RESEARCH CENTRE

Saclay - Île-de-France

IN PARTNERSHIP WITH:

CNRS, CentraleSupélec

2020

ACTIVITY REPORT

Project-Team

DISCO

Dynamical Interconnected Systems in COmplex Environments

IN COLLABORATION WITH: Laboratoire des signaux et systèmes (L2S)

DOMAIN

Applied Mathematics, Computation and Simulation

THEME

Optimization and control of dynamic systems

Contents

Project-Team DISCO

Creation of the Team: 2010 January 01, updated into Project-Team: 2012 January 01

Keywords

Computer sciences and digital sciences

A6.1.1. – Continuous Modeling (PDE, ODE)

A6.1.3. – Discrete Modeling (multi-agent, people centered)

A6.4.1. – Deterministic control

A6.4.3. – Observability and Controlability

A6.4.4. – Stability and Stabilization

Other research topics and application domains

B2.5. – Handicap and personal assistances

B3.6. – Ecology

B4.3.1. – Biofuels

B5.2.3. – Aviation

B7.2.1. – Smart vehicles

1 Team members, visitors, external collaborators

Research Scientists

- Catherine Bonnet [Team leader, Inria, Senior Researcher, HDR]
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2 Overall objectives

2.1 Objectives

The goal of the project is to better understand and well formalize the effects of complex environments on the dynamics of the interconnections, as well as to develop new methods and techniques for the analysis and control of such systems.

It is well-known that the interconnection of dynamic systems has as consequence an increased complexity of the behavior of the total system.

In a simplified way, as the concept of dynamics is well-understood, the interconnections can be seen as associations (by connections of materials or information flows) of distinct systems to ensure a pooling of the resources with the aim of obtaining a better operation with the constraint of continuity of the service in the event of a fault. In this context, the environment can be seen as a collection of elements, structures or systems, natural or artificial constituting the neighborhood of a given system. The development of interactive games through communication networks, control from distance (e.g. remote surgical operations) or in hostile environment (e.g. robots, drones), as well as the current trend of large scale integration of distribution (and/or transport and/or decision) and open information systems with systems of production, lead to new modeling schemes in problems where the dynamics of the environment have to be taken into account.

In order to tackle the control problems arising in the above examples, the team investigates new theoretical methods, develops new algorithms and implementations dedicated to these techniques.

3 Research program

3.1 Analysis of interconnected systems

The major questions considered are those of the characterization of the stability (also including the problems of sensitivity compared to the variations of the parameters) and the determination of stabilizing controllers of interconnected dynamic systems. In many situations, the dynamics of the interconnections can be naturally modelled by systems with delays (constant, distributed or time-varying delays) possibly of fractional order. In other cases, partial differential equations (PDE) models can be better represented or approximated by using systems with delays. Our expertise on this subject, on both time and frequency domain methods, allows us to challenge difficult problems (e.g. systems with an infinite number of unstable poles).

- Robust stability of linear systems

  Within an interconnection context, lots of phenomena are modelled directly or after an approximation by delay systems. These systems may have constant delays, time-varying delays, distributed delays …

  For various infinite-dimensional systems, particularly delay and fractional systems, input-output and time-domain methods are jointly developed in the team to characterize stability. This research is developed at four levels: analytic approaches (H_∞-stability, BIBO-stablity, robust stability, robustness metrics) [2, 1, 6, 7], symbolic computation approaches (SOS methods are used for determining easy-to-check conditions which guarantee that the poles of a given linear system are not in the closed right half-plane, certified CAD techniques), numerical approaches (root-loci, continuation methods) and by means of softwares developed in the team [6, 7].

- Robustness/fragility of biological systems

  Deterministic biological models describing, for instance, species interactions, are frequently composed of equations with important disturbances and poorly known parameters. To evaluate the impact of the uncertainties, we use the techniques of designing of global strict Lyapunov functions or functional developed in the team.

  However, for other biological systems, the notion of robustness may be different and this question is still in its infancy (see, e.g. [64]). Unlike engineering problems where a major issue is to maintain stability in the presence of disturbances, a main issue here is to maintain the system response in the presence of disturbances. For instance, a biological network is required to keep its functioning in case of a failure of one of the nodes in the network. The team, which has a strong expertise in robustness for engineering problems, aims at contributing at the develpment of new robustness metrics in this biological context.

3.2 Stabilization of interconnected systems

- Linear systems: Analytic and algebraic approaches are considered for infinite-dimensional linear systems studied within the input-output framework.

  In the recent years, the Youla-Kučera parametrization (which gives the set of all stabilizing controllers of a system in terms of its coprime factorizations) has been the cornerstone of the success of the H_∞-control since this parametrization allows one to rewrite the problem of finding the optimal stabilizing controllers for a certain norm such as H_∞ or H_2 as affine, and thus, convex problem.

  A central issue studied in the team is the computation of such factorizations for a given infinite-dimensional linear system as well as establishing the links between stabilizability of a system for a certain norm and the existence of coprime factorizations for this system. These questions are fundamental for robust stabilization problems [2, 1].

  We also consider simultaneous stabilization since it plays an important role in the study of reliable stabilization, i.e. in the design of controllers which stabilize a finite family of plants describing a system during normal operating conditions and various failed modes (e.g. loss of sensors or actuators, changes in operating points). Moreover, we investigate strongly stabilizable systems, namely systems which can be stabilized by stable controllers, since they have a good ability to track reference inputs and, in practice, engineers are reluctant to use unstable controllers especially when the system is stable.

- Nonlinear systems

  In any physical systems a feedback control law has to account for limitation stemming from safety, physical or technological constraints. Therefore, any realistic control system analysis and design has to account for these limitations appearing mainly from sensors and actuators nonlinearities and from the regions of safe operation in the state space. This motivates the study of linear systems with more realistic, thus complex, models of actuators. These constraints appear as nonlinearities as saturation and quantization in the inputs of the system [10].

  The project aims at developing robust stabilization theory and methods for important classes of nonlinear systems that ensure good controller performance under uncertainty and time delays. The main techniques include techniques called backstepping and forwarding, contructions of strict Lyapunov functions through so-called "strictification" approaches [4] and construction of Lyapunov-Krasovskii functionals [5, 6, 7] or or Lyapunov functionals for PDE systems [9].

3.3 Synthesis of reduced complexity controllers

- PID controllers

  Even though the synthesis of control laws of a given complexity is not a new problem, it is still open, even for finite-dimensional linear systems. Our purpose is to search for good families of “simple” (e.g. low order) controllers for infinite-dimensional dynamical systems. Within our approach, PID candidates are first considered in the team [1], [68].

  For interconnected systems appearing in teleoperation applications, such as the steer-by-wire, Proportional-Derivative laws are simple control strategies allowing to reproduce the efforts in both ends of the teleoperation system. However, due to delays introduced in the communication channels these strategies may result in loss of closed loop stability or in performance degradation when compared to the system with a mechanical link (no communication channel). In this context we search for non-linear proportional and derivative gains to improve performance. This is assessed in terms of reduction of overshoot and guaranteed convergence rates.

- Delayed feedback

  Control systems often operate in the presence of delays, primarily due to the time it takes to acquire the information needed for decision-making, to create control decisions and to execute these decisions. Commonly, such a time delay induces desynchronizing and/or destabilizing effects on the dynamics. However, some recent studies have emphasized that the delay may have a stabilizing effect in the control design. In particular, the closed-loop stability may be guaranteed precisely by the existence of the delay. The interest of considering such control laws lies in the simplicity of the controller as well as in its easy practical implementation. It is intended by the team members to provide a unified approach for the design of such stabilizing control laws for finite and infinite dimensional plants [3, 8].

- Finite Time and Interval Observers for nonlinear systems

  We aim to develop techniques of construction of output feedbacks relying on the design of observers. The objectives pertain to the design of robust control laws which converge in finite time, the construction of intervals observers which ensure that the solutions belong to guaranteed intervals, continuous/discrete observers for systems with discrete measurements and observers for systems with switches.

Finally, the development of algorithms based on both symbolic computation and numerical methods, and their implementations in dedicated Scilab/Matlab/Maple toolboxes are important issues in the project.

4 Application domains

4.1 Analysis and Control of life sciences systems

The team is involved in life sciences applications. The two main lines are the analysis of bioreactors models (microorganisms; bacteria, microalgae, yeast, etc..) and the modeling of cell dynamics in Acute Myeloblastic Leukemias (AML) in collaboration with St Antoine Hospital in Paris.

4.2 Energy Management

The team is interested in Energy management and considers control problems in energy networks.

5 Highlights of the year

5.1 Invited Professorship

Giorgio Valmorbida was awarded the “Chaires Franco-Brésiliennes” de l’état de São Paulo de l’année 2020.

6 New software and platforms

6.1 New software

6.1.1 P3δ

Name: Partial pole placement via delay action

Keywords: Delay systems, Control design, Automatic control

Functional Description: A Python implementation of recent methods for the stability analysis and stabilization of linear time-delay systems exploiting the delay action. Its control design strategy is based on properties of the spectral distribution of the time-delay system.

