1st "DelSys" Workshop

on

Observers and Controllers for Complex Dynamical Systems

Emphasizing

Low-order Controllers

20-22 November 2012

Supélec / L2S, Paris, France.

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1st Delsys Workshop

on

Observers and Controllersfor Complex Dynamical Systems

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Scope

The 1stDelsys Workshop on **Observers and Controllersfor Complex Dynamical Systems** emphasizing ***Low-order Controllers*** will focus on the most innovative mathematical methods proposed in the last few years for the analysis and design of complex dynamical systems.

The aim of the workshop is to bring together researchers from several universities over the world to discuss emerging topics related to complex dynamical systems. This workshop is organized within the ***International Scientific Research Network*** coordinated by ***CNRS***, ***"DelSys"*** which aims at gathering researchers from France, Belgium, Italy, England, Sweden, Germany, Spain, Mexico, Romania, Czech Republic, Turkey, USA.

Context

Time-delay systems represent a wide class of dynamical systems which appears in many fields as, for example, in biology (modeling population dynamics), in mechanical or electrical engineering (modeling lossless propagation in hydraulics or in electrical circuits), in communication (modeling congestion mechanisms in communication networks), in transportation (car following models) to cite only a few. As mentioned in the generic examples cited above, delays appear as a natural way in the representation of transport or interconnected systems where either information or materials are exchanged between several entities. In this context, it naturally appears a real need of a *better understanding* of the *effects* caused by *delays* (constant or time-varying, distributed or not) on the dynamics of interconnected systems in order to improve the dynamical behavior using strategies adapted to the specific cases considered.

The *International scientific coordination network on Delay Systems* "DelSys" gathers several European research teams working in the field of time-delay systems. The main objectives of "DelSys" are twofold: first, to *better organize* the *European research* on such topics and second to *better emphasize* the *research trends* in the field. In this sense, we will organize regular joint meetings, invited sessions at international conferences and symposia as well as we will edit monographs and special issues (at various international journals) covering the topics presented and discussed at these various manifestations. A particular attention will be also paid to *educational issues* as, for example, by proposing appropriate Master and PhD introductory lectures to the delay area or spring/summer/autumn schools.

Thematic areas

For this first edition of the ***Delsys Workshop***, a particular focus on ***Low-Order Controller*** has been proposed. The more particular topics that will be considered on the workshop are:

- ***Observation and Identification of time-delay systems***
  (2 presentations)
- ***Low-order control for complex systems***
  (14 presentations)
- ***Networked control systems***
  (6 presentations)
- ***Partial differential equations and applications***
  (5 presentations)

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Program of the workshop

Tuesday, November 20th

09.00-09.30: Welcome

09.30-10.30: Observation and Estimation of Time Delay Systems

09.30-10.00: **Output Stabilization of Time-Varying Input Delay System using Interval Observer Technique**

Andrey Polyakov — Inria, France,
Denis Efimov — Inria, France ,
Wilfird Perruquetti — Inria/LAGIS, France,
Jean-Pierre Richard — Inria/LAGIS, France.

10.00-10.30: **An approach for estimating parameters in infinite-dimensional systems**

Torsten Knüppel — TU Dresden, Germany,
Frank Woittennek — TU Dresden, Germany.

10.30-11.00: Coffee Break

11.00-12.30: Low order controllers for time-delay systems Part I

11.00-11.30: **Controller structure for automatic visual tracking on mobile carriers**

Arnaud Quadrat — SAGEM DS, France,
Alban Quadrat — Inria, Paris, France.

11.30-12.00: **On Stable Stabilizing Controller for Infinite-dimensional Systems**

Hakki Ulas Unal — KU Leuven, Belgium,
Altug Iftar — Anadolu Univ., Eskisehir, Turkey.

12.00-12.30: **On the Design of First Order Controllers for Unstable Infinite Dimensional Plants**

Hitay Özbay — Bilkent University, Turkey,
A.Nazli Gündes — University of California, USA.

12.30-14.00: Lunch

14.00-17.30: Low order controllers for time-delay systems Part II

14.00-14.30: **Noncommutative geometric structures on stabilizable infinite-dimensional linear systems**

Alban Quadrat — Inria, Paris, France.

14.30-15.00: **Signal shapers in feedback loops, aspects of arising neutrality in vibration compensation**

Tomas Vyhlidal — Czech Technical University, Czech Republic,
Martin Hromcik — Czech Technical University, Czech Republic,
Vladimir Kucera — Czech Technical University, Czech Republic.

