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Activity Report 2015

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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Creation of the Team: 2011 January 01, updated into Project-Team: 2012 July 01

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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.

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.

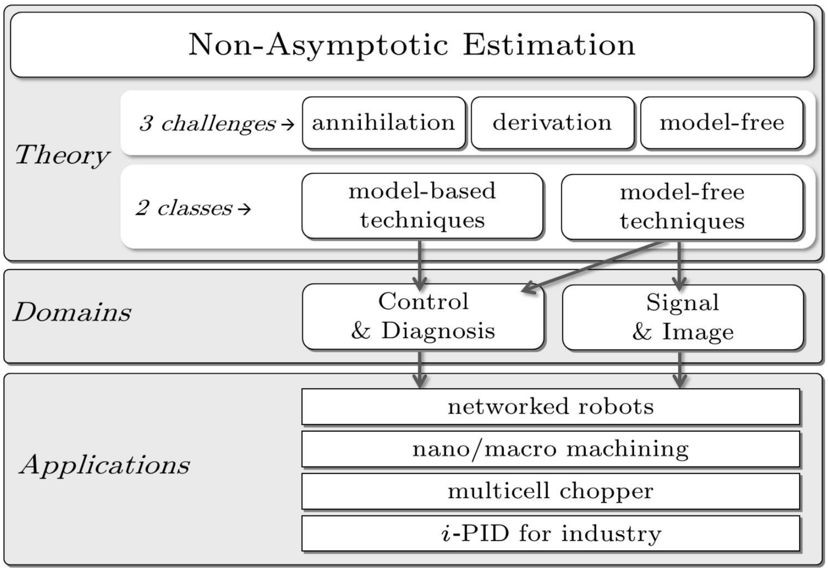

Figure 1. Non-A is a method-driven project, centered around non-asymptotic estimation techniques (i.e. providing estimates in finite-time), and connected to applications.

	Upstream Researches	*Application Fields*
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 CRIStAL	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:

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

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.

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 problem [2]. This involves linear/homogeneous/nonlinear state models, including ordinary equations, systems with delays, hybrid systems with impulses or switches [3], 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:

[2] Left 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.

[3] Note 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.

- 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.

4. Highlights of the Year

4.1. Highlights of the Year

- Concepts of Homogenenty, Implicit Lyapunov Functions and Convergence in Finite/Fixed time are now extended to different classes of dynamic systems (e.g time delay systems [27], distributed parameters systems [67], time-varying systems [42], MIMO systems[38], [25], differential inclusions [37], multi agent systems [19],[23]). In this context, ANR Project Finite4SOS (cordinator: Wilfrid Perruquetti) is accepted for 2015-2020. It is aimed at development of different tools for non-asymptotic control and estimation for System of Systems.
- Living sensor is a biological organism, which can be utilized as a sensor of some enveronmental characteristics. In collaboration with Aquatic Ecotoxicology (EA) team from CNRS Lab "Environnements et Paleoenvironnements Oceaniques et Continentaux", University of Bordeaux 1, we developed innovative methods for monitoring the water quality using oysters as biological sensors [16], [51], [15]. The project ANR WAQMOS (coordinator: Denis Efimov) is supported for 2015-2020. It is aimed at creation of novel oyster-based living sensors (including hardware and software development).
- We provided a novel solution for motion control of wheeled mobile robots with obstacle avoidance (for single robot [32], [32] and a formation of robots [60]).
- From september 2015, model-free control [84],[7] is applied to control the traffic on A25 (access ramp « La Chapelle-d'Armentières »), users and DiRN are satified with results (http://www.lavoixdunord.fr/region/feu-intelligent-de-l-a25-quel-bilan-quatre-mois-apres-ia11b49733n3187841).

Awards

- Prize of "ABB AWARD: Best application/case study paper", IFAC Safeprocess, Paris, 2015, see [80].

5. New Software and Platforms

5.1. Blimp

FUNCTIONAL DESCRIPTION

Scientific research and development on the control of autonomous airships 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 airships 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.

- Contact: Jean-Pierre Richard

5.2. SLIM

FUNCTIONAL DESCRIPTION

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.

