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Activity Report 2014

Project-Team NON-A

Non-Asymptotic estimation for online systems

RESEARCH CENTER
Lille - Nord Europe

THEME
**Optimization and control of dynamic
systems**

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Project-Team NON-A

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2. Overall Objectives

2.1. Objectives

For engineers, a wide variety of information cannot be directly obtained through measurements. Some parameters (constants of an electrical actuator, delay in a transmission, etc.) or internal variables (robot's posture, torques applied to a robot, localization of a mobile robot, etc.) are unknown or unmeasured. In addition, usually the signals from sensors are distorted and tainted by measurement noises. In order to simulate, to control or to supervise processes, and to extract information conveyed by the signals, one has to estimate parameters or variables.

Estimation techniques are, under various guises, present in many parts of control, signal processing and applied mathematics. Such an important area gave rise to a huge international literature. From a general point of view, the performance of an estimation algorithm can be characterized by three indicators:

- The computation time (the time needed to obtain the estimation). Obviously, the estimation algorithms should have as small as possible computation time in order to provide fast, real-time, on-line estimations for processes with fast dynamics (for example, a challenging problem is to make an Atomic Force Microscope work at GHz rates).
- The algorithm complexity (the easiness of design and implementation). Estimation algorithms should have as low as possible algorithm complexity, in order to allow an embedded real-time estimation (for example, in networked robotics, the embedded computation power is limited and can be even more limited for small sensors/actuators devices). Another question about complexity is: can an engineer appropriate and apply the algorithms? For instance, an algorithm application is easier if the parameters have a physical meaning w.r.t. the process under study.
- The robustness. The estimation algorithms should exhibit as much as possible robustness with respect to a large class of measurement noises, parameter uncertainties, discretization steps and other issues of numerical implementation. A complementary point of view on robustness is to manage a compromise between existence of theoretical proofs versus universalism of the algorithm. In the first case, the performance is guaranteed in a particular case (a particular control designed for a particular model). In the second case, an algorithm can be directly applied in "most of the cases", but it may fail in few situations.

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

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

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

The researches developed by *Non-A* are within the continuity of the project-team *ALIEN* in what concerns the *algebraic tools* that are developed for finite-time estimation purposes. However, *Non-A* also aims at developing complementary estimation techniques, still aiming at the finite-time performance but based on the so-called *higher-order sliding mode* algorithms, interval estimation techniques and, as well as, fixed-time algorithms.

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

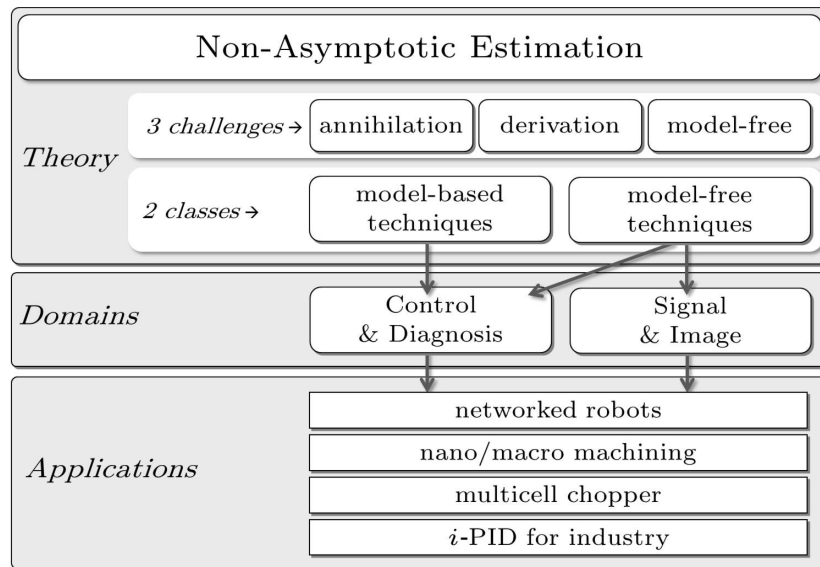


Figure 1. *Non-A* is a method-driven project, centered around non-asymptotic estimation techniques (*i.e.* providing estimates in finite-time), and connected to applications.

2.2. Members complementarity

The members of the *Non-A* project work in different places: Lille, Cergy, Reims and Nancy. They share a common 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.

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

3. Research Program

3.1. General annihilators

Estimation is quite easy in the absence of perturbations. It becomes challenging in more realistic situations, faced to measurement noises or other unknown inputs. In our works, as well as in the founding text of *Non-A*, we have shown how our estimation techniques can successfully get rid of perturbations of the so-called *structured* type, which means the ones that can be annihilated by some linear differential operator (called the annihilator). *ALIEN* already defined such operators by integral operators, but using more general convolution operators is an alternative to be analyzed, as well as defining the “best way to kill” perturbations. Open questions are:

OQ1) Does a normal form exist for such annihilators?

OQ2) Or, at least, does there exist an adequate basis representation of the annihilator in some adequate algebra?

OQ3) And lastly, can the annihilator parameters be derived from efficient tuning rules?

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

3.2. Numerical differentiation

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

Two classes of techniques are considered here (**Model-based** and **Model-free**), both of them aiming at non-asymptotic estimation.

¹Atomic Force Microscope, for which fast filtering is required

In what we call *model-based techniques*, the derivative estimation is regarded as an observation problem, which means the software-based reconstruction of unmeasured variables and, more generally, a left inversion problem². This involves linear/homogeneous/nonlinear state models, including ordinary equations, systems with delays, hybrid systems with impulses or switches³, which still has to be exploited in the finite-time and fixed-time context. Power electronics is already one of the possible applications.