15.00-15.30: **Neutral systems with commensurate delays**

Catherine Bonnet — Inria, Paris, France,
Andre Fioravanti — UNICAMP, Bresil,
Le Ha Vy NGuyen — Inria, Paris, France,
David Avanessoff — Inria, Paris, France,

15.30-16.00: Coffee Break

16.00-16.30: **Eigenvalue based analysis and controller synthesis for systems described by differential algebraic equations**

Wim Michiels — KU Leuven, Belgium,
Suat Gumussoy — The Mathworks, Belgium.

16.30-17.00: **Controller design for a class of delayed and constrained systems**

Chariffa Mouassaoui — Irccyn Nantes, France,
Jean-Jacques Loiseau — Irccyn Nantes, France,
Rosa Abbou — Irccyn Nantes, France.

17.00-17.30: **Further Remarks on the Robustness of Smith Predictor-Based Congestion Control Algorithms for Computer Networks**

Luca De Cicco — Politecnico di Bari, Italy,
Savario Mascolo — Politecnico di Bari, Italy,
Silviu-Iulian Niculescu — CNRS/L2S, France.

Wednesday, November 21th

09.00-12.00: Low order controllers for time-delay systems Part III

09.00-09.30: Delay-independent stability via reset loop

Sophie Tarbouriech	CNRS/LAAS, France,
Luca Zaccarian	CNRS/LAAS, France,
FelixPerez Rubio	Universidad de Murcia, Spain,
Alfonso Banos	Universidad de Murcia, Spain.

09.30-10.00: Further analysis on the mechanism of instability for discrete-delay approximation of distributed-delay feedback control

Keqin Gu	Southern Illinois University, USA

10.00-10.30: Coffee Break

10.30-11.00: Low complexity control with convex and non-convex constraints. From MPC to interpolation based alternatives.

Sorin Olaru	Supélec, France

11.00-11.30: Low Order Controllers for Nonlinear Systems

George Bitsoris	University of Patras, Greece

11.30-12.00: Control-oriented input-delay model of the distributed temperature of a SI engine exhaust catalyst

Delphine Bresch-Pietri	IFPEn/Mines de Paris, France,
Thomas Leroy	IFPEn, France,
Nicolas Petit	Mines de Paris, France.

12.00-14.00: Lunch

14.00-18.00: Networked Control Systems using Lyapunov methods

14.00-14.30: Stabilization of Linear Input Delayed Dynamics Under Sampling

Frédéric Mazenc	Inria, France,
Dorothée Normand-Cyrot	CNRS/L2S, France.

14.30-15.00: Every discrete-time system with delay can be considered as an interconnected system

Rob Gielen	TUE, Eindhoven, Holland,
Mircea Lazar	TUE, Eindhoven, Holland,
Andrew R. Teel	UCSB, USA,
SasaV. Raković	University of Maryland, USA.

15.00-15.30: New inequalities for time-delay systems

Alexandre Seuret	CNRS/LAAS, France,
Frédéric Gouaisbaut	UPS/LAAS, France.

15.30-16.00: Coffee Break

16.00-16.30: Propagation, conservation laws and control Liapunov functions

Vladimir Rasvan	University of Craiova, Romania,
Dan Popescu	University of Craiova, Romania.

16.30-17.00 State-dependent sampling for online control

Christophe Fiter	LAGIS, France,
Laurentiu Hetel	CNRS/LAGIS, France,
Wilfrid Perruquetti	LAGIS/Inria, France,
Jean-Pierre Richard	LAGIS/Inria, France.

17.00-17.30: On stability and control design for time-delay systems based on the Lyapunov-Krasovskii approach

Pablo Millan	Univ. Sevilla, Spain,
Luis Orihuela	Univ. Sevilla, Spain
Carlos Vivas	Univ. Sevilla, Spain,
Francesco Rubio	Univ. Sevilla, Spain.

17.30-18.00: Prediction-free tracking control for systems with incommensurate lumped and distributed delays.

Nicole Gehring	Universität des Saarlandes, Germany,
Joachim Rudolph	Universität des Saarlandes, Germany.

Thursday, November 22th

09.00-12.00: Partial differential equations and applications;

09.00-09.30: Analysis, Modeling and Control of an Oilwell Drilling System

Sabine Mondie Cuzange — CINVESTAV, Mexico
Belem Saldivar Márquez — CINVESTAV, Mexico

09.30-10.00: Low Order Control Laws for a Rotary Drilling System

Islam Boussaada — L2S, France,
Hugues Mounier — UPS/L2S, France,
Silviu.-Iulian Niculescu — CNRS/L2S, France,
Arben Cela — ESIEE Paris, France.

10.00-10.30: Coffee Break

10.20-11.00: A time-delay approach for the modeling and control of plasma instabilities in thermonuclear fusion

Emmanuel Witrant — GIPSA-Lab, France,
EriK Olofsson — KTH, Sweden,
Silviu-Iulian Niculescu — CNRS/L2S, France,
Per Brunsell — KTH, Sweden.