Release Contributions: Generic and control-oriented MID

URL: https://iboussaa.gitlabpages.inria.fr/partial-pole-placement-via-delay-action/P3d-Home.html

Contacts: Islam Boussaada, Guilherme Mazanti, Silviu-Iulian Niculescu

Partners: Cyb’Air-IPSA, ICODE, CentraleSupélec

7 New results

7.1 Multiplicity-induced-dominancy

Participants Jean Auriol *(L2S, CNRS)*, Tamas Balogh *(BME, Budapest)*, Amina Benarab, Catherine Bonnet, Islam Boussaada, Ali El Ati *(IPSA)*, Tamas Insperger *(BME, Budapest)*, Guilherme Mazanti, Csenge Molnar *(BME, Budapest)*, Hugues Mounier *(L2S, CentraleSupélec)*, Silviu-Iulian Niculescu, Karim Trabelsi *(IPSA)*.

The effects of the multiplicity of spectral values on the exponential stability of reduced-order retarded differential equation were studied in recent works by the team, in which a property called multiplicity-induced-dominancy (MID) was introduced for reduced-order systems. The MID is explored in the general class of n-th order retarded differential equations with a single delay in [37] where the existence of a real root with maximal multiplicity is characterized in terms of the equation parameters. This root is shown to be always strictly dominant, determining thus the asymptotic behavior of the system. The dominancy proof is based on improved a priori bounds on the imaginary part of roots on the complex right half-plane and a suitable factorization of the characteristic function, which is an alternative technique to the argument principle.

A control-oriented version of the MID property is proposed in [50]. As a matter of fact, it is shown that the dominancy of a multiple spectral value holds even if the corresponding multiplicity is not maximal. A sufficient condition is given for the dominancy of a real root with multiplicity $n+1$ for n-th order retarded equations. In particular, the stabilizing effect of such a multiplicity holds for real-rooted open-loop plants. The delay intervals are derived as well as the set of parameters satisfying stabilizability and dominancy conditions. The efficiency of the proposed controller design is shown in the case of a multi-link inverted pendulum.

In [39], the MID property is extended to a given pair of complex conjugate roots for a generic second-order retarded differential equation. Necessary and sufficient conditions for the existence of such a pair are provided, and it is also shown that such a pair is always necessarily dominant. It appears also that when the frequency corresponding to this pair of roots tends to 0, then the pair of roots collapse into a real root of maximal multiplicity. The latter property is exploited in the dominancy proof together with a study of crossing imaginary roots.

Further extension of the MID is shown for a wider class of delay differential-algebraic system. It is shown in [38] that the MID property holds for scalar first-order neutral delay equations as well as for a first-order lossless propagation model. In [51], for second order neutral time-delay differential equations, necessary and sufficient conditions for the existence of a root of maximal multiplicity are given in terms of this root and the parameters of the given equation. Links with dominancy of this root and with the exponential stability property of the solution of the considered equations are emphasized.

In [25] single and double inverted pendulum systems subjected to delayed state feedback are analyzed in terms of stabilizability. The maximum (critical) delay that allows a stable closed-loop system is determined via the MID property of the characteristic roots. It is shown that, using the MID-based approach, the critical delay and the associated control gains can be easily carried out from the expression of the characteristic equation and its derivatives. Such a combination of inverted pendulums is usually used to describe biomechanics structures such as the human balance. The delayed nature of the central nervous system (CNS) action on the interaction muscle-tendon is essentially due to the propagation of the neural signals. In [48], the CNS is modeled as a delayed proportional-derivative (PD) controller exploiting the MID property. The birth of oscillation in the muscle-tendon junction is characterized through a critical delay and PD gains.

In [49] a control-oriented model of torsional vibrations occurring in rotary oil-well drilling process is proposed. Such vibrations are known to constitute an important source of economic losses; drill bit wear, pipe disconnection, borehole disruption and prolonged drilling time, among other consequences. More precisely, torsional vibrations are assumed to be governed by a wave equation with weak damping term. An appropriate stabilizing controller with a reduced number of parameters is proposed for damping such torsional vibrations. Such a controller allows further exploration of the effect of multiple roots with maximal admissible multiplicity for linear neutral systems with a single delay. The MID-based design is further exploited to quench the torsional vibrations along the rotary drilling system. The proposed control law guarantees the existence of robustness margins with respect to delays and parameters uncertainties.

7.2 Pole placement techniques for time-delay systems

Participants Amrane Souad *(University Mouloud Mammeri de Tizi Ouzou, Algeria)*, Fazia Bedouhene *(University Mouloud Mammeri de Tizi Ouzou, Algeria)*, Islam Boussaada, Silviu-Iulian Niculescu, Sami Tliba *(L2S, CentraleSupélec)*.

The interest in investigating multiple spectral values does not rely on the multiplicity itself, but rather on its connection with the dominance of the corresponding root, and the ensuing applications in stability analysis and control design. The effect of the coexistence of such distinct real spectral values on the asymptotic stability of the trivial solution were recently emphasized by the team and shown for reduced-order systems. It was stressed that the coexistence of an appropriate number of real spectral values makes them rightmost roots of the corresponding quasipolynomial. Furthermore, if they are negative, this guarantees the asymptotic stability of the trivial solution. This property was called coexistent real roots inducing dominancy (CRRID).

For instance, [47] provides an appropriate stability criterion for second-order systems based on the manifold defined by the coexistence of the maximal number of negative spectral values. Next, such ideas are exploited in the context of delayed output feedback by an appropriate partial pole placement guaranteeing simultaneously the stability in closed-loop and an appropriate exponential decay rate. To perform such an analysis, the argument principle is employed.

The CRRID is further explored in [11] where the structural properties of a class of functional Vandermonde matrices is exploited to emphasize some qualitative properties of a class of linear autonomous n-th order differential equation with forcing term consisting in the delayed dependent-variable. More precisely, it deals with the stabilizing effect of delay parameters coupled with the coexistence of the maximal number of real spectral values. The derived conditions are necessary and sufficient and represent a novelty in the litterature. Under appropriate conditions, such a configuration characterizes the spectral abscissa corresponding to the studied equation. A new stability criterion is proposed. This criterion extends recent results in factorizing quasipolynomial functions. The applicative potential of the proposed method is illustrated through the stabilization of coupled oscillators.

As an application of the proposed partial pole placement, the problem of active vibration damping for a thin axisymmetric membrane is considered in [44]. The considered mechanical system is equipped with two piezoelectric circular patches: one of them works as a sensor and the other is used as an actuator. Both are fixed on the membrane, one on each side, and centered according to its axis of symmetry. The model of this system is obtained from a finite element analysis, leading to a linear state-space model. The design of the proposed control scheme is based on delayed proportional actions. The CRRID is exploited to an assignment of spectral values in an appropriate sector corresponding to a desired damping. The purpose of this work is to investigate the properties of the proposed output feedback controller in terms of vibration damping of the main observable and controllable vibrating modes as well as its robustness with respect to the neglected modes.

7.3 PID tuning for controlling delayed dynamics

Participants Catherine Bonnet, Islam Boussaada, Jie Chen *(City University of Hong Kong)*, Jianqi Chen *(City University of Hong Kong)*, Andong Liu *(City University of Hong Kong)*, Dan Ma *(Northeastern University, China)*, Silviu Niculescu.

Nowadays, the PID controller is the most used in controlling industrial processes. In [55], the MID property which is merely a delayed-output-feedback where the candidates' delays and gains result from the manifold defining the maximal multiplicity of a real spectral value, is employed in the PID tuning for delayed plants. More precisely, the controller gains (k_i, k_p, k_d) are tuned using the intentional multiplicity algebraic constraints allowing the stabilization of unstable delayed plants. The specificity of such a design is related to the analytical assignment of the closed-loop solution decay rate.

7.4 Characterizing PID Controllers for Linear Time-Delay Systems: A Parameter-Space Approach

Participants Silviu-Iulian Niculescu, Xu-Guang Li *(Northeastern Univ at Shenyang, China)*, Jun-Xiu Chen *(Northeastern Univ at Shenyang, China)*, Tianyou Chai *(Northeastern Univ at Shenyang, China)*.

The paper [18] addresses the proportional-integral-derivative (PID) controller design problem for linear time-delay systems. All the controller gains and the delay are treated as free parameters and no particular constraints are imposed on he controlled plants. First, we will develop an algebraic algorithm to solve the stability problem w.r.t. to the delay parameter. Consequently, for any given PID controller, the distribution of the characteristic roots in the complex plane can be accurately obtained and the exhaustive stability range of the delay be automatically calculated. Next, a global understanding of the distribution of the characteristic roots in the right-half plane over the whole 3-dimensional controller gain-parameter space may be achieved and all structural changes regarding the distribution on the unstable characteristic roots can be analytically determined. To achieve such a goal, a complete positive real root classification (for some appropriate auxiliary characteristic equation) will be explicitly proposed. Finally, a new parameter-based methodology is proposed for determining the stability set in the whole set of parameters defined by the controller gains (proportional, integral, derivative) and the delay.

7.5 Frequency-sweeping techniques in delayed dynamics analysis

Participants Arben Cela *(ESIEE Paris)*, Xu-Guang Li *(Northeastern University, China)*, Xu Li *(Northeastern University, China)*, Jiang-Chian Li *(Northeastern University, China)*, Zhi-Zhong Mao *(Shenyang University)*, Silviu Niculescu, Lu Zhang *(Shenyang University)*.

The stability of linear systems with multiple (incommensurate) delays is investigated in [65], by extending a recently proposed frequency-sweeping approach. First, we consider the case where only one delay parameter is free while the others are fixed. The complete stability w.r.t. the free delay parameter can be systematically investigated by proving an appropriate invariance property. Next, we propose an iterative frequency-sweeping approach to study the stability under any given multiple delays. Moreover, we may effectively analyze the asymptotic behavior of the critical imaginary roots (if any) w.r.t. each delay parameter, which provides a possibility for stabilizing the system through adjusting the delay parameters. The approach is simple (graphical test) and can be applied systematically to the stability analysis of linear systems including multiple delays. A deeper discussion on its implementation is also proposed. Finally, various numerical examples complete the presentation.