Model-free techniques concern the works initiated by *ALIEN*, which rely on the only information contained in the output signal and its derivatives. The corresponding algorithms rely on our algebraic annihilation viewpoint. *One open question is: How to provide an objective comparison analysis between Model-based and Model-free estimation techniques? For this, we will only concentrate on Non-Asymptotic ones. This comparison will have to be based on the three Indicators 1 (time), 2 (complexity) and 3 (robustness).*

3.3. Model-free control

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

3.4. Applications

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

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

In the present period, we choose to give a particular focus to the first item (Networked robots), which already received some development. It can be considered as the objective 4.

These applications are described with more details below.

4. Application Domains

4.1. Networked Robots

Both economically and scientifically, cooperation in robot swarms represents an important issue since it concerns many service applications (health, handicap, urban transports...) and can increase the potential of sensor networks⁴. It involves several challenges such as:

²Left invertibility deals with the question of recovering the full state of a system (“observation”) together with some of its inputs (“unknown input observers”), and also refers to algebraic structural conditions.

³Note that hybrid dynamical systems (HDS) constitute an important field of investigation since, in this case, the discrete state can be considered as an unknown input.

⁴Integrating wireless sensor networks and multi-robot systems increases the potential of the sensors: robots, in comparison, are resource-rich and can be involved in taking decisions and performing appropriate actions on themselves on sensors and/or the environment.

- Because autonomy is a key for being able to increase the network size, maximize the autonomy of the robots in their different tasks of localization, motion, communication;
- Aiming at making 1+1 be more than 2, extend the global potential of the swarm by introducing collaboration (exchanging information with other robots) and cooperation (acting with other robots);
- Include time and energy saving considerations at the design stage. The self deployment of autonomous groups of mobile robots in an unknown environment (including different kinds of static or moving obstacles) involves localization, path planning and robust control problems. Both the control and signal aspects of our researches are oriented to solve some problems coming from - or taking advantage of - such collaboration frameworks. To mention a few:
 - Localization using as few as possible landmarks and exteroceptive information by means of derivative estimates;
 - Image-based sensing algorithms inspired by our multidimensional estimation techniques;
 - Detection and adaptation to sudden loss of communication, time-varying topology, or communication delays;
 - Robust, autonomous, energy-aware controllers based on either model-free or model-based techniques.

Several algorithms have already been applied to the control of formations of mobile robots: an illustrative platform is currently developed at EuraTechnologie center within the framework of Non-A⁵. They are now being extended to medical devices (such as wheelchairs) within the European project SYSIASS (see <http://www.sysiass.eu>), in collaboration with partners from hospital settings. Another future application concerns Wireless Sensor and Robot Networks (WSRN, Fig. 2), dedicated to the surveillance of zones, to the exploration of hostile areas, or to the supervision of large scale sensor networks. The main idea here is to integrate mobile nodes (the mobile robots) within the sensor network, allowing to overcome a sensor defection, to maintain the connectivity of the network, or to extend the coverage area during a random deployment. This involves consideration about mobile actuators within a mobile network of sensors and control networks (wireless) with strong constraints on the possibilities of communication in a noisy and non-homogeneous environment. This work is made in close collaboration with the Inria project-team POPS (Lille), which brings its expertise in terms of sensor networks. It takes place in the framework of the Inria ADT SENSAS and represents our contribution to the LABEX proposal ICON.

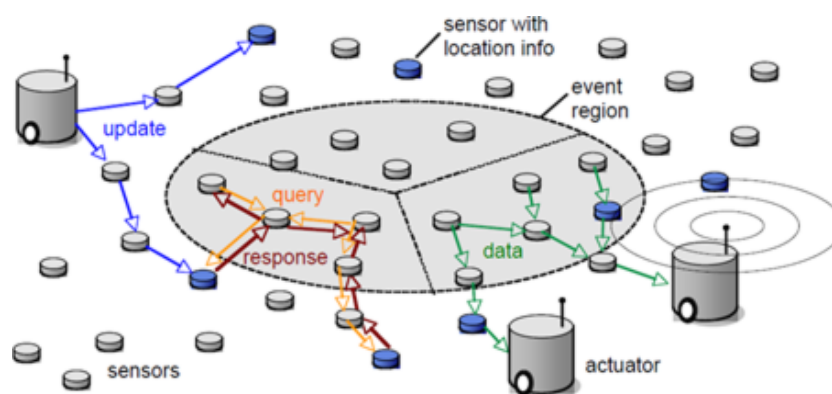


Figure 2. An illustration of collaboration in a Wireless Sensor and Robot Network.

⁵"RobotCity" was exhibited for the first time during the opening ceremony held on April 6th, 2011

4.2. Nano/Macro machining

Nano machining

Recent research investigations have reported the development of a number of process chains that are complementary to those used for batch manufacturing of Micro Electro Mechanical Systems (MEMS) and, at the same time, broaden the application domain of products incorporating micro and nano scale features. Such alternative process chains combine micro and nano structuring technologies for master making with replication techniques for high volume production such as injection moulding and roll-to-roll imprinting. In association with the Manufacturing Engineering Center of Cardiff, Arts et Metiers ParisTech center of Lille develops a new process chain for the fabrication of components with nano scale features. In particular, AFM probe-based nano mechanical machining is employed as an alternative master making technology to commonly used lithography-based processes (Fig.). Previous experimental studies demonstrated the potential of this approach for thermoplastic materials. Such a manufacturing route also represents an attractive prototyping solution to test the functionalities of components with nano scale features prior to their mass fabrication and, thus, to reduce the development time and cost of nano technology-enabled products. Application of our control and estimation techniques improves the trajectory tracking accuracy and the speed of the machining tools.