11.00-11.30: Control Architectures for Haptic Interfaces Including Communication Delays: An Experimental Comparative Study

Bogdan Liacu — L2S, France,
Claude Andriot — CEA-LIST, France,
Didier Dumur — E3S, France,
Frédéric Colledani — CEA-LIST, France,
Silviu-Iulian Niculescu — CNRS/L2S, France,
Patrick Boucher — E3S, France.

11.30-12.00: Controller as an Explicit Function of Delay: 1st Order LTI Case

Leo Byun — Northeastern University, USA,
Rifat Sipahi — Northeastern University, USA.

12.00-12.30: The conservation of information and the congestion control modeling problem: 1st Order LTI Case

Corentin Briat — ETH Zürich, Switzerland

12.30-14.00: Lunch and closing session

Book of abstract

Observation and Estimation of Time Delay Systems

Title: **Output Stabilization of Time-Varying Input Delay System using Interval Observer Technique**

Authors: A. Polyakov, D. Efimov, W. Perruquetti and J.-P. Richard

Abstract: The output stabilization problem for a linear system with a time-varying input delay is considered. The interval observer technique is extended to delay control systems and applied for obtaining guaranteed interval estimates of the system state. The procedure of the interval observer design, which is based on resolving of the Silvester's equation, is presented. Interval predictor method is introduced in order to design a linear stabilizing feedback. The control design procedure is based on Linear Matrix Inequalities (LMI). The theoretical results are supported by numerical simulation.

Title: **An approach for estimating parameters in infinite-dimensional systems**

Authors: T. Knüppel and F. Woittennek

Abstract: The scope of the presentation is the identification of parameters in infinite-dimensional systems by means of lumped measurements. The presented approach is based on a representation of the system as system of partial differential equations and appropriate boundary conditions. Its main idea is to write the model equations as system of convolution equations over an appropriate ring of (ultra-) distributions (cf. [2]). These merely contain lumped system variables, namely boundary values of the distributed variables. By simple algebraic manipulations it is possible to obtain from the convolution equations a system of equations containing only known trajectories. The coefficients of these equations depend non-linearly on the unknown parameters. They can be computed by solving a non-linear minimization problem. Contrary to the approaches published in [3] and [1] the proposed method requires more elaborate numerical techniques. However, the involved algebraic manipulations are much simpler. This allows for a straight-forward extension to more complex systems, as for example non-linear ones or those with spatially dependent coefficients. Another advantage of the proposed method is its compatibility with inhomogeneous initial conditions.

References: [1] N. Gehring, T. Knüppel, J. Rudolph, and F. Woittennek. Algebraische Methoden zur Parameteridentifikation für das schwere Seil. at-Automatisierungstechnik, 2012.

[2] H. Mounier, J. Rudolph, and F. Woittennek. Boundary value problems and convolutional systems over rings of ultradistributions. In J. Levine and Ph. Müllhaupt, editors, Advances in the Theory of Control, Signals and Systems with Physical Modelling, volume 407 of Lecture Notes In Control and Information Sciences. Springer-Verlag, 2010.

[3] J. Rudolph and F. Woittennek. Ein algebraischer Zugang zur Parameteridentifikation in linearen unendlichdimensionalen Systemen. at-Automatisierungstechnik, 55(9):457-467, 2007.

Low order controllers for time-delay systems Part I

Title: **Controller structure for automatic visual tracking on mobile carriers**

Authors: A. Quadrat and A. Quadrat.

Abstract: The purpose of this talk is to study image-based pointing and tracking for inertially stabilized camera platform in which a time-delay occurs and cannot be neglected in practice. Within the fractional representation approach to infinite-dimensional linear systems, we first study the parametrization of all stabilizing controllers of a simplified model defined by a differential time-delay equation. In particular, we show that any stabilizing controller has the form of a feedback between a stabilizing controller of the system without delay and a distributed delay. This result seems to be periodically and independently found again by many authors, for instance, by Meinsma and Zwart, Mirkin and Zhong, and more recently by the authors of this talk. Using the lattice

approach to synthesis problems, we shall show how this result can be generalized to a larger class of MIMO systems (e.g., fractional derivative systems) and explain that its proof does not need techniques based on doubly coprime factorizations as is classically done in the literature. Moreover, we shall review the general structure of all the stabilizing controllers of an internally stabilizable MIMO plant which does not necessarily admit doubly coprime factorizations. Finally, we shall show that only a single stabilizing controller (e.g., PID, finite-dimensional controller) is required for this general parametrization and not a doubly coprime factorization of the plant (the computation of which is generally involved).