- Contact: Jean-Pierre Richard

6. New Results

6.1. Homogeneity Theory

Homogeneity is one of the tools we develop for finite-time convergence anasysis. In 2015 this concept has received various improvements:

- The concept of homogeneous evolution equation in a Banach space has been introduced in [67]. It provides the background for the extencion of all homogeneity-based tools for control design and analysis to distributed parameters systems.
- Scalability is a property describing the change of the trajectory of a dynamical system under a scaling of the input stimulus and of the initial conditions. Particular cases of scalability include the scale invariance and fold change detection (when the scaling of the input does not influence the system output). In the paper [19] is shown that homogeneous systems have this scalability property while locally homogeneous systems approximately possess this property.
- In the paper [25] the notion of homogeneity in the bi-limit is extended to local homogeneity and then to homogeneity in the multi-limit. The converse Lyapunov/Chetaev theorems on (homogeneous) system instability are obtained. The problem of oscillation detection for nonlinear systems is addressed. The sufficient conditions of oscillation existence for systems homogeneous in the multi-limit are formulated.
- The notion of weighted homogeneity is extended in [81] to the time-delay systems. It is shown that the stability/instability of homogeneous functional systems on a sphere implies the global stability/instability of the system. The notion of local homogeneity is introduced, a relation between stability/instability of the locally approximating dynamics and the original time-delay system is established using Lyapunov-Razumikhin approach
- In [27] global delay independent stability is analyzed for nonlinear time-delay systems by applying homogeneity theory. It is shown that finite-time stability can be encountered in this class of systems under uniformity of the convergence time with respect to delay. Some additional tools for stability analysis of time-delay systems using homogeneity are also presented: in particular, it is shown that if a time-delay system is homogeneous with nonzero degree and it is globally asymptotically stable for some delay, then this property is preserved for any delay value, which is known as the independent of delay (IOD) stability.
- Theorems on Implicit Lyapunov Functions for finite-time and fixed-time stability analysis of nonlinear systems are presented in [37]. Based on these resutls, new homogenenous nonlinear control laws are designed for robust stabilization of a chain of integrators. The presented results are extended to Multi-Input Multi-Output in [38]. A time-suboptimal control design algorithm based Implicit Lyapunov Function Method is developed in [40]. A robustness-oriented comparison of the optimal and suboptimal solutions in practical implementations of the proposed controller is performed via the

numerical example of double integrator. A novel scheme of practical implimentation of the implicit Lypunov function-based control is developed in [79]. It replaces the implicitely defined Lyapunov function (in the feedback law) with the homogenous norm of the state. Such a modification simplifies the practical application of the finite-time stabiliting feedback control.

- The uniform stability notion for a class of nonlinear time-varying systems is studied in [42] using the homogeneity framework. It is assumed that the system is weighted homogeneous considering the time variable as a constant parameter, then several conditions of uniform stability for such a class of systems are formulated. The results are applied to the problem of adaptive estimation for a linear system. The detailed report on time-varying homogenety is given in [83].
- In the paper [52] we consider the continuous homogeneous observer defined in the case of the triple integrator. Originally, convergence of the algorithm was only proved when the degree of homogeneity was sufficiently close to 0 without more tractable information. We show here that, in the case of the triple integrator, the observer presents global finite-time stability for any negative degree under constructive conditions on the gains. This is achieved with a homogeneous Lyapunov function design.
- The work [61] addresses the stabilization of dynamical systems in presence of uncertain bounded perturbations using theory. Under some assumptions, the problem is reduced to the stabilization of a chain of integrators subject to a perturbation and is treated in two steps. The evaluation of the disturbance and its compensation. Homogeneous observer and control are the tools utilized to achieve a global asymptotic stability and robustness. The result is formally proven and, to validate the theory, it is applied to the control of the telescopic link of a hydraulic actuated industrial crane used in forestry.
- A geometric homogeneity of evolution equation in a Banach space is introduced in [67]. Scalability property of solutions of homogeneous evolution equations is proven. Some qualitative characteristics of stability of trivial solution are also provided. In particular, finite-time stability of homogeneous evolution equations is studied. Theoretical results are supported by examples from mathematical physics.
- The second order planar nonlinear affine control problem is studied [69]. A homogeneous robust finite-time stabilizing control is developed for the most general case of matched and, the more challenging, mismatched nonlinear perturbations. A homogeneous observer is designed for the planar system. Explicit restrictions on the observer gains and nonlinearities are presented. The main contribution lies in the proposed combination of the explicit and implicit Lyapunov function methods as well as weighted homogeneity while providing finite-time stability analysis.

