. Join was invited by Pr. É. Delaleau at the LRM/ENIB (Brest, France) in order to apply works on model-free control developed in the ALIEN team-project (see [39]) on problems related to the control of shape memory alloys antagonistic actuators. The prepublication [61] is a first step of this work which should leads to a laboratory prototype.
- July - September 2007, J.R. Trapero Arenas, a doctoral student of Engineering at the University of Castilla-La Mancha (Spain) has been accepted as a visiting researcher to the Department of mathematics and computer science, University René Descartes – Paris V. During this time Mr Trapero works on the problem of identification through derivative algebraic techniques in collaboration with M. Mboup.
- W. Perruquetti attended a one week seminar with LIAMA[20], Behang Univ. of Aeronautic and Aerospace, and intergroup of Écoles centrale in Bejing, April 2007. This meeting aimed at creating joint projects among the selected trends, it was decided to promote ALIEN techniques for two kind of applications: cooperative robotics and image & signal processing.

9.4. Invitations

ENIT, Ecole Nationale d'Ingénieurs de Tunis, Tunisia From June 27th to July 1rst, J.P. Richard was invited at the ENIT. The goals included preparation of a Winter School (see above), participation to several MR juries and presentation of the conference: "Theory and Applications of Time Delay Systems" (June 28th). A PhD student (Ms K. Ibn Taarit) was also recruited (joint supervision, "co-tutelle").

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