Title: **On Stable Stabilizing Controller for Infinite-dimensional Systems**

Authors: H.U. Unal and A. Iftar

Abstract: In order to design low order stabilizing controller for general infinite dimensional systems, one of the approaches is to design a stable stabilizing controller, if it is possible. Once such a controller is designed, then, by using appropriate model order reduction techniques, low order stable stabilizing controller can be obtained. However, it is not an easy task to show the existence of a stable stabilizing controller for infinite dimensional systems, due to the possibly infinitely many right-half plane poles and blocking zeros. In this work, the problem of designing a stable stabilizing controller is considered for infinite-dimensional real linear systems. The considered systems may have infinitely many poles and blocking zeros in the right-half-plane. It is shown that the well-known parity interlacing property for real-rational systems is also a necessary condition in the present case. In addition, it is also sufficient under certain assumptions. The sufficiency is shown by constructing a unit function interpolating with the plant's characteristic function at the extended right-half-plane blocking zeros of the plant. In order to construct such a function, it is assumed that the right-half-plane blocking zeros of the plant are uniformly separated. Furthermore, it is also assumed that the plant has a finite relative degree and, in the case this degree is non-zero, the plant's characteristic function can be written as a (possibly infinite) product of real-rational functions.

Title: **On the Design of First Order Controllers for Unstable Infinite Dimensional Plants**

Authors: H. Özbay and A.N. Gündes

Abstract: A design method for first order controller design is reviewed for a class of unstable infinite dimensional plants, including systems with time delays, fractional order systems, and systems represented by PDEs. The approach is based on the small gain theorem and requires minimization of an H1 norm over a low number of parameters. Gain margin optimization for PD controllers and integral action gain margin optimization for PI controllers is discussed. For certain classes of plants it is shown that two-dimensional brute force search required for the solution of the above problems can be reduced to two one-dimensional plots. This presentation is based on [1], [2], [3], [4].

References:
[1] H. Özbay, A. N. Gündes, "Resilient PI and PD Controller Designs for a Class of UnstablePlants with I/O Delays," Appl. Comp. Math., 2007, pp. 1826.

[2] D. Üstebay, H. Özbay, A. N. Gündes, "A new PI and PID control design method for integrating systems with time delays: applications to AQM of TCP flows," WSEAS Trans. Systems and Control, 2007, pp. 117124.

[3] A. N. Günde¸s, H. Özbay, A. B. Özgüler, "PID controller synthesis for a class of unstable MIMO plants with I/O delays," Automatica, 2007, pp. 135142.

[4] H. Özbay, C. Bonnet, A. R. Fioravanti, "PID controller design for fractional-order systemswith time delays, Systems & Control Letters, 2012, pp. 1823.

Low order controllers for time-delay systems Part II

Title: **Noncommutative geometric structures on stabilizable infinite-dimensional linear systems**

Authors: A. Quadrat

Abstract: The purpose of the talk is to show how ideas, techniques, and results of noncommutative geometry developed by Alain Connes at the end of the eighties can be used to study infinite-dimensional linear systems (e.g., differential time-delay systems, partial differential systems) defined by transfer matrices. In particular, within a noncommutative geometry approach, we shall show that an internally stabilizable plant in the sense of Desoer and Vidyasagar admits noncommutative geometric structures such as Grassmann/Levi-Civita connections and curvatures. Thus, we shall first introduce the 1-dimensional quantized calculus developed by Alain Connes and show that it is a very natural differential calculus for infinite-dimensional linear systems defined by transfer matrices. Then, we shall show that systems of coordinates naturally exist on an internally stabilizable plant which makes the use of noncommutative geometric extension of classical differential geometric ideas, concepts, and results possible. The introduction of these concepts in mathematical system theory is the first step toward exploiting the natural geometries of a plant in the study of stabilization problems (e.g., Nyquist theorem, internal/strong/simultaneous/robust/optimal stabilization, metrics for robustness such as nu-gap metric, H_infinity-problem, model reduction).

Title: **Signal shapers in feedback loops, aspects of arising neutrality in vibration compensation**

Authors: T. Vyhlidal, M. Hromcik and V. Kucera

Abstract: Input shapers with time delays have proved useful in many applications related to controls for various flexible devices, for example flexible manipulators and cranes. In the presentation, the dynamics analysis of closed loop systems with signal shapers is performed. It is shown that involvement of the shapers with lumped delays in the closed loop can cause neutrality of its dynamics. Particularly, it can happen if the newly introduced inverse shapers with lumped delays are used. Even though the shaper can well damp the oscillations on the target frequency induced either by the reference or disturbance changes, the dynamics and even stability can be endangered by high frequency neutral poles. In order to overcome this stability risk, the recently established concept of signal shapers with equally distributed delays is applied leading to solely retarded dynamics of the closed loop. The portal crane simulation example demonstrates the derived results. It is shown that the best performance in compensation of payload oscillations is achieved if the inverse shaper with distributed delay is used. On the other hand, it is demonstrated that implementation of inverse shapers with lumped delay can truly lead to stability loss.