6.2. Algebraic Technique For Estimation, Differentiation And Its Applications

Algebraic technique is the other tool we develop for providing finite-time convergence.

- The integer order differentiation by integration method based on the Jacobi orthogonal polynomials for noisy signals was originally introduced by Mboup, Join and Fliess. The paper [35] proposes an extention of this method from the integer order to the fractional order to estimate the fractional order derivatives of noisy signals. Two fractional order differentiators are deduced from the Jacobi orthogonal polynomial filter, using the Riemann-Liouville and the Caputo fractional order derivative definitions respectively. Exact and simple formulas for these differentiators are given by integral expressions. Some error bounds are provided for the corresponding estimation errors. The noise error contribution due to a large class of stochastic processes is studied in discrete case.
- Armed with structures, group sparsity can be exploited to improve the performance of adaptive estimation. In the paper [45], the adaptive estimation algorithm for cluster structured sparse signals, called A-CluSS, is proposed. In particular, a hierarchical Bayesian model is built, where both sparse prior and cluster structured prior are exploited simultaneously. The adaptive updating formulas for statistical variables are obtained via the variational Bayesian inference and the resulted algorithms

can adaptively estimate the cluster structured sparse signals without knowledge of block size, block numbers and block locations. In [75], a group sparse regularized least-mean-square (LMS) algorithm is proposed to cope with the identification problems for multiple/multi-channel systems. An iterative online algorithm is proposed via proximal splitting method.

6.3. Set-Theoretic Methods of Control And Estimation

Interval and ellipsoidal estimations can be regarded as particular finite-time algorithms, since they provide guaranteed estimates of the values from the intial time. We develop these tools for some years now.

- An approach to interval observer design for Linear Parameter-Varying (LPV) systems is proposed in [20]. Stability conditions are expressed in terms of matrix inequalities. Applying L1/L2 framework the robustness and estimation accuracy with respect to model uncertainty are analyzed.
- New delay-dependent conditions of positivity for linear systems with time-varying delays are introduced in [56]. These conditions are applied to interval observer design for systems with time-varying delays in the state equations and in the measurements. In [28] the problem of interval observer design is addressed for a class of descriptor linear systems with time 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. Efficiency of the proposed approach is illustrated by numerical experiments with Leontief delayed model.
- The work [29] is devoted to interval observers design for discrete-time Linear Parameter-Varying (LPV) systems under the assumption that the vector of scheduling parameters is not available for measurements. Two problems are considered: a pure estimation problem and an output stabilizing feedback design problem where the stability conditions are expressed in terms of Linear Matrix Inequalities (LMIs).
- The paper [48] investigates the interval observer design for a class of nonlinear continuous systems, which can be represented as a superposition of a uniformly observable nominal subsystem with a Lipschitz nonlinear perturbation. It is shown in this case there exists an interval observer for the system that estimates the set of admissible values for the state consistent with the output measurements. In [77] similar methodology is extended to singular systems.
- A finite-time version, based on Implicit Lyapunov Functions, for the Attractive Ellipsoid Method is developed in [65]. Based on this, a robust control scheme [36] is presented to ensure finite-time convergence of the solutions of a chain of integrators with bounded output perturbations to a minimal ellipsoidal set. The control parameters are obtained by solving a minimization problem of the " size " of the ellipsoid subject to a set of Linear Matrix Inequalities, and by applying the implicit function theorem.
- In [78] we consider a problem of sliding mode control design for LTI systems with multiplicative disturbances of the input and noisy measurements of the output. We apply the minimax observer to provide the best possible estimate of the system's state. Then we solve a problem of optimal reaching for the observer: we design sub-optimal control algorithms generating continuous and discontinuous feedback controls that steer the observer as close as possible to a given sliding hyperplane in a finite time.

6.4. Observability And Observer Design For Nonlinear Systems

- In [18] a method to carried out the state estimation is proposed for a class of nonlinear systems with unknown inputs whose dynamics is governed by differential-algebraic equations (DAE). We achieve, under suitable conditions, to replace the original DAE for a system with differential equations only by using a zeroing manifold algorithm inducing a state space dimension reduction.
- In the paper [44], we investigate the estimation problem for a class of partially observable nonlinear systems. For the proposed Partial Observer Normal Form (PONF), necessary and sufficient conditions are deduced to guarantee the existence of a change of coordinates which can transform the studied system into the proposed PONF.