In most of the numerical examples of time-delay systems proposed in the literature, the number of unstable characteristic roots remains positive before and after a multiple critical imaginary root (CIR) appears (as the delay, seen as a parameter, increases). This fact may lead to some misunderstandings: (i) A multiple CIR may at most affect the instability degree; (ii) It cannot cause any stability reversals (stability transitions from instability to stability). As far as we know, whether the appearance of a multiple CIR can induce stability is still unclear (in fact, when a CIR generates a stability reversal has not been specifically investigated). In [66], we provide a finer analysis of stability reversals and some new insights into the classification: the link between the multiplicity of a CIR and the asymptotic behavior with the stabilizing effect. Based on these results, we present an example illustrating that a multiple CIR's asymptotic behavior is able to cause a stability reversal. To the best of the authors' knowledge, such an example is a novelty in the literature on time-delay systems.

The work [69] focuses on the stability property of a class of distributed delay systems with constant coefficients. More precisely, we will discuss deeper the stability analysis with respect to the delay parameter. Our approach will allow to give new insights in solving the so-called complete stability problem. There are three technical issues need to be studied: First, the detection of the critical zero roots; second, the analysis of the asymptotic behavior of such critical zero roots; third, the asymptotic behavior analysis of the critical imaginary roots with respect to the infinitely many critical delays. We extended our recently-established frequency-sweeping approach, with which these technical issues can be effectively solved. More precisely, the main contributions of this paper are as follows: (i) Proposing a method for the detection of the critical zero roots. (ii) Proposing an approach for the asymptotic behavior analysis of such critical zero roots. (iii) The invariance property for the critical imaginary roots can be proved. Based on these results, a procedure was proposed, with which the complete stability analysis of such systems was accomplished systematically. Moreover, the procedure represents a unified approach: Most of the steps required by the complete stability problem may be fulfilled through observing the frequency-sweeping curves. Finally, some examples illustrate the effectiveness and advantages of the approach.

7.6 Weierstrass approach to asymptotic behavior of retarded differential equations

Participants Jie Chen *(City University of Hong Kong)*, Liliana Felix *(University of San Luis Potosi)*, Alejandro Martinez-Gonzalez, Cesar F. Mendez-Barrios *(University of San Luis Potosi)*, Silviu Niculescu.

The work [67] focuses on the analysis of the behavior of characteristic roots of time-delay systems, when the delay is subject to small parameter variations. The analysis is performed by means of the Weierstrass polynomial. More specifically, such a polynomial is employed to study the stability behavior of the characteristic roots with respect to small variations on the delay parameter. Analytic and splitting properties of the Puiseux series expansions of critical roots are characterized by allowing a full description of the cases that can be encountered. Several numerical examples encountered in the control literature are considered to illustrate the effectiveness of the proposed approach.

7.7 Some remarks on the regular splitting of quasi-polynomials with two delays. Characterization of double roots in degenerate cases

Participants Silviu-Iulian Niculescu, Alejandro Martinez-Gonzalez, Fernando Mendez-Barrios *(UASLP, Mexico)*.

The paper [34] addresses the classification of multiple critical roots of dynamical continuous linear time-invariant systems including two constant delays in their mathematical representation. By considering the associated Weierstrass polynomial and its algebraic properties, the paper presents the splitting behavior of such critical roots when the delays are subject to small variations. Some degenerate cases are also considered. Furthermore, the proposed methodology allows to relax some of the existing assumptions in the literature and can be generalized to systems including more than two delays. The effectiveness of the proposed approach is illustrated through several numerical examples.

7.8 Controllability of linear delay systems and of its samples version

Participants Silviu-Iulian Niculescu, Hugues Mounier *(L2S)*.

The paper [56] focuses on the controllability preservation through sampling of linear time-delay systems. We make use of a module theoretic framework acting as a unifying one for most of the existing delay system controllability notions. The controllability properties are envisioned through ring theoretic properties. Some illustrative examples complete the presentation.

7.9 Some Insights on the Asymptotic Stabilization of a Class of SISO Marginally Stable Systems Using One Delay Block

Participants Silviu-Iulian Niculescu, José-Enrique Hernández-Díez, Fernando Mendez-Barrios *(UASLP, Mexico)*.

The stability of a class of marginally stable SISO systems is studied by applying one delay block as a feedback controller. More precisely, we consider an open-loop system with no zeros and whose poles are located exactly on the imaginary axis. Furthermore, a control law formed uniquely by a proportional gain and a delayed behavior is proposed for its closed-loop stabilization. The main ideas are based on a detailed analysis of the characteristic quasi-polynomial of the closed-loop system as the controller parameters (gain, delay) are varied. More precisely, by using the Mikhailov stability criterion, for a fixed delay value, some gains margin guaranteeing the closed-loop stability are explicitly computed. The particular case when the characteristic roots of the open-loop system are equidistantly distributed on the imaginary axis is also addressed. Finally, an illustrative example shows the effectiveness of the approach.

7.10 Bézout Identity in Pseudoratoinal Transfer Functions

Participants Catherine Bonnet, Yutaka Yamamoto *(Univ of Kyoto, Japan)*.

Coprime factorizations of transfer functions play various important roles, e.g., minimality of realizations, stabilizability of systems, etc. We have studied the Bézout condition over the ring $\epsilon'(\mathbb{R}_-)$ of distributions of compact support and the ring $\mathscr{M}(\mathbb{R}_-)$ of measures with compact support. These spaces are known to play crucial roles in minimality of state space representations and controllability of behaviors. We have given a new attempt of deriving general results from that for measures. It is clarified that there is a technical gap in generalizing the result for $\mathscr{M}(\mathbb{R}_-)$ to that for $\epsilon'(\mathbb{R}_-)$. A detailed study of a concrete example is given in [46].

7.11 Stability analysis of Piece-Wise Affine Systems

Participants Giorgio Valmorbida, Leonardo Broering Groff, Joao Manoel Gomes da Silva Jr *(Universidade Federal do Rio Grande do Sul)*, Francesco Ferrante *(Gipsa-lab)*.

Piece-wise affine systems appear when linear dynamics are defined in different partitions of the state space. This type of system naturally appears whenever actuators have different stages or saturate or whenever non-linear control laws are obtained as the solution to a parameterised optimization problem as, for instance for systems with feedback laws based on the so-called explicit Model Predictive Control. Even though the dynamics is simple to describe, the stability analysis, performance assessment and robustness analysis are difficult to perform since, due to the often used explicit representation, the Lyapunov stability and dissipation tests are often described in terms of a number of inequalities that increase exponentially on the number of sets in the partition since they are based on the enumeration of the partition transitions. Moreover regional stability and uncertainties corresponding to modification on the partition are difficult to study in this scenario.

To overcome these difficulties we have proposed an implicit representation for this class of systems in terms of ramp functions. The main advantage of such a representation lies on the fact that the ramp function can be exactly characterized in terms of linear inequalities and a quadratic equation, namely a linear complementarity condition. Thanks to the characterization of the ramp function and the implicit description of the PWA system the verification of Lyapunov inequalities related to piecewise quadratic functions can be cast as a pair of linear matrix inequalities.

We are now applying the results to the local analysis and synthesis of PWA control laws. These results generalise the local analysis of saturating systems and avoid the complexity of PWA system analysis which is currently based on enumeration of the transition in a PWA partition. We have also developed an event-triggered strategy that also avoids the enumeration and relies on an piece-wise quadratic triggering function. This strategies allow to reduce the number of evaluation of control actions.

We have also shown that the step function can be written as an ill-posed algebraic loop with two ramp functions. We were thus able to unify the analysis of continuous and discontinuous PWA functions and thus to perform the analysis with partition-based Lyapunov functions. As a first case to apply the developed methodology, we have studied the class of systems with ternary inputs.

A strategy for the solution of quadratic programs, based on the representation of PWA function in terms of ramp function, is currently under development.

7.12 Stability analysis of Slope Restricted Lurie Systems

Participants Giorgio Valmorbida, Ross Drummond *(University of Oxford)*, Pedro Luis Dias Peres *(UNICAMP)*, Ricardo C. L. Fontoura Oliveira *(UNICAMP)*.

For nonlinear Lurie Systems in discrete-time, the stability or stabilisation can be studied with two main approaches: the Lyapunov analysis and the multiplier analysis. For the Lyapunov analysis, a model given by a difference equation is considered and, if the nonlinearity is sector and slope restricted, no necessary and sufficient condition for stability is known to date. We have proposed new classes of Lyapunov functions to study the local and global properties for the nonlinear distcrete-time systems.

For the design of control laws, we have recently proposed an iterative method for the approaches of Lyapunov functions computation. This method is now being extended to consider the frequency-domain strategy of obtaining Zames-Falb multipliers.

7.13 New advances on backstepping

Participants Frédéric Mazenc, Michael Malisoff *(LSU)*, Sabine Mondie *(CINVESTAV)*, Javier Zamudio *(CINVESTAV)*, Laurent Burlion *(Rutgers Univ.)*.