Title: **Neutral systems with commensurate delays**

Authors: C. Bonnet, A. Fioravanti, V. NGuyen and D. Avanessoff

Abstract: In this talk, based on [1] and [2], we present an overview of Hinfty-stability properties of neutral systems with commensurate delays as well as their stabilizability properties by finite dimensional controllers. An asymptotic analysis of high modulus poles is done and the Matlab Toolbox Yalta is used to locate the poles of small modulus. Several examples are given.

References:
[1] C. Bonnet, A.R. Fioravanti and J.R. Partington, Stability of neutral systems with multiple delays and poles asymptotic to the imaginary axis, SIAM.J. Control and Optimization , Vol 49, n.2 (2011) pp 498-516.

[2] L.H.V Nguyen, A. Fioravanti and C. Bonnet, Analysis of neutral systems with commensurate delays and many chains of poles asymptotic to the same points on the imaginary axis, IFAC TDS 2012, Boston, 22-24, 2012.

Title: **Eigenvalue based analysis and controller synthesis for systems described by differential algebraic equations**

Authors: W. Michiels and S. Gumussoy

Abstract: An eigenvalue based framework is developed for the stability analysis and control of coupled systems with time-delays, which are naturally described by delay differential algebraic equations. The spectral properties of these equations are analyzed and numerical methods for stability assessment as well as computing H-infinity norms are presented, which explicitly take into into account the effect of small delay perturbations. Subsequently, the design of stabilizing and optimal H-infinity controllers with a prescribed structure or order is addressed, based on a direct optimization approach. The effectiveness of the approach is illustrated with numerical examples. The algorithms have been implemented in publicly available software.

Title: **Controller design for a class of delayed and constrained systems**

Authors: C. Mouassaoui, J.-J. Loiseau and R. Abbou

Abstract: In this work, we propose a controller designing approach for a class of delayed systems with saturations, subjected to bounded perturbations. It is based on the Bounds Calculus for Input-Output systems and Intervals and Sets properties. This approach gives necessary and sufficient conditions on the controller parameters, for which the system requirements will be completely met. The approach is applied to an inventory regulation problem in production systems. Such systems are characterized by the presence of delays due to production processes, and constraints due to the finite capacities of production and stocks. They are subjected to unknown but bounded demand that affects the inventory level. A saturated predictor feedback structure is proposed to control the inventory level. This structure takes into account the work in process amounts that is an important point in product planning and management methods. The obtained conditions are also used to propose a sizing method for an optimal dimensioning of the plant

Title: **Further Remarks on the Robustness of Smith Predictor-Based Congestion Control Algorithms for Computer Networks**

Authors: Luca De Cicco, S. Mascolo and S.-I. Niculescu

Abstract: A cornerstone component of Internet is the end-to-end congestion control algorithm that has been implemented in the Transmission Control Protocol by Van Jacobson. The problem of congestion control is particularly challenging due to the fact that the sender and receiver are connected through a series of communication links characterized by a time-varying end-to-end delay and an unpredictable and time-varying available bandwidth. It has been shown that the plant dynamics can be modeled by means of a time-delay system composed of (i) an integrator, modeling a queue, (ii) a time delay which is due to the propagation of the information from a source to a destination, and (iii) a load disturbance which models the time-varying link available bandwidth. Put in those terms, the goal of the congestion controller is to drive the queue length to a desired set-point while avoiding packet drops and maintaining full-link utilization, i.e. the sending rate must match the network available bandwidth. In (Mascolo 1999) it has been shown that a Smith-predictor plus a proportional gain is an effective controller, even though, as it is well-known in the literature, it is not able to reject a load disturbance, i.e. the available bandwidth. To overcome this issue, several modifications of the Smith-predictor scheme were studied in the past. Among those, the one proposed by Matausek and Micic is particularly interesting due to its simple tuning having a clear physical interpretation. For this reason, we consider the Matausek-Micic modified Smith predictor as candidate for the design of a congestion control scheme which is able to reject the load disturbance. In this paper, we compare the robustness features of the Smith predictor proposed in (Mascolo 1999) and the one presented in (Matausek-Micic, 1999) with respect to the delay uncertainty, which in data networks are due to queuing. We have found that the Matausek-Micic modified Smith predictor is very sensitive to delay mismatches when the nominal delay is small, whereas for the standard Smith-predictor it is possible to provide a delay-independent bound on the delay uncertainty. This poses a practical issue when implementing the Matausek-Micic controller for data networks with low propagation delays, such as in the case of optical networks or local area networks.