- Using the theory of non-commutative rings, the delay identification problem of nonlinear time-delay systems with unknown inputs is studied in the paper [82]. Necessary and sufficient conditions are proposed to judge the identifiability of the delay, where two different cases are discussed for the dependent and independent outputs, respectively. After that, necessary and sufficient conditions are given to analyze the causal and non-causal observability for nonlinear time-delay systems with unknown inputs.
- In the paper [58], we investigate the stabilization of a linear plant subject to network constraints, partial state knowledge and time varying bounded parameter uncertainties. An event–triggered version of the Luenberger observer is proposed, and necessary conditions on the uncertainties are given in term of LMI's to enable output– based stabilization under different triggering strategies.
- The papers [47], [76] investigate an unknown input observer design for a large class of linear systems with unknown inputs and commensurate delays. A Luenberger-like observer is proposed by involving only the past and actual values of the system output. The required conditions for the proposed observer are considerably relaxed in the sense that they coincide with the necessary and sufficient conditions for the unknown input observer design of linear systems without delays.
- The paper [71] deals with the problem to estimate some states of a multi-output nonlinear dynamical system which is partially observable. To address this problem, this paper provides a set of geometrical conditions that guarantee the existence of a change of coordinates which decomposes the studied nonlinear dynamical system into two dynamical subsystems, where the first one is of the well-known output injection form. This transformed form allows us to design a simple reduced-order (Luenberger-like) observer to estimate the observable state.

6.5. Model-Free Control

- In the paper [41] the Universal Integral Control, introduced by H.K. Khalil, is revisited by employing mollifiers instead of a high-gain observer for the differentiation of the output signal. The closed loop system is a classical functional differential equation with distributed delays on which standard Lyapunov arguments are applied to study the stability. Low-pass filtering capability of mollifiers is demonstrated for a high amplitude and rapidly oscillating noise.
- The paper [64] proposes an universal adaptive control structure for robot manipulators, without knowing the dynamic model of the system, as well it is robust to corrupt payload change and initial conditions.
- In [66], the control design of an artificial pancreas, a hot research topic in diabetology, is tackled via the newly introduced model-free control and its corresponding "intelligent" proportional controller, which were already quite successful in many concrete and diverse situations. It results in an insulin injection for type 1 diabetes which displays via constant references a good nocturnal/fasting response, but unfortunately a poor postprandial behavior due to long hyperglycemia. When a variable reference is introduced, that switches between a constant one, when glycemia is more or less normal or moderate, and an exponential decay reference path, when a high glycemia rate indicates a meal intake, the results in silico, which employ real clinical data, become excellent. We obtain a bolus-shaped insulin injection rate during postprandial phases. The hyperglycemic peaks are therefore lowered a lot.

6.6. Sliding Mode Control And Estimation

- The paper [22] addresses the problem of oscillatory failure case detection in the electrical flight control system of a generic commercial airplane. A non-homogeneous differentiator is first used to provide accurate derivatives in noisy environment and fast convergence time. In this study case, fault detection is addressed in the unknown input estimation issue for fault reconstruction with the same evaluation techniques currently employed in Airbus A380 airplanes. Performance and robustness of the developed monitoring strategy are assessed using a high-fidelity Airbus benchmark and a parametric test campaign for the flight scenarios defined in the EU-FP7 ADDSAFE project.

- A new sliding mode control approach is introduced in [26] with the dedicated mathematical tools. A time-delay modification/approximation of sign function is proposed in [57], and it is shown that by substituting this new "sign " realization in the conventional sliding mode algorithms the main advantages of the sliding mode tools are preserved (like rejection of matched disturbances and hyper-exponential convergence), while the chattering is reduced.
- The article [34] proposes a convex optimization approach for the design of relay feedback controllers. The case of linear systems is studied in the presence of matched perturbations. The system input is a generalized relay that may take values in a finite set of constant vectors. A simple design method is proposed using Linear Matrix Inequalities (LMIs).
- In the note [53] we study the effect of an implicit Euler time-discretization method on the stability of the discretization of a globally fixed-time stable, scalar differential inclusion representing a simple nonlinear system with a set-valued signum controller. The controller nonlinearity is a cubic term and it is shown that the fully-implicit method preserves the global Lyapunov stability property of the continuous-time system, contrarily the explicit discretization which does not. It allows to obtain finite-time convergence to the origin when the plant is undisturbed, while the cubic term provides the hyper-exponential convergence rate.
- The problem of finite-time stabilization of multi-input linear system by means of sliding mode relay feedback is considered in [68]. A new control design procedure, which combines convex embedding technique with implicit Lyapunov function method, is developed. The issues of practical implementation of the obtained implicit relay feedback are discussed. Theoretical result is supported by numerical simulation.