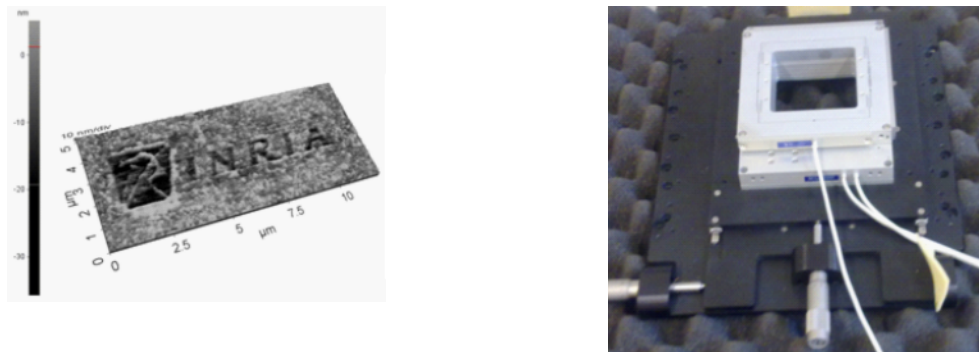


Figure 3. Left: A machined nano structure: $16 \mu\text{m} \times 8 \mu\text{m} \times \text{some nm}$. Right: Nano-positioning system available at Arts et Métiers ParisTech Lille ($75 \mu\text{m}$ range of motion).

Machining with industrial robots

Industrials are enthusiastic to replace machine-tools with industrial robots: compared to machine-tools, industrial articulated robots are very cheaper, more flexible, and exhibit more important workspaces. They can carry out machining applications like prototyping, cleaning and pre-machining of cast parts, as well as end-machining of middle tolerance parts. Such applications require high accuracy in the positioning and path tracking. Unfortunately, industrial robots have a low stiffness and are not that accurate⁶ and they deserve an increased quality of control. We deal with the modelling and the on-line identification of flexible-joint robot models. This can be used both for dynamic simulation and model-based control of industrial robots. We address the problem of real-time identification of the parameters involved in the dynamic linear model of an industrial robot axis. This is possible thanks to a special sensor developed by Arts et Métiers, subject to an EADS project within the FUI (Fonds Unique Interministériel). Control algorithms for other machining

⁶Industrial robots were designed to realize repeatable tasks. The robot repeatability ranges typically from 0.03 to 0.1mm, but the accuracy is often measured to be within several millimetres. Due to their serial structure, articulated robot has lower stiffness (less than 1 N/mm) than classical machine-tools (greater than 50 N/mm). These poor accuracy and stiffness are caused by many factors, such as geometric parameter errors (manufacturing tolerances), wear of parts and components replacement, as well as flexibility of links and gear trains, gear backlashes, encoder resolution errors and thermal effects.

actuators such as active magnet bearings are also under study. Within the framework of LAGIS, we also consider the remote control of industrial robots (via internet of Wi-Fi links, for instance), which sets numerous problems in relation with the communication delays.

4.3. Multicell Chopper

On the basis of benchmarks developed at ECS-lab (ENSEA Cergy), we intend to work on the control and observation of serial and parallel multicell choppers, as well as more usual power converters. These power electronic systems associated with their respective loads are typical hybrid dynamical systems and many industrial and/or theoretical challenging problems occur. For example, in the industrial problem of power supply for a supercomputer, the parallel multicell chopper appears as a new solution particularly with respect to the power efficiency. Nevertheless, the observation and control of such hybrid dynamical systems is a difficult task, where non asymptotic estimation and control can be useful.

5. New Software and Platforms

5.1. SLIM

Multi-robots cooperation can be found as an application in many domains of science and technology: manufacturing, medical robotics, personal assistance, military/security and spatial robots. The market of robots is quickly developing and its capacity is continuously growing. Concerning cooperation of mobile multi-robots, 3 key issues have to be studied: Localization, path planning and robust control, for which Non-A team has worked and proposed new algorithms. Due to the ADT SLIM, we implement our algorithms (localization, path planning and robust control) and integrate them into ROS (Robotic Operating System) as a package, named SLIM.

5.2. Blimp

Scientific research and development on the control of autonomous airship have shown a significant growth in recent years. New applications appear in the areas such as freight carrier, advertising, monitoring, surveillance, transportation, military and scientific research. The control of autonomous airship is a very important problem for the aerial robots research.

The development of Blimp by Non-A is used for experimentation and demonstration of controlling algorithms. The blimp is required to provide some environment information and status of itself, such as surveillance video of surrounding environment, gesture of blimp, altitude of blimp. With these basic information, one could localize blimp with certain algorithm (visual SLAM for example) or implement one controller in order to improve the stability and maneuverability of blimp.

6. New Results

6.1. Highlights of the Year

- We are becoming world-recognized on homogeneous approach to estimation and control [13], [24].
- New method of stability analysis and control design for time-delay systems: Implicit Lyapunov-Krasovski Functionals [72].
- New dynamical model of population of oysters for water quality monitoring [44].
- New local path planning algorithm for mobile robots based on intermediate objectives [33].
- New patent on method and device for detecting a failure on an aircraft [85].
- New book on robust control design [82].

6.2. Homogeneity Theory And Analysis Of Nonlinear Systems

Homogeneity is a kind of symmetry, if it is presented in a system model, then it may simplify analysis of stability and performance properties of the system. The new results obtained in 2014 are as follows:

- The problem of scalability of trajectories in homogeneous and locally homogeneous systems is considered [46]. It is shown that the homogeneous systems have scalability property, and locally homogeneous systems possess this property approximately.
- Constructive conditions for verification of input-to-state stability property for discontinuous systems using geometric homogeneity have been proposed in [48]. The characterization of the asymptotic gain for such systems has been presented in [47].
- The problem of finite-time output stabilization of the double integrator is addressed in [14] applying the homogeneity approach. Robustness and effects of discretization on the obtained closed loop system are analyzed.
- The paper [24] extends notion of homogeneity to the time-delay nonlinear systems. Generalizations and specifications of the homogeneity approach to time-delay nonlinear systems are given in [57], where, for instance, the stability independently on delay has been analyzed.
- In [75] the uniform stability notion for a class of non-linear time-varying systems is studied using the homogeneity framework. The results are applied to the problem of adaptive estimation for a linear system.
- The Implicit Lyapunov Function (ILF) method has been applied for homogeneous differentiator design [70]. The procedure for adjustment of differentiator parameters has been resented in the form of semi-definite programming problem. ILF-based algorithms of robust finite-time and fixed-time stabilization of the chain of integrators were developed in [34]. In [69] they were adapted for the second order sliding mode control design.
- The tutorial on homogeneous methods in high sliding mode control has been published [13]. It stresses some recently obtained results of the team about homogeneity for differential inclusions and robustness with respect to perturbations in the context of input-to-state stability.