Low order controllers for time-delay systems Part III

Title: **Delay-independent stability via reset loop**
Authors: S. Tarbouriech, L. Zaccarian, F. Perez Rubio and A. Banos
Abstract: This talk is focused on the design of hybrid controllers based on Lyapunov condition applied to systems with delay in the state. Reset controllers are proposed to guarantee delay independent stability of the closed-loop system.

Tiltle: **Further analysis on the mechanism of instability for discrete-delay approximation of distributed-delay feedback control**
Author: K. Gu
Abstract: The instability caused by approximation distributed-delay feedback by discrete-delay feedback is now a well-known phenomenon. It is known that there are two important mechanisms that may cause such instability. The first is due to the fact that the exponential instability of the associated difference equation implies the instability of the complete system. The other is the spectrum of difference equation may be sensitive to arbitrarily small variation of delays. In this presentation, a number of generalizations are considered. Approximation of general distributed delay that may not be the result of finite spectrum assignment is considered. The possibility of introducing physical constraints to force proportional delays (complete or partial) is considered. Such constraints may significantly improve the stability limit as compared to the case of independent delay variations.

Title: **Low complexity control with convex and non-convex constraints. From MPC to interpolation based alternatives.**
Author: S. Olaru
Abstract: The talk revisit in a first part the latest advances in the explicit and implicit model-based predictive control (MPC) based on convex optimization problems. The piecewise affine structure of the control law will be explored and the alternative interpolation-based procedures will be presented as a reduced-complexity alternative to the classical receding horizon optimization. In the second part of the talk, the specific case of discrete-time dynamical systems operating in presence of nonconvex state-space constraints will be exposed. These constraints can be understood as obstacles for the closed-loop trajectories and it will be shown that a predictive control strategy can deal, by its generic formulation, with such problems and several refinements will be pointed out with respect to the dual-mode principles and the numerical formulations of the optimization problems.

Title: **Low Order Controllers for Nonlinear Systems**
Author: G. Bitsoris
Abstract: The positive invariance and the stabilization of nonlinear systems described by state equations is studied. Two types of lower order state-feedback controllers are considered: Controllers using part of the state variables of the system and decentralized-type state-feedback controllers. Necessary and sufficient conditions for a lower order controller to guarantee the positive invariance of a given subset of the state space are presented. The additional conditions for guaranteeing the asymptotic stability are also established. An academic example for illustrating the proposed approaches is given.

Title: **Control-oriented input-delay model of the distributed temperature of a SI engine exhaust catalyst**
Authors : D. Bresch-Pietri, T. Leroy and N. Petit
Abstract: In this talk, a model for the internal temperature of SI engine catalyst is proposed. The modelling approach is based on a one-dimensional distributed parameter model, where the pollutant conversion is assumed to take place only at the beginning of the monolith. This infinite-dimension representation is shown here to be accurately approximated by a time-varying input-delay system, whose dynamics parameters (time constant, delay) are obtained analytically through a simple operational calculus reduction method. Following recent works, the distributed heat generated by the pollutant conversion is assimilated to a virtual temperature entering the system at a fictitious length. The gain used to calculate this second temperature introduces a

coupling inside the model, to account for the conversion efficiency dependence in the temperature. Relevance of this input-delay model is qualitatively highlighted by experimental data.

Networked Control Systems using Lyapunov methods

Title: **Stabilization of Linear Input Delayed Dynamics under Sampling**

Authors: F. Mazenc and D. Normand-Cyrot

Abstract: In this presentation we show that every discrete-time system with delay can be considered as an interconnected system with a particular structure. As a consequence, it is possible to transfer stability analysis and set invariance results for interconnected systems to discrete-time systems with delay. Thus it is established that the Krasovskii approach is a direct application of the classical Lyapunov theory while the Razumikhin approach is an application of the small-gain theorem. A novel stability analysis technique is presented based on dissipativity theory for interconnected systems. Furthermore, the recent concept of invariant families of sets is transferred to discrete-time systems with delay as well.

Title: **Every discrete-time system with delay can be considered as an interconnected system**

Authors: R. Gielen, M. Lazar, A.R. Teel and S.V. Raković

Abstract: In this presentation we show that every discrete-time system with delay can be considered as an interconnected system with a particular structure. As a consequence, it is possible to transfer stability analysis and set invariance results for interconnected systems to discrete-time systems with delay. Thus it is established that the Krasovskii approach is a direct application of the classical Lyapunov theory while the Razumikhin approach is an application of the small-gain theorem. A novel stability analysis technique is presented based on dissipativity theory for interconnected systems. Furthermore, the recent concept of invariant families of sets is transferred to discrete-time systems with delay as well.