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

- The method of Implicit Lyapunov-Krasovski Functional (ILKF) for stability analysis of time-delay systems is introduced in [39]. Theorems on Lyapunov, asymptotic, (hyper) exponential , finite-time and fixed-time stability analysis using ILKF are presented. The hyper exponential stabilization algorithm for a time-delay system is presented.
- A recent generalization of the classical ISS theory to multistable systems is presented in [17]. Based on it a robust synchronization protocols with respect to a compact invariant set of the unperturbed system are designed in [14], [49].
- The paper [21] 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. From a bank of Luenberger observers that plays the role of a fault detection and isolation scheme, the supervisory algorithm selects the suitable fault-tolerant controller by means of a hysteresis-based switching mechanism based on the method proposed in this paper.
- In [30] motivated by the problem of phase-locking in droop-controlled inverter-based microgrids with delays, the recently developed theory of input-to-state stability (ISS) for multistable systems is extended to the case of multistable systems with delayed dynamics. Sufficient conditions for ISS of delayed systems are presented using Lyapunov-Razumikhin functions. It is shown that ISS multistable systems are robust with respect to delays in a feedback [55].
- The work [31] aims at enlarging the sampling intervals in several state feedback control situations by designing a sampling map in the state space. For linear time invariant (LTI) systems with state-bounded perturbations this guarantees exponential stability with a chosen decay-rate. The approach is based on linear matrix inequalities (LMIs) obtained thanks to Lyapunov-Razumikhin stability conditions and convexification arguments. Then, the obtained results are extended to design the sampling map in three dynamic sampling control situations: event-triggered control, self-triggered control, and state-dependent sampling.

- In the paper [43] the problem of discrete and continuous state estimation for a class of uncertain switched LPV systems is addressed. Parameter identification techniques are applied to realize an approximate identification of the scheduled parameters of a switched LPV system with certain uncertainties and/or disturbances. A discrete state estimation is achieved using the parameter identification. A Luenberger-like hybrid observer, based on discrete state information and LMIs approach, is used for the continuous state estimation.
- The paper [70] contributes to the exponential stability analysis for impulsive dynamical systems based on a vector Lyapunov function and its divergence operator. The method relies on a 2D time domain representation. The results are applied to analyze the exponential stability of linear impulsive systems based on LMIs.

6.8. Networked Systems

- The problem of phase synchronization for a population of genetic oscillators (circadian clocks, synthetic oscillators, etc.) is considered in the paper [13]. The proposed analysis approach is based on the Phase Response Curve model of an oscillator. The performance of the obtained solutions is demonstrated via computer experiments for two different models of circadian/genetic oscillators.
- The paper [23] focuses on the design of fixed-time consensus for first order multi-agent systems with unknown inherent nonlinear dynamics. A distributed control protocol, based on local information, is proposed to ensure the convergence of the tracking errors in finite time. Some conditions are derived to select the controller gains in order to obtain a prescribed convergence time regardless of the initial conditions.
- The problem of phase regulation for a population of oscillating systems is considered in [24] based on a Phase Response Curve (PRC) model of an oscillator. The problem of phase resetting for a network of oscillators is solved by applying a common control input. Performance of the obtained solutions is demonstrated via computer simulation for three different models of circadian/neural oscillators.

6.9. Applications

- The problem of avoiding obstacles while navigating within an environment for a Unicycle-like Wheeled Mobile Robot (WMR) is of prime importance in robotics. The work [32] solves such a problem proposing a perturbed version of the standard kinematic model able to compensate for the neglected dynamics of the robot. The effectiveness of the solution is proved, supported by experiments and finally compared with the Dynamic Window Approach (DWA) to show how the proposed method can perform better than standard methods. The paper [60] presents a decentralized solution to control a leader-follower formation of unicycle wheeled mobile robots allowing collision and obstacle avoidance. The work [62] solves the obstacle avoidance problem extending the Potential Field (PF) method for a mobile robot. The usual definition of the PF has been modified to have a field which is continuous everywhere. It is shown that the system has an attracting equilibrium at the target point, repelling equilibriums in the centers of the obstacles and saddle points on the borders. Those unstable equilibriums are avoided capitalizing on the established Input-to-State Stability (ISS) property of this multi-stable system. To escape a local minima this work makes the most of ISS property that is not lost for perturbations. And for small properly designed disturbances the global attractivity of the target point is proved.
- The paper [63] investigates the behavior of central Jacobi differentiator in robot identification applications. It is applied to compute acceleration from noisy position measurements. Its frequency domain property is analyzed via a finite impulse response (FIR) filter point of view, indicating clearly the differentiators performance. Two revolute joints planar robot parameter identification is done. Comparisons between the Jacobi differentiator and the Euler differentiation combined with Butterworth filter are drawn.