In the paper [42], we develop an alternative approach of the fundamental design of nonlinear control laws called 'backstepping'. It relies on the introduction of artificial delays combined with Lyapunov-Krasovskii functionals of complete type, thus allowing a constructive approach for the design of asymptotically stabilizing controls of linear systems with delay in the input and state that are too long for being neglected.

In the work [13], we provide a new output feedback control design for a chain of saturating integrators with imprecise measurements where the outputs can also contain delays and sampling. Using a backstepping approach with a dynamic extension that leads to pointwise delays in the control and a dynamic extension, we obtain a stability result whose robustness is of input-to-state type. We use this theoretical result to solve a problem in the visual landing of aircraft in the glide phase in the presence of delayed and sampled image processing.

7.14 Bounded control for discrete-time systems

Participants Xuefei Yang *(Harbin Institute)*, Bin Zhou *(Harbin Institute)*, James Lam *(Hong Kong University)*, Frédéric Mazenc.

In the work [27], we address the problem of globally stabilizing discrete-time multiple integrators with bounded controls by utilizing the energy function based approach. In a first part, we stabilize a discrete-time double integrators system subject to input additive disturbances by a bounded feedback whose formula involves a linear function of the state and a saturation function only. Next, we use this result to stabilize a discrete-time chain of multiple integrators of arbitrary length by bounded control with the aid of a special canonical form. Compared with the existing results, the proposed controllers require fewer saturation functions, which allow a better use of the control energy. Moreover, some free parameters that are introduced into these controllers can help improve the transient performance of the closed-loop systems significantly. A numerical example to assess the effectiveness of the proposed method is given. The contribution [26], is devoted to the global asymptotic stabilization of discrete-time chains of integrators with bounded controls by utilizing the energy function based approach. First, a discrete-time double integrators system affected by input additive disturbances is stabilized by a bounded feedback whose formula involves a linear function of the state and only one saturation function. Next, this result is used to globally asymptotically stabilize by bounded feedback a chain of multiple integrators of arbitrary length. Compared with the existing results, the proposed controllers require fewer saturation functions, which allow a better use of the control energy. Moreover, some tuning parameters in these controllers can help improve the transient performance of the closed-loop systems significantly.

7.15 Observers

Participants Frédéric Mazenc, Thach Dinh *(CNAM)*, Tarek Raissi *(CNAM)*, Saeed Ahmed *(University of Kaiserslautern, Germany)*, Michael Malisoff *(LSU)*, Silviu Niculescu.

The aim of the contribution [32] is to cope with estimation issues for discrete-time nonlinear time-varying systems with input and output. We propose a new design technique which yields fixed-time observers, i.e. observers whose solution converges to the solution of the studied system before an instant chosen by the user. The construction relies on the use of past values of the output and the theory of the monotone systems to construct dead bit observer or fixed-time interval estimator depending on the absence or the presence of uncertainties. Finally, simulations are conducted to assess the effectiveness of the proposed schemes.

The work [24] is devoted to observers which converge in finite time too. We propose a reduced order observers for a class of nonlinear time-varying continuous-time systems. In a second step, we take advantage of the observers to design globally asymptotically stabilizing output feedback controls. We illustrate these observer and control designs in a tracking dynamics for a nonholonomic system in chained form.

Due to the fact that, usually in practice, the measured variables of a system are available at discrete times only, the paper [41] studies the problem of stabilizing continuous-time nonlinear systems with discrete measurements with a fast rate of convergence. We propose an estimate of the state variable that converges with a rate of convergence that can be made arbitrarily large by reducing the size of the largest sampling interval. The proof of the convergence result is based on a the stability analysis technique called " trajectory based approach " and developed by F. Mazenc and co-authors in recent contributions.

7.16 Sequential predictors

Participants Frédéric Mazenc, Michael Malisoff *(LSU)*, Indra Bhogaraju *(LSU)*.

The contributions [40] and [20]are dedicated to the study of time-varying linear discrete time systems with uncertainties and time-varying measurement delays, whose outputs are perturbed by uncertainty. We design sequential predictors, that is interconnected predictors whose number is proportional to the size of the delay. They ensure a robustness property of input-to-state stability type with respect to the considered uncertainties. The number of required sequential predictors is any upper bound for the delay in our feedback stabilized closed loop systems. Using this technique, arbitrarily large delays can be handled. We illustrate the work in a digital control problem for a continuous time system that is discretized through sampling.

7.17 Stability Analysis of Linear Partial Differential Equations

Participants Giorgio Valmorbida, Aditya Gahlawat *(University of Illinois at Urbana-Champaign)*.

We proposed a method to perform stability analysis of one-dimensional Partial Integro-Differential Equations. The relevance of the proposed results lies on the fact that we cast the Lyapunov inequalities as a differential inequality in two dimensions. The proposed structure for the inequalities is motivated by the same structure as the one used in the study of backstepping feedback laws, a successful strategy applied for several one-dimensional PDE systems. The advantage of the proposed Lyapunov analysis can be studied in a simpler manner as well as the fact that the backstepping law can be approximated by simpler laws and the stability can still be studied trhough the solution to the set of proposed inequalities.

We rely on Lyapunov analysis to establish the exponential stability of the systems. Then we present a test for the verification of the underlying Lyapunov inequalities, which relies on the existence of solutions of a system of coupled differential equations.

We illustrate the application of this method in several examples of PDEs defined by polynomial data, we formulate a numerical methodology in the form of a convex optimization problem which can be solved algorithmically. We show the effectiveness of the proposed numerical methodology using examples of different types of PDEs.

We are currently studying the extensions of coupled PDE-ODE systems.

7.18 Stability analysis of wave equations in one space dimension with nonlinear boundary conditions

Participants Yacine Chitour *(L2S, Univ. Paris-Saclay & CentraleSupélec)*, Swann Marx *(LS2N, École Centrale de Nantes)*, Guilherme Mazanti.

Wave equations in one space dimension are useful models for propagation phenomena and the analysis of the asymptotic behavior of their solution is an important question both from theoretical and applied points of view. In many practical applications, the action of a controller on a wave propagation phenomenon can only occur through the boundary of the propagation domain, and, even though such a controller can often be designed to be linear, nonlinearities are usually present in its practical implementation, due to nonlinearities in the components used for implementation or saturation phenomena.

The work [62] considers a wave equation in one space dimension with a set-valued boundary condition, which contains nonlinear boundary conditions as particular cases but can also be used to describe switching phenomena or uncertainties. The study is performed within an L^p functional framework, for $p \in [1, +\infty]$. Necessary and sufficient conditions for existence and uniqueness of solutions are derived, showing in particular that set-valued boundary dampings are a quite natural framework for the analysis of wave equations: solutions may exist and be unique even when the boundary condition is not described by a functional relation, which allows one to easily address problems involving dry damping or sliding mode.

The work also provides several results characterizing the asymptotic behavior of such wave equations, retrieving some already known optimal estimates of decay rates but also providing new ones and solving some open problems in the literature, in particular involving saturation-type dampings. In case the boundary damping is subject to perturbations, the paper also derives sharp results regarding asymptotic perturbation rejection and input-to-state stability. The techniques used in the paper might be applied to more general hyperbolic systems, a line of research currently in investigation.

7.19 Existence and characterization of equilibria of some game models for crowd motion

Participants Romain Ducasse *(LJLL, Université de Paris)*, Guilherme Mazanti, Saeed Sadeghi Arjmand, Filippo Santambrogio *(Institut Camille Jordan, Université Claude Bernard - Lyon 1)*.

Mean field games have been introduced around 2006 as an approximation, as the number of players tends to infinity, of games with rational, indistinguishable players interacting with other only through their “average” behavior. Originally motivated by problems in economics and engineering, mean field games have been also used as models in many other applications.

This line of research aims at proposing mean field game models for crowd motion, in which players are the agents of the crowd and their goal is typically to reach a certain target set minimizing some criterion involving their travel time. The recent work [63] has adressed the case of stochastic minimal-time mean field games in which agents wish to reach the boundary of a given set in minimal time, but the movement of each agent is submitted to a Brownian motion. The main results of the paper concern the existence of equilibria, characterized as a solution to a system of PDEs, as well as the description of some of its properties, in particular its long-time asymptotic behavior.

Despite recent advances on mean field games, their practical applications are still quite limited due to the difficulties in the theoretical analysis of mean field games with more realistic assumptions. An ongoing research effort by G. Mazanti and S. Sadeghi Arjmand deals with studying mean field games for crowd motion with more realistic assumption, involving in particular the study of many-population games and games submitted to state constraints. Interesting preliminary results have been obtained and are the topic of a work in preparation.

7.20 A Current Sensorless Delay–Based Control Scheme for MPPT–Boost Converters in Photovoltaic Systems

Participants Silviu-Iulian Niculescu, José-Enrique Hernández-Díez, Fernando Mendez-Barrios *(UASLP, Mexico)*, Ernesto Bárcenas-Bárcenas *(UASLP, Mexico)*.

We have dealt with the design of a current sensorless delay–based controller for the closed–loop stabilization of a photovoltaic system under an MPPT scheme using a boost dc/dc converter. Some applications of such topology are dc microgrids, solar vehicles, or standalone systems, to mention a few. The basis of this control scheme relies on the feedback linearization control technique coupled with a delay–based low-order controller. In order to study the stability, the proposed approach uses a geometric point of view which allows the partitioning of the controller parameters space into regions with similar stability characteristics (same number of unstable characteristic roots). Our most important contribution relies on providing practical guidelines to tune the gains of the proposed delay–based controller, ensuring asymptotic stability of the closed–loop system and fulfilling the requirements for photovoltaic applications. In addition, the proposed approach allows the design a nonfragile controller with respect to the controller gains. Furthermore, in order to test the effectiveness of the control scheme presented, experimental results evaluating the closed–loop system performance under setpoint changes and abrupt irradiance disturbances are addressed using a solar array simulator and a battery bank as load.