Title: **New inequalities for time-delay systems**

Authors: A. Seuret and F. Gouaisbaut

Abstract: In the last decade, the Jensen's inequality has been intensively used in the context of time-delay or sampled-data systems since it is an appropriate tool to obtain tractable stability conditions expressed in terms linear matrix inequalities (LMI). However, it is also well-known that this inequality unavoidably introduces an undesirable conservatism in the stability conditions and looking at the literature, reducing this gap is a relevant issue and an open problem. In this paper, we propose an alternative inequality based on the Fourier Theory, more precisely on the Wirtinger's inequalities. It is shown that this resulting inequality encompasses the Jensen's one and also leads to tractable LMI conditions. In order to illustrate the potential gain of employing this new inequality with respect to the Jensen's one, an application on various stability analysis of time-delay systems are provided.

Title: **Propagation, conservation laws and control Liapunov functions**

Authors: V. Rasvan and D. Popescu

Abstract: This presentation starts from two basic applications representing propagation systems in one space dimension - initial boundary value problems for hyperbolic partial differential equations with one space dimension. The first application arises from combined heat electricity generation with linear propagation equations with constant coefficients and bilinearly controlled boundary conditions. Since the linear propagation equations are basically nonlinear and linearized, a somehow careful analysis of the basic equations – describing the one dimensional isentropic flow - shows that the nonlinear model is within the class of boundary controlled conservation laws. The second application is a well known benchmark - the overhead crane with the rope having distributed mass. This leads to a propagation model with space varying parameters. The common feature of these models is that one can associate some "natural Liapunov function(al)s" that may be used in synthesizing the feedback control, thus playing the role of control Liapunov functions. The results on these applications show that the structure of the control Liapunov function has an important role in obtaining controllers with prescribed, possibly low order dynamics. However, the delay inclusion in the controller structure can hardly be avoided and this introduces the infinite dimension in the controller.

Title: **State-dependent sampling for online control**

Authors: C. Fiter, L. Hetel, W. Perruquetti and J.-P. Richard

Abstract: In this work, we present a state-dependent sampling control approach that enlarges the sampling intervals of state feedback control. We consider the case of linear time invariant systems and guarantee their exponential stability for a chosen decay rate. The approach is based on LMIs obtained thanks to Lyapunov-Razumikhin stability conditions and convex embeddings, and follows two steps. In the first step, we compute a Lyapunov-Razumikhin function that guarantees exponential stability for all time-varying sampling intervals up to some given bound. This value can be used as a lower-bound of the state-dependent sampling function designed in the following step. In the second step, a mapping of the state space is designed offline, and provides an estimation of the maximal allowable sampling interval for each region of the state space. The approach is illustrated with numerical examples from the literature for which the number of actuations is shown to be reduced with respect to the periodic sampling case.

Title: **On stability and control design for time-delay systems based on the Lyapunov-Krasovskii approach**

Authors: P. Millan, L. Orihuela, C. Vivas and F. Rubio

Abstract: This talk is concerned with the stability analysis criteria and control designs for continuous time systems affected by time-varying delays. First, an introduction to the stability analysis problem is presented, together with one particular criterion to find the degree of stability and the L2-gain of a class of systems affected by nonlinear uncertainties. After that, the presentation moves from analysis to control design. In particular, a new H2/Hinf control design technique, valid for a family of time delays systems (TDSs), is introduced. This method outperforms previous designs particularized for specific kinds of TDSs. After that, some applications of this controller in the context of networked control systems are shown. Lastly, the main points of the talk are summarized.

Title: **Prediction-free tracking control for systems with incommensurate lumped and distributed delays.**

Authors : N. Gehring and J. Rudolph

Abstract : Linear systems with lumped and distributed delays can be represented by modules over the ring of entire functions in C(s)[exp(-tau s]. While in the case of commensurate delays spectral controllability is sufficient for the existence of a basis of this module, in the incommensurate case addressed here additional conditions are required. Exploiting the relations between the (known) delay amplitudes a new module with favorable freeness properties can be defined. Based on that, necessary and sufficient conditions for the freeness of this module are presented. If these conditions are satisfied a basis can be used to derive a flatness-based tracking control without any explicit predictions. The approach is illustrated on examples.

Partial differential equations and applications

Title: **Analysis, Modeling and Control of an Oilwell Drilling System**

Authors: S. Mondie Cuzange and B. Saldivar Márquez

Abstract : The oscillations occurring during the drilling process constitute a major problem to solve in the oil extraction industry. Drilling vibrations most frequently occurring in the field are torsional (stick-slip) and axial (bit-bounce) which may cause equipment failures increasing drilling operation costs. Important challenges are the modeling of drillstring dynamics and the design of effective controllers to reduce undesirable behaviors. Due to its distributed nature, the system can be modeled by the wave equation subject to mixed boundary conditions, this modeling strategy is widely used to reproduce the oscillatory behavior of physical systems.