- In [50] the velocity of valve movement activity is estimated using three different differentiation schemes: an algebraic-based differentiator method, a non-homogeneous higher order sliding mode differentiator and a homogeneous finite-time differentiator. We demonstrate that this estimated velocity can be used for water quality monitoring as the differentiators can detect very rapid change in valve movements of the oyster population resulting from some external stimulus or common input.
- In the paper [15] 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. Through this study, it is demonstrated that the developed dynamical model of the oyster valve movement can be used for estimating normal physiological rhythms of permanently immersed oysters and can be considered for detecting perturbations of these rhythms due to changes in the water quality, i.e. for ecological monitoring.
- Spawning observations are important in aquaculture and biological studies, and until now, such a detection is done through visual analysis by an expert. Using measurements of valve activity (i.e. the distance between the two valves) in populations of bivalves under natural environmental condition (16 oysters in the Bay of Arcachon, France, in 2007, 2013 and 2014), algorithms for an automatic detection of the spawning period of oysters are proposed in the paper [16], [51]. The fault detection method presented in the paper can also be used to detect complex oscillatory behavior which is of interest to control engineering community.
- The work presented in the paper [33] is undertaken within the European FP7 funded Advanced Fault Diagnosis for Sustainable Flight Guidance and Control (ADDSAFE) project. It proposes new fault detection and fault diagnosis techniques that could significantly help developing environmentally-friendlier aircraft. LPV model-based fault detection schemes are proposed and compared for robust and early detection of faults in aircraft control surfaces servo-loop. The proposed methodologies are based on a slight modification of the H_∞/H_- LPV optimization techniques for systems modelled in, first polytopic manner, second linear fractional representation fashion. It is shown that the proposed fault detection schemes can be embedded within the structure of in-service monitoring systems as a part of the Flight Control Computer software. Several important examples on model and signal based fault detection in aircraft Electrical Flight Control System are studied in [80].
- For analyzing the transients of induction heating systems, time-dependent phasor transformations were proposed so far in the literature. Applying these transformations to a linear R, L, C circuit equations leads to differential equations in the complex domain from which equivalent circuits modeling the envelopes of sinusoidal waveforms were derived. The work [46] proposes a phasor transformation which is based on fictitiously replacing the real voltage and current signals of a system by complex ones. It leads to transformed system equations in the real domain where instantaneous amplitudes, phases and frequencies appear explicitly, which makes the transformed equations suitable for the feedback control design. The methodology is applied to a parallel induction heating system in order to design a sliding mode controller.
- The problem of air-to-fuel ratio regulation for a direct injection engine is addressed in [54]. A LPV model of the engine is used, for which an interval observer is designed. The interval observer is applied for the model validation and control synthesis. The results of design are confirmed by implementation.
- Modular Robot Manipulators are user-configurable manipulators which provide rapid design and inexpensive implementation. To be easy-use, smart actuators embedded with position input and position feedback controller are adopted, these local controllers render the manipulators position controlled, but also result in limited performance and precision. The paper [72] targets the case that the built-in controller does not provide desirable precision for set-point regulation. Firstly a joint-level model is established, of which the nominal model can be identified with derivative observer based on the position feedback, then an auxiliary adaptive controller coping with parametric

uncertainty is proposed which leads to an error close to zero, a switching control strategy is introduced considering the actuator saturation. The paper [73] addresses the set-point control of actuators integrated with built-in controller, which presents steady-state error (SSE) under certain load. To eliminate the SSE, a model of the actuator-plus-controller system is established and identified, a switched adaptive controller is developed to work with the embedded one, considering the physical constraints, a switching control strategy is proposed. The proposed algorithms are implemented on a 5-DOF modular manipulator, with comparison to classic integral controller.