8 Partnerships and cooperations

8.1 International initiatives

Informal international partners - Kyoto University

- Leeds University
- Louisiana State University
- City University of Hong Kong
- CTU in Prague
- KU Leuven
- Harbin Institute
- University of Kaiserslautern
- Rutgers University
- Centro de Investigación y de Estudios Avanzados del Instituto Politécnico Nacional
- University Mouloud Mammeri

8.2 International research visitors

8.2.1 Visits of international scientists

Jaqueline Godoy Mesquita, from University of Brasília (Brazil) and at the time in a sabbatical year at Justus Liebig Universität (Giessen, Germany), visited DISCO Team in February 10–14, 2020. In addition to scientific work, discussions were held to improve collaborations between DISCO Team and researchers from University of Brasília.

Fazia Bedouhene, from University Mouloud Mammeri (Algeria), visited the Disco Team in January 15-25, 2020.

8.3 National initiatives

Islam Boussaada is a member of the administration council of the Association SAGIP (https://www.sagip.org), which structures and promotes the disciplines of automatic control and industrial engineering at the national level.

8.3.1 ANR

- Giorgio Valmorbida is a member of the ANR HANDY - Hybrid And Networked Dynamical sYstems (http://projects.laas.fr/handy). Project Summary: Networked dynamical systems are ubiquitous in current and emerging technologies. From energy grids, fleets of connected autonomous vehicles to online social networks, the same scenario arises in each case: dynamical units interact locally to achieve a global behavior. When considering a networked system as a whole, very often continuous-time dynamics are affected by instantaneous changes, called jumps, leading to so-called hybrid dynamical systems. The jumps may originate from (i) the intrinsic dynamics of the nodes, like in multimedia delivery with fixed rate encoding, (ii) intrinsic limitations of the control actions, possibly constrained to a finite set of possible selections, like in power converters within energy grids, (iii) the creation/loss of links or the addition/removal of nodes like in renewable energy systems and social networks. Hybrid phenomena thus play an essential role in these control applications, and call upon the development of novel adapted tools for stability and performance analysis and control design. In this context, the aim of HANDY project is to provide methodological control-oriented tools for realistic networked models, which account for hybrid phenomena.

9 Dissemination

9.1 Promoting scientific activities

9.1.1 Scientific events: selection

Catherine Bonnet was Associate Editor for the 2020 American Control Conference, Denver, USA and the 2021 American Control Conference, New Orleans, USA.

Frederic Mazenc was Associate Editor for European Control Conference, Rotterdam, The Netherlands (2021).

Giorgio Valmorbida is a member of the Editorial Board of the Control Systems Society, serving as an editor for the ACC and the CDC (2018, 2019, 2020, 2021).

Silviu-Iulian Niculescu was Editor of the 2020 IFAC World Congress (Berlin, Germany).

Member of the conference program committees Catherine Bonnet and Islam Boussaada are members of the International Program Committee of the 16th IFAC Workshop on Time Delay Systems (TDS 2021), Guangzhou, China.

Frederic Mazenc is member of the IFAC Technical Committee on Linear Control Systems, 4th IFAC Workshop on Linear Parameter-varying systems, 19-20 July 2021.

Catherine Bonnet and Giorgio Valmorbida are members of the scientific committee of the GDRI (International Research Group funded by CNRS) SpaDisco since 2017.

Giorgio Valmorbida is a member of the steering committee of the GDRI (International Research Group funded by CNRS) SpaDisco since 2017.

Reviewer The team reviewed papers for several international conferences including IEEE Conference on Decision and Control, IEEE American Control Conference, European Control Conference, Mathematical Theory of Networks and Systems ...

9.1.2 Journal

Member of the editorial boards Frederic Mazenc is Editor of the Asian Journal of Control.

Frederic Mazenc is Associate Editor of IEEE Control Systems Letters.

Giorgio Valmorbida is Associate Editor of IMA Journal of Mathematical Control and Information.

Giorgio Valmorbida is Associate Editor of Journal of Control, Automation and Electrical Systems.

Silviu-Iulian Niculescu is Foundig-Editor and Editor-in-Chief of the Springer Nature series “Advances in Delays and Dynamics” (since its creation in 2012): https://www.springer.com/series/11914

Silviu-Iulian Niculescu is Editor of IFAC PapersOnLine (2020-2023).

Silviu-Iulian Niculescu is Editor of the IMA Journal of Mathematical Control and Information (since 2010).

Silviu-Iulian Niculescu is Editor of the European Journal of Control (since 2010).

Silviu-Iulian Niculescu is Editor of Frontiers in Control Engineering (since its creation in 2020).

Silviu-Iulian Niculescu is Guest Editor for the special issue devoted to “PID Control in the Information Age: Theoretical Advances and Applications” at the International Journal of Robust and Nonlinear Control (2020-2021): https://gdr-macs.cnrs.fr/content/pid-control-information-age-theoretical-advances-and-applications-ijrnc

Reviewer - reviewing activities The team reviewed papers for several journals including SIAM Journal on Control and Optimization, Automatica, IEEE Transactions on Automatic Control, Systems and Control Letters, IEEE Control Systems Letters ...

9.1.3 Invited talks

- Guilherme Mazanti gave an invited talk at the conference *Mean Field Games: Recent Progress*, which took place in Chicago–IL, United States, in February 2020.

- Guilherme Mazanti gave an invited talk at the conference *Mean Field Games and Applications*, which was part of the program *High Dimensional Hamilton–Jacobi PDEs* organized by the Institute for Pure and Applied Mathematics (IPAM), UCLA, United States, and which took place in May 2020.

- Guilherme Mazanti gave an invited talk at the *Virtual Thematic Workshop in Math Sciences: Nonlinear Dynamical Systems and Delay Equations*, organized by the Young Affiliates Network of The World Academy of Sciences (TYAN / TWAS), which took place on October 26th, 2020.

9.1.4 Leadership within the scientific community

Catherine Bonnet is a member of the IFAC Technical Committees on *Distributed Parameter Systems*, on *Biological and Medical Systems* and on *Robust Control.* She is a member of the management committee of the COST Action FRACTAL (2016-2020).

Silviu Niculescu is the chair of the IFAC TC 2.2 "Linear Control Systems" since 2017 (including 300-350 researchers throught the world). The TC is coordinating 4 "Working Groups" (WG) including the WG on "Time-Delay Systems".

9.1.5 Scientific expertise

Since September 2015, Catherine Bonnet is a member of the Evaluation Committee of Inria and since 2019 of the Bureau of the Evaluation Committee of Inria. In 2020, she has been an expert for Ville de Paris, France.

Since September 2016, Islam Boussaada is a member of the Scientific Council of IPSA (Engineering School in Aeronautic and Aerospace approved by CTI).

Since September 2018, Islam Boussaada is a member of the Development Council of Sup'Biotech (Engineering School in Biotechnologies approved by CTI).

Since 2019 Frederic Mazenc is Membre of the "Commission de Développement Technologique" (Inria Saclay).

9.1.6 Research administration

Catherine Bonnet is a member of the :

- *Parity Committee* of Inria created sice its creation in 2015.
- Bureau du Comité des Projets du CRI Saclay-Ile-de-France since 2018.
- Coordination committee of the Mentoring Program of Inria Saclay-Île-de-France.
- PhD referent committee at L2S, CentraleSupelec.

She is the Parity Referent at L2S for CNRS since November 2020.

Since 2019 Frederic Mazenc is Membre of the "Commission de Développement Technologique" (Inria Saclay).

9.2 Teaching - Supervision - Juries

9.2.1 Teaching

- Licence: Islam Boussaada, *Control of bioprocesses*, 27h, 1st year, CentraleSupélec Université Paris-Saclay, France.
- Licence: Silviu Niculescu, *Mathematics*, 15h, 1st year, ENSMP Paris, France.
- Licence: Silviu Niculescu, *Introduction to optimization*, 30h, 1st year, ESIEE Paris, France.
- Licence: Giorgio Valmorbida, *Signal Processing*, 1st year, 43h CentraleSupélec Université Paris-Saclay.
- Master: Giorgio Valmorbida, *Optimization*, 2nd year, 43h CentraleSupélec Université Paris-Saclay.
- Master: Giorgio Valmorbida, *Hybrid Systems*, 3rd year, 18h CentraleSupélec Université Paris-Saclay.
- Master: Giorgio Valmorbida, *Control*, , 2nd years, 55.5h, CentraleSupélec Université Paris-Saclay.
- Master: Giorgio Valmorbida, *Projects and Internship supervision*, 2nd and 3rd years, 81h, CentraleSupélec Université Paris-Saclay.
- Master: Giorgio Valmorbida, *Nonlinear Systems*, 3h, CentraleSupélec Executive Education, Université Paris-Saclay.