6.3. Model-Free Control

The model free control techniques form a new and quickly developing area of control theory. It has been established by the team members and nowadays these tools find many practical applications and attract a lot of attention due to their clear advantages for designers: they provide a control law independently in the model knowledge. The achievements obtained in 2014 are as follows:

- The paper [67] proposes a motion planning approach for non-holonomic mobile robots using i-PID controller. The effectiveness and the robustness of the proposed method are shown via several simulations.
- In [60] we show that the open-loop transfer functions and the stability margins may be defined within the recent model-free control setting. Several convincing computer experiments are presented including one which studies the robustness with respect to delays.

6.4. Algebraic Technique For Estimation, Differentiation And Its Applications

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

- The article [19] presents an algebraic on-line parameters estimation method for Linear Time Invariant (LTI) systems subject to polynomial perturbations. Particular attention is given to practical implementation.

- In the paper [43], we extend the modulating functions method to estimate the state and the unknown input of a linear time-varying system defined by a linear differential equation. Numerical results are given to show the accuracy and the robustness of the proposed estimators against corrupting noises.
- The paper [17] presents a new sensorless parameter identification method for permanent magnet stepper motors. The method exploits derived linear parameterizations and least-squares algorithms.
- In [36] a continuous-time least-squares parameter estimation method through evolution equations is proposed. A deterministic framework for the estimation under noisy measurements is proposed using a Sobolev space with negative index to model of the noise.
- Causation between time series is a most important topic in econometrics, financial engineering, biological and psychological sciences, and many other fields. A new setting is introduced in [42] for examining this rather abstract concept. The corresponding calculations, which are much easier than those required by the celebrated Granger-causality, do not necessitate any deterministic or probabilistic modeling.
- The paper [59] proposes a solution to the problem of velocity and position estimation for a class of oscillating systems whose position, velocity and acceleration are zero mean signals. The proposed scheme considers that the dynamic model of the system is unknown and only noisy acceleration measurements are available.
- The communications [63], [78] are devoted to solar irradiance and irradiation short-term forecasts, which are useful for electricity production. Several different time series approaches are employed.
- In [68] we present a simple algorithm to compute the factors of a Unimodular-Upper polynomial matrix decomposition. Such decomposition is useful for spatial multiplexing in multi-input multi-output(MIMO) channel transmission system since it enables to reduce the MIMO channel matrix into independent channels by a pre- and post-filtering.
- A fault-tolerant control method based on algebraic derivative estimation is introduced in [32]. It is applied on an electromagnetically supported plate as an example of a nonlinear and an open-loop unstable system.

6.5. Observability And Observer Design For Nonlinear Systems

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

- The paper [12] deals with the observability analysis of linear time systems whose outputs are affected by unknown inputs. Three different definitions of observability are proposed. Sufficient conditions are deduced for each proposed definition.
- In [11] a method of the state estimation is proposed for a class of nonlinear systems with unknown inputs whose dynamics is governed by differential-algebraic equations (DAE). The estimation is done using a sliding mode high order differentiator.
- The recent algebraic parametric method proposed by Fliess and Sira-Ramirez has been extended to numerical differentiation problem in noisy environment [66]. The obtained algebraic differentiators are non-asymptotic and robust against corrupting noises.
- The paper [41] investigates the observer design problem of nonlinear impulsive systems with impact perturbation. By using the concept of normal form, it proposes a full order finite time observer, which guarantees the finite time convergence independent of the impact perturbation.
- The development of adaptive observer techniques for nonlinear systems in the output canonical form is proposed in [22] applying additional impulsive feedback in the observer equations. The stability is investigated.
- In [55] the problem of adaptive observer design in the presence of disturbances is studied, and an augmented adaptive observer is proposed using sliding mode methodology.

6.6. Sliding Mode Control And Estimation

Sliding mode algorithms are very popular for finite-time estimation and regulation. The recent results obtained by the group are as follows:

- In [71] the high-order sliding mode control design algorithm has been developed for MIMO system using ILF Method. Procedure for tuning of control parameters is presented using Linear Matrix Inequalities.
- A novel hybrid automaton admitting the modeling of both conventional and modern (high order) sliding mode systems is presented [65]. A scheme for defining hybrid-automaton executions beyond Zeno points is proposed by means of introduction of Filippov-like executions.
- The paper [35] surveys mathematical tools required for stability/convergence analysis of modern sliding mode control systems and introduces the generalized Lyapunov theorems. Application of these results to finite-time stability analysis and settling time estimation of twisting second order sliding mode controller are given [73].
- The problem of the sliding mode control design is considered in [81] for the linear time-invariant disturbed system with the noised measurements of the output. The control law, which provides to the closed-loop system the optimal reaching (as close as possible) of the selected sliding surface, is designed using minimax state observer.
- The paper [50] deals with a signal-based method for robust and early detection of lock-in-place failures (a.k.a. jamming) in aircraft control surface servo-loops. The signal-based scheme is proposed using a sliding-mode differentiator. The developed monitoring scheme has been tested on Airbus test facilities located at Toulouse, France.
- In the paper [79], we investigate the problem of adaptive observer for simultaneous estimation of state and parameter for a class of nonlinear systems. Necessary condition for the existence of such an observer is derived. The paper [76] uses developed technique for states estimation and parameter identification for nonlinear Dengue epidemic model.
- The paper [80] investigates the problem of global finite-time observer design for a class of nonlinear systems which can be transformed into the output depending normal form.