- The communication [74] is devoted to a comparison between various meteorological forecasts, for the purpose of energy management, via different time series techniques. The first group of methods necessitates a large number of historical data. The second one does not and is much easier to implement, although its performances are today only slightly inferior. Theoretical justifications are related to methods stemming from a new approach to time series, artificial neural networks, computational intelligence and machine learning.
- ALINEA is a well known ramp metering closed-loop control the aim of which is to improve highway traffic. The report [84] shows that ALINEA may be slightly modified in order to be efficiently implemented without any need of crucial time-varying quantities, like the critical density and the free-flow speed, which are most difficult to estimate correctly online.
- For malaria patients, a usual observation problem consists in estimation of sequestered parasites Plasmodium falciparum from measurements of circulating ones. The model of an infected patient is rather uncertain, and for all rates (death, transition, recruitment and infection) in the model it is assumed that only intervals of admissible values are given. In addition, the measurements of the concentration of circulating parasites are subjected by a bounded noise, while some parameters, like the rate of infection of blood cells by merozoites, are completely unknown and highly time-varying. In order to evaluate the concentration of sequestered parasites, an interval observer is designed in [85], which provides intervals of admissible value for that concentration, with the interval width proportional to the model uncertainty.

7. Bilateral Contracts and Grants with Industry

7.1. Bilateral Contracts with Industry

- a PhD CIFRE with SAGEM (France), supervisors are Alban Quadrat and Hugues Mounier

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 2020 in 2015), "Campus international sur la securite et intermodalite de transport", project "CONTRAERO" with LML and IEMN, 2011–2015 (becoming CONTRATECH 2016-2020 with LML, IEMN, LAMIH and ONERA)

8.2. National Initiatives

- ANR project Finite4SoS (Finite time control and estimation for Systems of Systems), coordinator Prof. Wilfrid Perruquetti (NON-A team, Inria): 2015-2020

- ANR project WaQMoS (Coastal waters quality surveillance using bivalve mollusk-based sensors), coordinator Dr. Denis Efimov (NON-A team, Inria): 2015-2020
- ANR project TourboTouch (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 project ROCC-SYS (Robust Control of Cyber-Physical Systems), coordinator Dr. L. Hetel: 2013-2018
- ANR project MSDOC (Multidimentional System: Digression od Stability), coordinator Bachelier Olivier (Poitiers University) : 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

- UCoCoS "Understanding and Controling Complex Systems", European Joint Doctorate, starting from April 2016, partners KU Leuven (Belgium), TU/e (Netherlands) and Centrale Lille (France).

8.4. International Initiatives

8.4.1. Inria Associate Teams not involved in an Inria International Labs

- Associate team with Norwegian University of Science and Technology (Tronheim, 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

- Tel Aviv University, Israel
- Sliding Mode Control Lab., UNAM, Mexico
- Department Control Automatico, CINVESTAV-IPN, Mexico
- 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?article1799)

8.5. International Research Visitors

8.5.1. Visits of International Scientists

- Professor Arie Levant, Tel Aviv University, Israel (Inria, 4 months)
- Professor Emilia Fridman, Tel Aviv University, Israel (Ecole Centrale de Lille, 1 month)
- Dr. Francisco Bejarano, National Polytechnic Institute, Mexico (Ecole Centrale de Lille, 1 month)

8.5.1.1. Internships

- Ivan De Jesus Salgado Ramos, National Polytechnic Institute, Mexico, till Apr 2015
  Subject:PID control design based on the different differentiation techniques

8.5.2. Visits to International Teams

8.5.2.1. Research stays abroad

- Gang Zheng, 2 months visit to Nanjing University of Sicence and Technology

9. Dissemination

9.1. Promoting Scientific Activities

9.1.1. Scientific events organisation

9.1.1.1. Member of the organizing committees

- J.-P. Richard, a member of NOC of 20th IFAC World Congress, Toulouse, France, 10-14 July 2017

9.1.2. Scientific events selection

9.1.2.1. Member of the conference program committees

- 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/
- Gang Zheng, Associate Editor, SIAM CT15, Paris, France (SIAM Conference of Control & Its Applications 2015), 8-10 July 2015, http://www.siam.org/meetings/ct15/