- Master : Catherine Bonnet, *Stability properties and stabilization of interconnected dynamical systems involving delays*, 20h, IPSA, France.
- Master : Silviu Niculescu, *Signals and Systems*, 12h, ESIEE Paris, France.
- Master : Giorgio Valmorbida, *Control*, 40.5, Master MAE (M1), Université Paris-Saclay.
- Master : Giorgio Valmorbida, *Stability of Dynamical Systems*, Master ATSI (M2), Université Paris-Saclay.
- Master: Guilherme Mazanti, *Tutorials — Optimization*, 21h, 2nd year, CentraleSupélec, Université Paris-Saclay.
- Master: Guilherme Mazanti, *Introductory course to research and innovation: MID, a novel approach in control design*, 10h, 4th year, IPSA.
- Doctorat : Silviu Niculescu, *Controlling Delayed Dynamics: Advances in Theory, Methods and Applications*, 7h, CISM Udine, Italy.

9.2.2 Supervision

- PhD in progress: Souad Amrane, on real pole-placement for retarded functional differential equations, University Mouloud Mammeri. Since 09/2017. Supervisors: Fazia Bedouhene and Islam Boussaada.
- PhD in progress: Amina Benarab, Characterization of the exponential decay of linear delay systems solutions, University Paris Saclay. Since 10/2019. Supervisors: Catherine Bonnet, Islam Boussaada and Karim Trabelsi.
- PhD in progress: Jose Castillo, Design, Modeling and control of multi drones for aerial handling, University Paris Saclay, 10/2018, Islam Boussaada and Juan Escareno.
- PhD in progress: Naouel Debiane, Bond Graph modeling for robust control and diagnosis of macatronic systems, University of Lille. Since 03/2017. Supervisors: Belkacem Ould-Bouamama and Islam Boussaada.
- PhD in progress: Ali Diab, Commande par filtrage non linéaire des systèmes d'assistance direction, Université Paris-Saclay. Since 10/2019. Supervisors: Giorgio Valmorbida and William Pasillas-Lepine.
- PhD in progress: Ricardo Falcon Prado, Active vibration control of flexible structures under input saturation through delay-based controllers and anti- windup compensators, University Paris Saclay. Since 10/2019. Supervisors: Islam Boussaada and Sami Tliba.
- PhD: Javier Eduardo Pereyra Zamundio, New backstepping design for systems with delay: finite time stabilization, robust stabilization, CINVESTAV, Instituto Politecnico Nacional. Since 10/2019. Supervisors: Sabine Mondié and Frédéric Mazenc. This Phd student resigned for personal reasons in October 2020.
- PhD in progress : Amira Remadna, On pole-placement approach for retarded functional differential equations, University Badji Mokhtar-Annaba. Since 09/2019. Supervisors: Islam Boussaada and Azzedine Benchettah.
- PhD in progress: Saeed Sadeghi Arjmand, Mean field games with free final time, École Polytechnique. Since 10/2019. Supervisors: Anne-Sophie de Suzzoni and Guilherme Mazanti.

9.2.3 Juries

- Catherine Bonnet was member of the Grenoble and Nancy Junior Researcher Inria recruiting committees. She was also a member of a Lecturer recruiting committee of the Claude Bernard University, Lyon 1.
- Catherine Bonnet was a member of the PhD thesis of Deesh Dileep *Design tools for the robustde-centralised control oflarge-scale systems withtime-delays'*, 6 March 2020, KU Leuven and an external examiner of the PhD thesis of Asmahan Alajyan, *Delay systems with variable delays*, 4 December 2020, Leeds University.
- Frederic Mazenc was member of the committe of mid term supervision of the Phd of Mattia Giaccagli, who is supervised by Vincent Andrieu and Daniele Astolfi.

10 Scientific production

10.1 Major publications

[1] C. Bonnet and J. Partington. 'Stabilization of some fractional delay systems of neutral type'. In: *Automatica* 43 (2007), pp. 2047–2053.

[2] C. Bonnet, A. R. Fioravanti and J. R. Partington. 'Stability of Neutral Systems with Commensurate Delays and Poles Asymptotic to the Imaginary Axis'. In: *SIAM Journal on Control and Optimization* 49.2 (Mar. 2011), pp. 498–516. URL: https://hal.inria.fr/hal-00782325.

[3] I. Boussaada, I.-C. Morarescu and S.-I. Niculescu. 'Inverted pendulum stabilization: characterization of codimension-three triple zero bifurcation via multiple delayed proportional gains'. In: *Systems Control Lett.* 82 (2015), pp. 1–9.

[4] M. Malisoff and F. Mazenc. *Constructions of Strict Lyapunov Functions*. Communications and Control Engineering Series. Springer-Verlag London Ltd., 2009.

[5] F. Mazenc, M. Malisoff and S.-I. Niculescu. 'Reduction Model Approach for Linear Time-Varying Systems with Delays'. In: *IEEE Transactions on Automatic Control* 59.8 (2014), pp. 2068–2014.

[6] W. Michiels and S.-I. Niculescu. *Stability, Control, and Computation for Time-Delay Systems*. Ed. by S.-I. Niculescu and W. Michiels. Philadelphia, PA: Society for Industrial and Applied Mathematics, 2014.

[7] S.-I. Niculescu. *Delay Effects on Stability: a Robust Control Approach*. Vol. 269. Lecture Notes in Control and Information Sciences. Springer, 2001.

[8] M. B. Saldivar, I. Boussaada, H. Mounier and S.-I. Niculescu. *Analysis and Control of Oilwell Drilling Vibrations*. Springer International Publishing, May 2015. URL: https://hal.archives-ouvertes.fr/hal-01123773.

[9] G. Valmorbida, M. Ahmadi and A. Papachristodoulou. 'Stability Analysis for a Class of Partial Differential Equations via Semidefinite Programming'. In: *IEEE Transactions on Automatic Control* 61.6 (June 2016), pp. 1649–1654.

[10] G. Valmorbida, S. Tarbouriech and G. Garcia. 'Design of Polynomial Control Laws for Polynomial Systems Subject to Actuator Saturation'. In: *IEEE Transactions on Automatic Control* 58.7 (July 2013), pp. 1758–1770.

10.2 Publications of the year

International journals

[11] F. Bedouhene, I. Boussaada and S.-I. Niculescu. 'Real spectral values coexistence and their effect on the stability of time-delay systems: Vandermonde matrices and exponential decay'. In: *Comptes Rendus Mathématique* 358.9-10 (4th Sept. 2020), pp. 1011–1032. DOI: 10.5802/crmath.112. URL: https://hal.archives-ouvertes.fr/hal-02476403.

[12] C. Bonnet and J. R. Partington. 'L_2 and BIBO stability of systems with variable delays'. In: *Systems and Control Letters* (1st May 2020). URL: https://hal.inria.fr/hal-03136388.

[13] L. Burlion, M. Malisoff and F. Mazenc. 'Stabilization for a Chain of Saturating Integrators Arising in the Visual Landing of Aircraft with Sampling'. In: *Systems and Control Letters* 135 (Jan. 2020), p. 104574. DOI: 10.1016/j.sysconle.2019.104574. URL: https://hal.inria.fr/hal-03113487.

[14] Y. Chitour, G. Mazanti and M. Sigalotti. 'On the gap between deterministic and probabilistic joint spectral radii for discrete-time linear systems'. In: *Linear Algebra and its Applications* 613 (15th Mar. 2021), pp. 24–45. DOI: 10.1016/j.laa.2020.12.013. URL: https://hal.archives-ouvertes.fr/hal-01961003.

[15] J.-E. Hernández-Díez, C. F. Méndez Barrios, S.-I. Niculescu and E. Bárcenas-Bárcenas. 'A Current Sensorless Delay–Based Control Scheme for MPPT–Boost Converters in Photovoltaic Systems'. In: *IEEE Access* 8 (23rd Sept. 2020), pp. 174449–174462. DOI: 10.1109/access.2020.3024566. URL: https://hal.archives-ouvertes.fr/hal-02950794.

[16] D. Ioan, S. Olaru, I. Prodan, F. Stoican and S.-I. Niculescu. 'From Obstacle-Based Space Partitioning to Corridors and Path Planning. A Convex Lifting Approach'. In: *IEEE Control Systems Letters* 4.1 (2020), pp. 79–84. DOI: 10.1109/LCSYS.2019.2922414. URL: https://hal-centralesupelec.archives-ouvertes.fr/hal-02328848.

[17] M. Kuře, J. Bušek, T. Vyhlídal and S.-I. Niculescu. 'Algorithms for cable-suspended payload sway damping by vertical motion of the pivot base'. In: *Mechanical Systems and Signal Processing* 149 (Feb. 2021), p. 107131. DOI: 10.1016/j.ymssp.2020.107131. URL: https://hal-centralesupelec.archives-ouvertes.fr/hal-03108536.

[18] X.-G. Li, S.-I. Niculescu, J.-X. Chen and T. Chai. 'Characterizing PID Controllers for Linear Time-Delay Systems: A Parameter-Space Approach'. In: *IEEE Transactions on Automatic Control* (13th Oct. 2020). DOI: 10.1109/TAC.2020.3030860. URL: https://hal.archives-ouvertes.fr/hal-03075462.

[19] G. Mazanti, I. Boussaada and S.-I. Niculescu. 'Multiplicity-induced-dominancy for delay-differential equations of retarded type'. In: *Journal of Differential Equations* 286.15 (18th Mar. 2021), pp. 84–118. DOI: 10.1016/j.jde.2021.03.003. URL: https://hal.archives-ouvertes.fr/hal-02479909.

[20] F. Mazenc, M. Malisoff and I. Bhogaraju. 'Sequential Predictors for Delay Compensation for Discrete Time Systems with Time-Varying Delays'. In: *Automatica* 122 (Dec. 2020). DOI: 10.1016/j.automatica.2020.109188. URL: https://hal.inria.fr/hal-03113504.