6.7. Non-Linear, Sampled And Time-Delay Systems

Nonlinearities, sampling, quantization and time-delays cause serious obstructions for control and observer design in many fields of techniques and engineering (e.g. networked and internet systems, distributed systems etc.). The proposed by the team algebraic approach suits well for estimation and regulation in such a type of systems. The recent results are listed below:

- The method of Implicit Lyapunov-Krasovski Functional for stability analysis of time-delay systems is introduced in [72].
- The article [31] proposes a convex optimization approach for the design of relay feedback controllers. Furthermore, the approach is used in the sampled-data case in order to guarantee (locally) the practical stabilization to a bounded ellipsoid of the order of the sampling interval.
- The paper [40] addresses the controller design problem for bilateral teleoperation over unreliable networks. The stability and tracking performance analysis are presented for a novel force-reflecting emulator control scheme.
- The problem of time optimal control design is considered for a chain of integrators in [74]. The suboptimal continuous ILF-based solution is presented and compared with the optimal discontinuous feedback.
- In the erratum [26] recently proposed conditions on finite-time stability in time-delay systems are revisited and it is shown that they are incorrect. General comments on possibility of finite-time convergence in time-delay systems and a necessary condition are given.

- The problem of formulation of an equivalent characterization for instability is considered in [56]. The necessary part of the Chetaev's theorem on instability is formulated. Using the developed necessary instability conditions, the Anti-control Lyapunov Function (ALF) framework is extended and the Control Chetaev Function (CCF) concept is proposed as a counterpart of the Control Lyapunov function (CLF) theory.
- The paper [25] extends the notion of oscillations in the sense of Yakubovich to hybrid dynamics. Several sufficient stability and instability conditions for a forward invariant set are presented. The consideration is illustrated by analysis of a model of two-link compass-gait biped robot.
- The paper [15] deals with the design of an active fault-tolerant control strategy based on the supervisory control approach technique for linear time invariant MIMO systems affected by disturbances, measurement noise, and faults.
- The problem of phase regulation for a population of oscillating systems is considered in [21]. The proposed control strategy is based on a Phase Response Curve (PRC) model of an oscillator.
- The paper [51] deals with the design of an estimator-based supervisory Fault Tolerant Control scheme for Linear Time Invariant systems. A formal stability proof based on dwell-time conditions is established.
- In [39], we propose a general statistical framework for model based compressive sensing, where both sparsity and structure priors are considered simultaneously. It is based on the Latent Variable Analysis and the Gamma-Gaussian modelling.
- The paper [64] investigates the left invertibility for nonlinear time delay system with internal dynamics under some assumptions imposed on the internal dynamics. Causal and non causal estimation of the unknown inputs are respectively discussed, and the high-order sliding mode observer is used to estimate the observable states.
- In the paper [54] a simple second order model is proposed for modeling the pressure dynamics with a pure time delay on the control input. The Artstein transformation is applied in order to design the stabilizing robust nonlinear controller.

6.8. Set-Theoretic Methods of Control And Estimation

In many cases due to parametric and/or signal uncertainties presented in a plant model it is not possible to design a conventional observer, which provides a point-wise estimate of state in a finite time or asymptotically. In this case it is still frequently possible to design observers, which generate an estimate on the set of the admissible values of the state at the current instant of time. The recent new results in this field are listed below:

- An interval observer for Linear Time-Varying systems is proposed in [38]. A constructive approach to obtain a time-varying change of coordinates, ensuring the cooperativity of the observer error in the new coordinates, is provided in order to simplify the design of the interval observer.
- In [58] the problem of interval observer design is addressed for a class of descriptor linear systems with delays. An interval observation for any input in the system is provided. The control input is designed together with the observer gains in order to guarantee interval estimation and stabilization simultaneously.
- The estimation problem of a system with unknown time-delay and unknown input gains is considered in [49]. The interval observation technique is applied in order to obtain guaranteed interval of the system state.
- The book [82] introduces newly developed robust control design technique for a wide class of continuous-time dynamical systems called the "attractive ellipsoid method." It studies nonlinear affine control systems in the presence of uncertainty and presents a constructive and easily implementable control strategy that guarantees certain stability properties.

6.9. Networked Robots

The mobile robots constitute an important area of practical development for the team:

- The paper [33] presents a path planning algorithm for autonomous navigation of non-holonomic mobile robots in complex environments. The irregular contour of obstacles is represented by segments. The optimal path planning problem is formulated as a constrained receding horizon planning problem and the trajectory is obtained by solving an optimal control problem with constraints.
- In [62] robot dynamic parameters are estimated based on power model associated with modulating functions, which avoids measuring or calculating the joint acceleration. At the same time, an advanced causal Jacobi derivative estimator is applied in order to get on-line robust derivatives from noisy measurements.
- The paper [61] provides a solution for the stabilization of a nonholonomic wheeled mobile robot which is affected by additive input disturbances. The solution is based on the supervisory control framework, finite-time stability and robust multi-output regulation.
- The demo video with the developments of NON-A team in networked robotics is given by https://www.youtube.com/watch?v=Mq_hB0UkzkY

6.10. Applications

As it was mentioned, Non-A is a kind of "method-driven" project, which deals with different aspects of finite-time estimation and control. Thus different applications are possible, ones touched this year are as follows (skipping the networked robots considered in the previous section):