9.1.2.2. Reviewer

The members of NON-A team are reviewers and contributors of all top-ranked conferences in the field of automatic control (IEEE Conference on Decision and Control, IFAC World Congress, European Control Conference, American Control Conference, etc)

9.1.3. Journal

9.1.3.1. Member of the editorial boards

- 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: 3.176)

9.1.3.2. Reviewer - Reviewing activities

The members of NON-A team are reviewers of all top-ranked journals in the field of automatic control (IEEE Transactions on Automatic Control, Automatica, SIAM Journal of Control and Optimization, International Journal of Robust and Nonlinear Control, etc)

9.1.4. Invited talks

- Andrey Polyakov has been invited to give a talk for the conference "Optimization and Applications in Control and Data Science", 13-15 May 2015, Moscow, Russia, (https://sites.google.com/site/polconf/).

9.1.5. Leadership within the scientific community

The NON-A team is the leader in the field of non-asymptotic control and estimation using homogenety framework. For European Control Conference 2015 the tutorial session "Homogneity in Control: Geometry and Applications" has been organized and contributed by members of NON-A team.

9.1.6. Research administration

- Wilfrid Perruquetti, directeur adjoint scientifique de l'INS2I, CNRS

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 : 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), Séminaire episteme (24h); 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

HdR : Gang Zheng, "Analyse d'observabilité et synthèse d'observateur pour des systèmes dynamiques complexes", "Université Lille de Sciences et Technologies", 26 November 2015

PhD: Guo Qi, "Estimation dynamique des paramèters de robots manipulateur", EC-Lille, 8 December 2015, supervisors are W. Perruquetti and M. Gautier

PhD: Nehla Debbabi, "Approches algébriques et Théorie des valeurs extrêmes pour la détection de ruptures : Applications aux signaux biomédicaux", Tunis, 14 December 2015

PhD: Matteo Guerra, "Supervisory control of collective motion of mobile robots", EC-Lille, 17 December 2015, supervisors are W. Perruquetti, D. Efimov and G. Zheng

PhD in progress : Zilong Shao, "Oscilatory 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: 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 Separeted Flows", 2015-..., supervisors are J.-P. Richard, F. Kerherve, A. Polyakov

PhD in progress: Francisco Lopez Ramirez, "Control and Estimation via Implicit Homogeneous Lyapunov Function", 2015-..., supervisors are W. Perruquetti, D. Efimov and A. Polyakov

PhD in progress: Tatiana Kharkovskaia, "Interval Observers for Distributed Parametr Systems", 2015-..., supervisors are D. Efimov, J.-P. Richard, A. Kremlev

PhD in progress: Langueh Désiré Kokou, "Inversion a gauche, singularités d'inversion, immersion et formes normales pour les systemes dynamiques", 2015-..., supervisors are Thierry Floquet and Gang Zheng

PhD in progress: Gabriele Perozzi, "Save exploration of aerodynamic field by microdron", 2015-..., supervisors are Denis Efimov and Jean-Marc Biannic

PhD in progress: Guillaume Rance, "Etude de systèmes flexibles a retard et application aux viseurs", 2015-..., the supervisors are Alban Quadrat and Hugues Mounier

9.2.3. Juries

The team members are also involved in various examination committees of Theses and Habilitations, recruitment committees, in France and abroad.

10. Bibliography

Major publications by the team in recent years

[1] H. AHMED, R. USHIROBIRA, D. EFIMOV, D. TRAN, M. SOW, L. PAYTON, J.-C. MASSABUAU. *A fault detection method for an automatic detection of spawning in oysters*, in "IEEE Transactions on Control Systems Technology", December 2015, pp. 1–8, https://hal.inria.fr/hal-01185118

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[4] 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

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Publications of the year

Doctoral Dissertations and Habilitation Theses

[11] Q. GUO. *Online identification and control of robots using algebraic differentiators*, Ecole Centrale de Lille, December 2015, https://tel.archives-ouvertes.fr/tel-01259471

[12] G. ZHENG. *Observability Analysis and Observer Design for Complex Dynamical Systems*, Universite Lille 1, November 2015, Habilitation à diriger des recherches, https://tel.archives-ouvertes.fr/tel-01258527

Articles in International Peer-Reviewed Journals

[13] H. AHMED, R. USHIROBIRA, D. EFIMOV. *On Robustness of Phase Resetting to Cell Division under Entrainment*, in "Journal of Theoretical Biology", October 2015, https://hal.inria.fr/hal-01211491

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