[21] F. Mazenc, M. Malisoff and Z.-P. Jiang. 'Reduced-Order Fast Converging Observers for Systems with Discrete Measurements and Measurement Error'. In: *Systems and Control Letters* (2021). URL: https://hal.inria.fr/hal-03144750.

[22] F. Mazenc, M. Malisoff and M. Krstic. 'Stability Analysis for Time-Varying Systems with Asynchronous Sampling using Contractivity Approach'. In: *IEEE Control Systems Letters* 5.1 (Jan. 2021), pp. 49–54. DOI: 10.1109/lcsys.2020.2999409. URL: https://hal.inria.fr/hal-02749259.

[23] F. Mazenc, M. Malisoff and M. Krstic. 'Stability and Observer Designs Using New Variants of Halanay's Inequality *'. In: *Automatica* 123 (Jan. 2021). DOI: 10.1016/j.automatica.2020.109299. URL: https://hal.inria.fr/hal-02926765.

[24] F. F. Mazenc, S. Ahmed and M. Malisoff. 'Reduced Order Finite Time Observers and Output Feedback for Time-Varying Nonlinear Systems'. In: *Automatica* 119 (Sept. 2020), p. 109083. DOI: 10.1016/j.automatica.2020.109083. URL: https://hal.inria.fr/hal-02612353.

[25] C. A. Molnar, T. Balogh, I. Boussaada and T. Insperger. 'Calculation of the critical delay for the double inverted pendulum'. In: *Journal of Vibration and Control* 27.3-4 (2020), pp. 356–364. DOI: 10.1177/1077546320926909. URL: https://hal.archives-ouvertes.fr/hal-02889890.

[26] X. Yang, B. Zhou and F. Mazenc. 'Global Stabilization of Discrete-Time Integrators System By Bounded Controls'. In: *IEEE Transactions on Circuits and Systems - Part I* (Dec. 2020). URL: https://hal.inria.fr/hal-03114223.

[27] X. Yang, B. Zhou, F. Mazenc and J. Lam. 'Global Stabilization of Discrete-Time Linear Systems Subject to Input Saturation and Time Delay'. In: *IEEE Transactions on Automatic Control* (2021). DOI: 10.1109/tac.2020.2989791. URL: https://hal.inria.fr/hal-02565245.

International peer-reviewed conferences

[28] A. L. J. Bertolin, R. C. L. F. Oliveira, G. Valmorbida and P. L. D. Peres. 'Estabilização quadrática por realimentação de saída de sistemas Lur'e a tempo contínuo via LMIs'. In: Congresso Brasileiro de Automática - 2020. Porto Alegre, Brazil, 23rd Nov. 2020. DOI: 10.48011/asba.v2i1.1437. URL: https://hal.inria.fr/hal-03151866.

[29] A. L. J. Bertolin, P. L. D. Peres, R. C. L. F. Oliveira and G. Valmorbida. 'An LMI-based iterative algorithm for state and output feedback stabilization of discrete-time Lur'e systems'. In: CDC 2020 - 59th IEEE Conference on Decision and Control. Jeju Island, South Korea, 14th Dec. 2020, pp. 2561–2566. DOI: 10.1109/CDC42340.2020.9303964. URL: https://hal.inria.fr/hal-03151882.

[30] I. Boussaada, D. Ma, C. Bonnet, S.-I. Niculescu and J. Chen. 'Pole-placement by PID Control with guaranteed delay robustness'. In: 24th International Symposium on Mathematical Theory of Networks and Systems (MTNS 2021). IFAC-PapersOnLine. Cambridge, United Kingdom: https://mtns2020.eng.cam.ac.uk/, 23rd Aug. 2021. URL: https://hal.archives-ouvertes.fr/hal-03108561.

[31] I. Boussaada, G. Mazanti, S.-I. Niculescu, J. Huynh, F. Sim and M. Thomas. 'Partial Pole Placement via Delay Action: A Python Software for Delayed Feedback Stabilizing Design'. In: ICSTCC 2020 - 24th International Conference on System Theory, Control and Computing. 2020 24th International Conference on System Theory, Control and Computing (ICSTCC). Sinaia, Romania: http://ace.ucv.ro/icstcc2020/, 8th Oct. 2020, pp. 196–201. DOI: 10.1109/ICSTCC50638.2020.9259688. URL: https://hal.archives-ouvertes.fr/hal-02897102.

[32] T. N. Dinh, F. Mazenc, Z. Wang and T. Raissi. 'On Fixed-Time Interval Estimation of Discrete-Time Nonlinear Time-Varying Systems With Disturbances'. In: ACC 2020 - American Control Conference. Denver, CO, United States, 1st July 2020. DOI: 10.23919/ACC45564.2020.9147754. URL: https://hal-cnam.archives-ouvertes.fr/hal-03113667.

[33] M. Giordani Titton, J. M. Gomes da Silva Jr. and G. Valmorbida. 'Stability of Sampled-Data Control for Lurie Systems with Slope-Restricted Nonlinearities'. In: Congresso Brasileiro de Automática - 2020. Porto Alegre, Brazil, 23rd Nov. 2020. DOI: 10.48011/asba.v2i1.1661. URL: https://hal.inria.fr/hal-03151869.

[34] A. Gonzalez-Martinez, C. F. Méndez Barrios and S.-I. Niculescu. 'Some remarks on the regular splitting of quasi-polynomials with two delays. Characterization of double roots in degenerate cases'. In: IFAC 2020 - 21st IFAC World Congress. IFAC-PapersOnLine. Berlin / Virtual, Germany: https://www.ifac2020.org/, 11th July 2020. URL: https://hal.archives-ouvertes.fr/hal-03108290.

[35] D. Ioan, I. Prodan, S. Olaru, F. Stoican and S.-I. Niculescu. 'Navigation in cluttered environments with feasibility guarantees'. In: IFAC 2020 - 21st IFAC World Congress. IFAC-PapersOnLine. Berlin / Virtual, Germany: https://www.ifac2020.org/, 11th July 2020. URL: https://hal.archives-ouvertes.fr/hal-03108514.

[36] G. Mazanti, I. Boussaada and S.-I. Niculescu. 'On pole placement and spectral abscissa characterization for time-delay systems'. In: 10th European Nonlinear Dynamics Conference. Proceedings of the 10th European Nonlinear Dynamics Conference. Lyon, France, July 2021. URL: https://hal.archives-ouvertes.fr/hal-03108585.

[37] G. Mazanti, I. Boussaada and S.-I. Niculescu. 'On qualitative properties of single-delay linear retarded differential equations: Characteristic roots of maximal multiplicity are necessarily dominant'. In: IFAC 2020 - 21st IFAC World Congress. IFAC-PapersOnLine. Berlin / Virtual, Germany: https://www.ifac2020.org/, 11th July 2020. URL: https://hal.archives-ouvertes.fr/hal-02422706.

[38] G. Mazanti, I. Boussaada, S.-I. Niculescu and Y. Chitour. 'Effects of Roots of Maximal Multiplicity on the Stability of Some Classes of Delay Differential-Algebraic Systems: The Lossless Propagation Case'. In: 24th International Symposium on Mathematical Theory of Networks and Systems (MTNS 2021). IFAC-PapersOnLine. Cambridge, United Kingdom: https://mtns2020.eng.cam.ac.uk/, 23rd Aug. 2021. URL: https://hal.archives-ouvertes.fr/hal-02463452.

[39] G. Mazanti, I. Boussaada, S.-I. Niculescu and T. Vyhlídal. 'Spectral dominance of complex roots for single-delay linear equations'. In: IFAC 2020 - 21st IFAC World Congress. IFAC-PapersOnLine. Berlin / Virtual, Germany: https://www.ifac2020.org/, 11th July 2020. URL: https://hal.archives-ouvertes.fr/hal-02422707.

[40] F. Mazenc and M. Malisoff. 'Sequential Predictors for Delay Compensation for Perturbed Discrete Time Systems'. In: ACC 2020 - American Control Conference. Denver, United States, 1st July 2020. URL: https://hal.inria.fr/hal-03113797.

[41] F. Mazenc, M. Malisoff and S.-I. Niculescu. 'Sampled-Data Estimator for Nonlinear Systems with Arbitrarily Fast Rate of Convergence'. In: ACC 2020 - American Control Conference. Denver, France, 1st July 2020, pp. 1685–1689. DOI: 10.23919/acc45564.2020.9147808. URL: https://hal-centralesupelec.archives-ouvertes.fr/hal-03103831.

[42] J. E. Pereyra Zamudio, S. M. Cuzange and F. Mazenc. 'Constructive backstepping for a class of delay systems based on functionals of complete type'. In: IFAC 2020 - 21st IFAC World Congress. Berlin / Virtual, Germany, 12th July 2020. URL: https://hal.inria.fr/hal-02566162.

[43] S. Tliba, I. Boussaada and S.-I. Niculescu. 'An MID-based control of a vibrating axisymmetric membrane using piezoelectric transducers'. In: 10th European Nonlinear Dynamics Conference. Proceedings of the 10th European Nonlinear Dynamics Conference. Lyon, France, July 2021. URL: https://hal.archives-ouvertes.fr/hal-03108596.