- Method and device for detecting a failure on an aircraft are developed and patented [85].
- In [44] the measurements of valve activity in a population of bivalves under natural environmental conditions (16 oysters in the Bay of Arcachon, France) are used for a physiological model identification. A nonlinear auto-regressive exogenous (NARX) model is designed and tested. The developed dynamical model can be used for estimation of the normal physiological rhythms of permanently immersed oysters and, in particular, for ecological monitoring.
- The articles [53], [18], [20], [77] present novel control strategies for Permanent Magnet Synchronous Motor (PMSM), which does not ignore the relay nature of the actuators. A design procedure based on Linear Matrix Inequalities (LMI) allows us to derive the switching surfaces, which depend on the motor position. The sliding mode and nonlinear adaptive observers are designed for state estimation and parameters identification.
- The problem of air-fuel ratio stabilization in spark ignition engines is addressed in the paper [23]. The proposed strategy consists of proper switching among two control laws. The first one is based on an a priori off-line identified engine model and the second control law is adaptive. The supervisor realizes a switching rule between them providing better performance. Results of implementation on two vehicles are reported and discussed.
- The paper [37] deals with a control design for serial multicellular choppers. The novel scheme that uses two Petri nets (PNs) to carry out the control action is introduced. Experimental results from four and five-level choppers are used to emphasize the performance and the effectiveness of the proposed control scheme.
- The paper [52] is concerned with preliminary results on robot vibratory modes on-line identification using the external measurement provided by a laser tracker. A comparison between the algebraic method and the sliding modes for the parameter identification is proposed. Experimental identifications are proposed on a 6 degrees of freedom (DOF) manipulator robot Stäubli RX-170B.
- The papers [30], [29], [16] develop different fault detection schemes for robust and early detection of faults in aircraft control surfaces servo-loop. A complete Monte Carlo campaign from a high representative simulator, provided by Airbus as a part of the ADDSAFE project, as well as experimental results obtained on AIRBUS test facilities demonstrate the high fault detection performance, robustness and viability of the proposed techniques.

- The paper [28] deals with the problem of the practical tracking control of an experimental car-like system called the Robucar - a four-wheeled car in a single steering mode. A practical tracking controller is designed using the second-order sliding mode control. Experimental tests are presented and compared with the conventional sliding controller.
- Power converters are a very important for the control of high power systems. In the article [45] we propose a control strategy for minimizing the no-load conduction losses and analyze the transient behavior in case of load steps including output short-circuit.

7. Bilateral Contracts and Grants with Industry

7.1. Bilateral Contracts with Industry

- Agreement with Sick Company for equipment support of the research in the field of the in-door mobile robot navigation.

8. Partnerships and Cooperations

8.1. Regional Initiatives

- Project ARCIR «Estimation distribuée de systèmes dynamiques en réseaux», coordinator Prof. Mihaly Petreczky, URIA – Mines de Douai, 2013–2015
- CPER CIA, "Internet of Things", 2011–2015
- CPER CISIT (becoming ELSAT in 2015), "Campus international sur la securite et intermodalite de transport", project "CONTRAERO" with LML and IEMN, 2011–2015
- ADT Inria SLIM "Development of ROS software library for multi-robots cooperation", 2013–2014 Project Agrégation, Conseil Général du Val d'Oise, (<http://www.scilab.org/fr/community/scilabtec/2013/Projet-Agregation-la-simulation-numerique-dans-les-essais>)

8.2. National Initiatives

- ANR project TurboTouch (High-performance touch interactions), coordinator Prof. Géry Casiez (MJOLNIR team, Inria): 2014-2019
- ANR project ChaSLiM (Chattering-free Sliding Modes), coordinator Prof. B. Brogliato (BIBOP team, Inria): 2012-2015
- ANR ROCC-SYS (Robust Control of Cyber-Physical Systems), coordinator Dr. L. Hetel: 2014-2017
- We are also 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", "Complex Systems, Biological Systems and Automatic Control," and "Control in Electrical Engineering".
- Model-free control: collaborations with the startup ALIEN SAS (created by C. Join and M. Fliess).

8.3. European Initiatives

8.3.1. FP7 & H2020 Projects

- HYCON2 (<http://www.hycon2.eu/>) The FP7 NoE HYCON2, started in September 2010, is a four-year project coordinated by the CNRS (Françoise Lamnabhi-Lagarrigue). It aims at stimulating and establishing a long-term integration in the strategic field of control of complex, large-scale, and networked dynamical systems. It focuses in particular on the domains of ground and aerospace transportation, electrical power networks, process industries, and biological and medical systems. Our PhD students are regularly supported for their participation to the EECI training.

8.3.2. Collaborations in European Programs, except FP7 & H2020

- SYSIASS (<http://www.sysiass.eu/>) Here is the major issue on which the project SYSIASS seeks to answer by developing new technologies and putting them in the service of patients and health professionals from our regions. Indeed preserve the autonomy of the elderly and disabled people is a major issue in today's society. In Europe, with the progressive ageing of the population policy to support the elderly is increasingly based on the assumption that care must be provided efficiently to the patient where he is based. In addition, special attention is devoted to people with disabilities for their better integration into society. Advances in technology proposed by SYSIASS (SYStème Intelligent et Autonome d'aide aux Soins de Santé / Autonomous and Intelligent Healthcare System) will be realized in practice through an intelligent wheelchair that can provide better mobility to the patient and to allow health care professionals to easily transport patients to desired locations within a clinic or home environment. Moreover such a system must be able to communicate with the outside world, to adapt to specific patient needs and any special disability that he may have, and to facilitate access to medical data for health professionals. Our PhD students are regularly supported for participation in the associated EECI training.
- ICityForAll: EU Ambient Assisted Living Program (<http://www.icityforall.eu/>) The project is led by CEA and it includes University of Paris Descartes-UPD, CENTICH, Active Audio (SME, France), Tech. Univ of Munich - TUM (Germany), EPFL (Suisse), ENEA (Italy), Centro Ricerche FIAT-CRF (Italy). The goal of I'City for All (Age sensitive ICT systems for Intelligible City for All) is to enhance speech and audio alarms intelligibility in order to improve the sense of well-being of seniors through better social interactions, better security and then improved mobility. Mamadou Mboup is involved as a subcontractor of UPD.

8.4. International Initiatives

8.4.1. Inria Associate Teams

- Associate team with Norwegian University of Science and Technology (Trondheim, Norway) and UMEA university (Sweden), 2013-2016
Subject: "Dynamical precision improvement for industrial robots"

8.4.2. Inria International Partners

8.4.2.1. Informal International Partners

- Professor Emilia Fridman, Tel Aviv University, Israel
- Sliding Mode Control Lab., UNAM, Mexico
- Department Control Automatico, CINVESTAV-IPN, Mexico
- UPIBI, National Polytechnic Institute, Mexico
- Department of Control Systems and Informatics, Saint Petersburg State University of Information Technologies Mechanics and Optics (ITMO), Russia

8.4.3. Participation In other International Programs

- CNRS GDRI DelSys (<http://www.cnrs.fr/ins2i/spip.php?article217>)
- CNRS-CONACYT project, UNAM, Mexico, "Estimation of state for hybrid systems using sliding mode techniques", 2014

8.5. International Research Visitors

8.5.1. Visits of International Scientists

- Prof. Emilia Fridman, Tel Aviv State University, Israel, from Jun 2014 until Jul 2014
Subject: *Homogeneity application for time-delay systems : finite-time stability*

- Dr. Francisco Bejarano Rodriguez, National Polytechnic Institute, Mexico, until Jul 2014
Subject: *Observability and observer for linear time-delay systems with unknown inputs*
- Prof. Leonid Fridman, UNAM, Mexico, until Jul 2014
Subject: *State Observation and Parameter Identification in Hybrid Systems via High-Order Sliding-Modes*

8.5.1.1. Internships

- Mimia Benhadri, Skikda University Algeria, Jun 2014
Subject: *Time Delay Systems*
- Andrea Aparicio Martinez, UNAM, Mexico, from Jun 2014 until Jul 2014
Subject: *State Observation and Parameter Identification in Hybrid Systems via High-Order Sliding-Modes*
- Ivan De Jesus Salgado Ramos, National Polytechnic Institute, Mexico, from Jul 2014
Subject: *PID control design based on the different differentiation techniques*
- Tonametl Sanchez Ramirez, UNAM, Mexico, until Jul 2014
Subject: *State Observation and Parameter Identification in Hybrid Systems via High-Order Sliding-Modes*
- Carlos Vazquez Aguilera, UMEA, Sweden, from Nov 2014
Subject: *Application of discontinuous Lyapunov functions for dead-zone compensation*
- Konstantin Zimenko, ITMO, Russia, from Nov 2014
Subject: *Transfer functions for homogeneous finite-time stable systems*
- Zohra Kader from March 2014 to September 2014
Subject: *Left inversion of nonlinear time delay system.*

8.5.2. Visits to International Teams

8.5.2.1. Explorer programme

- Gang Zheng, Nanjing University of Science and Technology (China), in December 2014, supported Sino-French International Joint Laboratory of Automation and Signals (University Lille 1)
- Andrey Polyakov, UPIBI, National Polytechnic Institute, Mexico, in October 2014, supported by UPIBI-IPN

9. Dissemination

9.1. Promoting Scientific Activities

9.1.1. Scientific events organisation

9.1.1.1. member of the organizing committee

- J.-P. Richard, a member of NOC of 20th IFAC World Congress, Toulouse, France, 10-14 July 2017
- W. Perruquetti, National Projects Vice-Chair at ECC 2014, Strasbourg, France, 24-25 June 2014

9.1.2. Scientific events selection

9.1.2.1. responsible of the conference program committee

- J.-P. Richard, Associate Editor, EUCA-IEEE ECC'15, Linz, Austria (14th European Control Conference) June 15-17, 2015, <http://www.ecc15.at>
- J.-P. Richard, Associate Editor, IEEE MED'2015, Torremolinos, Spain (23rd IEEE Mediterranean Conference on Control and Automation) June 16-19, 2015, <http://med2015.uma.es>

- J.-P. Richard, Associate Editor, IFAC TDS'2015, Ann Arbor, MI, USA (12th IFAC Workshop on Time Delay Systems), Univ. of Michigan, 28-30 juin 2015, <http://me.engin.umich.edu/dirifac/>
- J.-P. Richard, Associate Editor, EUCA-IEEE ECC'14, Strasbourg, France (13th European Control Conference) June 24-27, 2014, <http://www.ecc14.eu>
- J.-P. Barbot, IPC-Chair, 13th International Workshop on Variable Structure Systems, Nantes, France, 29 June-2 July 2014

9.1.2.2. member of the conference program committee

- J.-P. Richard, IEEE ICCVE 2014, Vienna, Austria (3rd Int. Conference on Connected Vehicles & Expo), Nov. 3-7, 2014, <http://www.iccve.org/>
- J.-P. Richard, IOV 2014, Beijing, China (International Conference on Internet of Vehicles), Sept. 1-3, 2014, <http://www.bjiiov.org/>
- J.-P. Richard, SC2 2014, Beijing, China (4th Internat. Symposium on Cloud and Service Computing, co-conf. within IOV2014), Sept. 1-2, 2014, <http://www.bjiiov.org/>
- J.-P. Richard, IFIP WWIC 2014, Paris, France (12th IFIP Int. Conf. on Wired & Wireless Internet Communications), May 26-28, 2014, <http://www.lissi.fr/wwic2014/>
- J.-P. Richard, EuroHaptics'14, Versailles, France (14th EHS European conference on Haptic Systems), June 24-27, 2014, <http://www.eurohaptics.org/>
- J.-P. Richard, IEEE SaCoNeT 2014, Vilanova i la Geltrú, Spain (5th IEEE Int. Conference on SmART COMMUNICATIONS in NETWORK TECHNOLOGIES), June 18-20, 2014, <http://www.craax.upc.edu/saconet2014/>
- W. Perruquetti and D. Efimov, IFAC World Congress 2014, Cape Town, South Africa
- A. Polyakov, 13th International Workshop on Variable Structure Systems, Nantes, France

9.1.2.3. reviewer

Members of the team have been involved in the evaluation process of many papers submitted to many international conferences: IEEE Conference on Decision and Control, IFAC World Congress 2014, European Control Conference, American Control Conference, ICRA, ...