[44] S. Tliba, I. Boussaada, S.-I. Niculescu and R. P. Falcon. 'Delayed control design of a vibrating thin membrane via a partial pole placement'. In: ICSTCC 2020 - 24th International Conference on System Theory, Control and Computing. 2020 24th International Conference on System Theory, Control and Computing (ICSTCC). Sinaia, Romania: http://ace.ucv.ro/icstcc2020/, 8th Oct. 2020, pp. 196–201. URL: https://hal.archives-ouvertes.fr/hal-03108482.

[45] G. Valmorbida and F. Ferrante. 'On Quantization in Discrete-Time Control Systems: Stability Analysis of Ternary Controllers'. In: CDC 2020 - 59th IEEE Conference on Decision and Control. Jeju Island (virtual), South Korea: https://cdc2020.ieeecss.org/, 14th Dec. 2020. URL: https://hal.archives-ouvertes.fr/hal-03092417.

[46] Y. Yamamoto and C. Bonnet. 'Bézout Identity in Pseudoratoinal Transfer Functions'. In: MTNS 2020 - 24th International Symposium on Mathematical Theory of Networks and Systems. Cambridge, France, 23rd Aug. 2021. URL: https://hal.inria.fr/hal-03158705.

Conferences without proceedings

[47] S. Amrane, I. Boussaada, F. Bedouhene and S.-I. Niculescu. 'Some insights on rightmost spectral values assignment for time delay systems'. In: IFAC 2020 - 21st IFAC World Congress. Berlin / Virtual, Germany, 11th July 2020. URL: https://hal.archives-ouvertes.fr/hal-02889940.

[48] A. E. Ati, I. Boussaada, S.-I. Niculescu and P.-H. Poret. 'Analysis of the Delayed Central Nervous System Action in the Regulation of a Third-order Muscle-Tendon Model'. In: ICSTCC 2020 - 24th International Conference on System Theory, Control and Computing. Sinaia, Romania, 8th Oct. 2020. URL: https://hal.archives-ouvertes.fr/hal-02944531.

[49] J. Auriol, I. Boussaada, H. Mounier and S.-I. Niculescu. 'Torsional-vibrations Damping in Drilling Systems: Multiplicity-Induced-Dominancybased design'. In: 24th International Symposium on Mathematical Theory of Networks and Systems. Cambridge, United Kingdom, 23rd Aug. 2021. URL: https://hal.archives-ouvertes.fr/hal-02893005.

[50] T. Balogh, T. Insperger, I. Boussaada and S.-I. Niculescu. 'Towards an MID-based Delayed Design for Arbitrary-order Dynamical Systems with a Mechanical Application'. In: IFAC 2020 - 21st IFAC World Congress. Berlin / Virtual, Germany, 11th July 2020. URL: https://hal.archives-ouvertes.fr/hal-02889938.

[51] A. Benarab, I. Boussaada, K. Trabelsi, G. Mazanti and C. Bonnet. 'The MID property for a second-order neutral time-delay differential equation'. In: ICSTCC 2020 - 24th International Conference on System Theory, Control and Computing. Sinaia, Romania, 8th Oct. 2020, pp. 202–207. DOI: 10.1109/ICSTCC50638.2020.9259685. URL: https://hal.archives-ouvertes.fr/hal-02934532.

[52] C. Chenavier, R. Ushirobira and G. Valmorbida. 'A geometric stabilization of planar switched systems'. In: IFAC 2020 - 21st IFAC World Congress. Berlin, Germany, July 2020. URL: https://hal.archives-ouvertes.fr/hal-02366928.

[53] G.-X. Fan, Y.-J. Chen, X.-G. Li and S.-I. Niculescu. 'PID-Design-Delay: A MATLAB Toolbox for Stability Parameter-Space Characterization'. In: 2020 24th International Conference on System Theory, Control and Computing (ICSTCC). Sinaia, Romania, 8th Oct. 2020, pp. 13–18. DOI: 10.1109/ICSTCC50638.2020.9259689. URL: https://hal-centralesupelec.archives-ouvertes.fr/hal-03064595.

[54] J.-E. Hernández-Díez, C.-F. Méndez-Barrios and S.-I. Niculescu. 'Some Insights on the Asymptotic Stabilization of a Class of SISO Marginally Stable Systems Using One Delay Block'. In: IFAC World Congress. Berlin, Germany, July 2020. URL: https://hal.archives-ouvertes.fr/hal-02905296.

[55] D. Ma, I. Boussaada, C. Bonnet, S.-I. Niculescu and J. Chen. 'Multiplicity-Induced-Dominancy extended to neutral delay equations: Towards a systematic PID tuning based on Rightmost root assignment'. In: ACC 2020 - American Control Conference. Denver, United States, 1st July 2020. URL: https://hal.archives-ouvertes.fr/hal-02479679.

[56] H. Mounier and S.-I. Niculescu. 'Controllabilies of linear delay systems and of its samples version'. In: IFAC 2020 - 21st IFAC World Congress. Berlin / Virtual, Germany, 11th July 2020. URL: https://hal.archives-ouvertes.fr/hal-03108296.

[57] C. Stoica Maniu, C. Vlad, T. Chevet, S. Bertrand, A. Venturino, G. Rousseau and S. Olaru. 'Control Systems Engineering made Easy: Motivating Students through Experimentation on UAVs'. In: IFAC 2020 - 21st IFAC World Congress. Berlin / Virtual, Germany, 12th July 2020. URL: https://hal.archives-ouvertes.fr/hal-02632536.

[58] H. U. Unal, M. R. Roussel, I. Boussaada and S.-I. Niculescu. 'Insights from a qualitative analysis of a gene expression model with delays'. In: 24th International Symposium on Mathematical Theory of Networks and Systems. Cambridge, United Kingdom, 23rd Aug. 2021. URL: https://hal.archives-ouvertes.fr/hal-03108576.

Scientific books

[59] J. Chen, S.-I. Niculescu, C. F. Méndez Barrios and X. Chen. *Analytic eigenvalue perturbation theory for dynamical systems analysis*. Advances in design and control. 2021. URL: https://hal.archives-ouvertes.fr/hal-03108609.

Scientific book chapters

[60] S. Tliba, I. Boussaada and S.-I. Niculescu. 'Low complexity controller for active vibration damping of thin mechanical structures'. In: *Vibration Control and Actuation of Large-Scale Systems*. Emerging Methodologies and Applications in Modelling, Identification and Control. 2020. DOI: 10.1016/B978-0-12-821194-6.00004-4. URL: https://hal-centralesupelec.archives-ouvertes.fr/hal-02936311.

Edition (books, proceedings, special issue of a journal)

[61] J. d. J. Castillo-Zamora, J. P. Aguilera-Alvarez, J.-A. Escareno, I. Boussaada, J. J. Martinez-Nolasco and A. A. Jimenez-Garibay, eds. *A pedagogical approach to data fusion and kalman filter*. Congreso Internacional en Sistemas Mecatronicos. Vol. 42. Número Especial - Difusión del Conocimiento 2020 137. Celaya, Mexico, 23rd Nov. 2020. URL: https://hal.archives-ouvertes.fr/hal-02978429.

Reports & preprints

[62] Y. Chitour, S. Marx and G. Mazanti. *One-dimensional wave equation with set-valued boundary damping: well-posedness, asymptotic stability, and decay rates*. 6th Nov. 2020. URL: https://hal.archives-ouvertes.fr/hal-02463413.

[63] R. Ducasse, G. Mazanti and F. Santambrogio. *Second order local minimal-time Mean Field Games*. 29th Jan. 2021. URL: https://hal.archives-ouvertes.fr/hal-02616965.

10.3 Cited publications

[64] H. Kitano. 'Biological robustness'. In: *Nature* 5 (2004), pp. 826–837.

[65] X.-G. Li, S.-I. Niculescu and A. Cela. 'An iterative frequency-sweeping approach for stability analysis of linear systems with multiple delays'. In: *IMA Journal of Mathematical Control and Information* 36.02 (June 2019), pp. 379–398. DOI: 10.1093/imamci/dnx050. URL: https://hal.archives-ouvertes.fr/hal-02281960.

[66] X. Li, J.-C. Liu, X.-G. Li, S.-I. Niculescu and A. Cela. 'Reversals in stability of linear time-delay systems A finer characterization'. In: *Automatica* 108 (2019), p. 108479. DOI: 10.1016/j.automatica.2019.06.031. URL: https://hal-centralesupelec.archives-ouvertes.fr/hal-02328850.

[67] A. Martínez-González, C.-F. Méndez-Barrios, S.-I. Niculescu, J. Chen and L. Félix. 'Weierstrass approach to asymptotic behavior characterization of critical imaginary roots for retarded differential equations'. In: *SIAM Journal on Control and Optimization* 57.1 (Jan. 2019), pp. 1–22. URL: https://hal.archives-ouvertes.fr/hal-01973973.

[68] H. Ozbay, C. Bonnet and A. Fioravanti. 'PID Controller Design for Fractional-Order Systems with Time Delays'. Anglais. In: *Systems and Control Letters* 61.1 (Jan. 2012), pp. 18–23. URL: http://hal.inria.fr/hal-00766062.

[69] L. Zhang, Z.-Z. Mao, X.-G. Li, S.-I. Niculescu and A. Cela. 'Stability analysis for a class of distributed delay systems with constant coefficients by using a frequency-sweeping approach'. In: *IET Control Theory and Applications* 13.1 (2019), pp. 87–95. DOI: 10.1049/iet-cta.2018.5520. URL: https://hal-centralesupelec.archives-ouvertes.fr/hal-02328849.