9.1.3. Journal

9.1.3.1. member of the editorial board

- T. Floquet, Member of Editorial Board, Mathematical Problems in Engineering (Impact Factor: 1.082)
- A. Polyakov, Member of Editorial Board, Journal of Optimization Theory and Applications (Impact Factor: 1.406)
- A. Polyakov, Associate Editor, Journal of the Franklin Institute (Impact Factor: 2.260)
- A. Polyakov, Editor, International Journal of Robust and Nonlinear Control (Impact Factor: 2.652)

9.1.3.2. reviewer

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

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

- Licence : Lotfi Belkoura; Automatique (systèmes linéaires monovariables)(75h), Introduction à la Robotique (25h), L3; Lille 1; France
- Licence : Gang Zheng; TP Automatic control (16h), L2; EC Lille; France
- Licence : Samer Raichy; Systèmes linéaires, Asservissements, Conversion d'énergie, Echantillonnages et systèmes discrets (192h), L3; ENSEA; France
- Licence : Rosane Ushirobira; TP Automatic control (16h), L2; TP Numerical Analysis (20h), L1; EC-Lille and Polytech Lille; France
- Master : Jean-Pierre Richard; Systèmes dynamiques (30h), Métiers de la recherche (4h), Modélisation des systèmes complexes(12h), Commande et observation (12h), Séminaire episteme (24h); EC-Lille; France
- Master : Wilfrid Perruquetti; Systèmes dynamiques non linéaires et à retards (30h), M2; Lille 1 – EC-Lille, France
- Master : Lotfi Belkoura; Représentation d'état (55h), M1; Projets (10h), M1; Introduction aux distributions (10h), M2; Lille 1; France
- Master : Rosane Ushirobira; Probability and Statistics (20h); M2; EC-Lille; France
- Master : Denis Efimov; TD Automatic control (12h), M1; Analysis of Nonlinear Systems (28h), M2, Lille 1; France

9.2.2. Supervision

- PhD: Omran Hassan, "Commande et observation des systèmes de contrôle en réseau", 2011–2014, supervisors are J.-P. Richard, F. Lamnabhi-Lagarigue and L. Hetel
- PhD: Maalej Sonia, "Algebraic estimation for robust control", 2011–2014, supervisors are L. Belkoura and A. Kruszewski
- PhD in progress : Matteo Guerra, "Supervisory control of collective motion of mobile robots", 2012–..., supervisors are W. Perruquetti, D. Efimov and G. Zheng
- PhD in progress : Zilong Shao, "Oscillatory control of robot manipulator", 2013–..., supervisors are W. Perruquetti, D. Efimov and G. Zheng
- PhD in progress : Hafiz Ahmed, "Identification and modeling of circadian rhythms for oysters", 2013–..., supervisors are D. Efimov, R. Ushirobira and D. Tran
- PhD in progress : Essaid Edjekouane, "Cyber-physical systems", 2012–..., supervisors are J.P. Barbot, S. Riachy and M. Ghanes
- PhD in progress: Guo Qi, "Estimation dynamique des paramètres de robots manipulateur", 2012–..., supervisors are W. Perruquetti and M. Gautier
- PhD in progress: Zohra Kader, "Observation et commande des systèmes affines à commutation", 2014–..., supervisors are L. Belkoura, C. Fiter, L. Hetel
- PhD in progress: Maxime Feingesicht, "Dynamic Observers for Control of Separated Flows", 2015–..., supervisors are J.-P. Richard, F. Kerherve, A. Polyakov

9.2.3. Juries

The team members are also involved in various examination committees of Theses and Habilitations, recruitment committees, in France and abroad (more than 10).

9.3. Popularization

- Non-A team participated in Innorobo 2014 at Lyon, which is the only European event on robotics (<https://team.inria.fr/non-a/2014/12/15/innorobo-2014/>).
- The new platform for mobile robot demonstration in Euratechnologie Inria Lille in December 2014 is provided by using the result of ADT SLIM (<http://www.inria.fr/en/centre/lille/news/robots-superheroes-of-cooperation-and-surveillance>).
- The invited paper [84] is published in the journal ERCIM News. It presents the main goals and the results of the Inria team-project NON-A in the context of Cyber-Physical Systems.

10. Bibliography

Major publications by the team in recent years

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- [3] E. BERNUAU, A. POLYAKOV, D. EFIMOV, W. PERRUQUETTI. *Verification of ISS, iISS and IOSS properties applying weighted homogeneity*, in "Systems & Control Letters", December 2013, vol. 62, n^o 12, pp. 1159-1167, <https://hal.inria.fr/hal-00877148>
- [4] D. EFIMOV, W. PERRUQUETTI, J.-P. RICHARD. *Development Of Homogeneity Concept For Time-Delay Systems*, in "SIAM Journal on Control and Optimization", December 2014, <https://hal.inria.fr/hal-00956878>
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Publications of the year

Articles in International Peer-Reviewed Journals

- [11] F. J. BEJARANO, W. PERRUQUETTI, T. FLOQUET, G. ZHENG. *Observation of Nonlinear Differential-Algebraic Systems with Unknown Inputs*, in "IEEE Transactions on Automatic Control", October 2014, pp. 0-1, <https://hal.inria.fr/hal-01075275>
- [12] F. J. BEJARANO, G. ZHENG. *Observability of linear systems with commensurate delays and unknown inputs*, in "Automatica", April 2014, vol. 50, n^o 8, pp. 2077-2083 [DOI : 10.1016/J.AUTOMATICA.2014.05.032], <https://hal.inria.fr/hal-00967944>
- [13] E. BERNUAU, D. EFIMOV, W. PERRUQUETTI, A. POLYAKOV. *On homogeneity and its application in sliding mode control*, in "Journal of The Franklin Institute", January 2014 [DOI : 10.1016/J.JFRANKLIN.2014.01.007], <https://hal.inria.fr/hal-00942326>
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