The resulting complexity in simulations makes useful the derivation a simpler model effectively reproducing the input-output behavior of the drilling system. The D'Alembert method provides transformation which leads to a neutral-type time-delay model which provides an input-output description of the system. The model is validated through simulations, by evaluating the most common practical strategies to reduce drilling vibrations.

Based on these two modeling strategies, stabilizing controllers are developed within Lyapunov theory: first, the drilling vibration is reduced via attractive ellipsoid method applied to the neutral type model. Second the stabilization of the boundary coupled wave PDE-ODE system is addressed. Simulation results show that these controllers are effective to suppress axial-torsional coupled oscillations.

Title: **Low Order Control Laws for a Rotary Drilling System**

Authors: I. Boussaada, H. Mounier, S.-I. Niculescu and Arben Cela

Abstract: The main purpose of this talk is the description of the qualitative dynamical response of a rotary drilling system with a drag bit, as well as the design of appropriate control laws. We consider a model that takes into consideration the axial and the torsional vibration modes of the bit. The studied model, based on the interface bit-rock, contains a couple of wave equations with boundary conditions consisting of the angular speed and the axial speed at the top additionally to the angular and axial acceleration at the bit whose contain a realistic frictional torque. Our analysis and control approach are based on the center manifold Theorem and Normal forms theory.

Title: **A time-delay approach for the modeling and control of plasma instabilities in thermonuclear fusion**

Authors: E.Witrant, E. Olofsson, S.-I. Niculescu and P. Brunsell

Abstract: This talk presents a summary of [1], where we investigated the stability problems and control issues that occur in a reversed-field pinch (RFP) device, EXTRAP-T2R, used for research in fusion plasma physics and general plasma (ionized gas) dynamics. The plant exhibits, among other things, magnetohydrodynamic instabilities known as resistive-wall modes (RWMs), growing on a time-scale set by a surrounding non-perfectly conducting shell. We propose a new modeling approach that takes into account experimental constraints, such as the actuators dynamics and control latencies leading to a multivariable time-delay model of the system. The open-loop field-error characteristics are estimated and a stability analysis of the resulting closed-loop delay differential equation (DDE) emphasizes the importance of the delay effects. We then design an optimal PID controller (its structure being constrained by the intelligent-shell (IS) control architecture) that achieves a direct eigenvalue optimization of the corresponding DDE. The presented results are substantially based on and compared with experimental data.

References: [1] E. Olofsson, E. Witrant, C. Briat, S.I. Niculescu and P. Brunsell, "Stability analysis and model-based control in EXTRAP-T2R with time-delay compensation", Proc. of 47th IEEE Conference on Decision and Control, Cancun (Mexico), December 9-11, 2008.

Title: **Control Architectures for Haptic Interfaces Including Communication Delays: An Experimental Comparative Study**

Authors: B.Liacu, C. Andriot, D. Dumur, F. Colledani, S.-I. Niculescu and P. Boucher

Abstract: The aim of this work is to present a comparative study of control algorithms for haptic interfaces and virtual environments subject to communication delays. It is well known that the presence of delays deteriorates the overall system performance. More precisely, delays introduce a feeling of viscosity in free motion and reduce the sense of stiffness in case of hard contacts. Six methods in their basic form (classic Proportional Derivative (PD), PD with local dissipation, PD with passivity observer, PD with passive set-point modulation, wave scattering transform and Smith predictor) are analyzed and compared, using a real-time experimental platform which enables tracking the impact of delays, from the point of view of position tracking error and transparency degree.

Title: **Controller as an Explicit Function of Delay: 1st Order LTI Case**

Authors: L. Byun and R. Sipahi

Abstract: On a 1st order LTI system with single constant delay, a low-order controller is designed as an explicit function of the delay term, in a way to regulate/stabilize the closed-loop system against the destabilizing effect of the delay. That is, the controller adapts to the delay value autonomously, to maintain stability. One intriguing result obtained is the ability to use larger controller gains scheduled with respect to delay, to maintain stability independent of delay, which would not be otherwise possible without having the delay parameter explicitly in the controller.

Title: **The conservation of information and the congestion control modeling problem**

Authors: Corentin Briat

Abstract: In communication networks, such as Internet, the congestion phenomenon is responsible for a reduction in network efficiency by inducing large communication delays and data loss. Modeling congestion to fully understand the phenomenon and deriving new congestion control protocols is then of great interest. Attacking the congestion problem from the systems and control theory viewpoint is not new. However, recent advances have made the models very accurate and flexible. In this talk, a complete model for congestion will be developed from a unique fundamental principle: the conservation of information. Models for transmission channels, queues and users are directly obtained from this principle. Models for transmission channels, queues and users are directly obtained from this principle. The corresponding network model hence consists of building blocks along with simple interconnection rules, as in electrical circuits (metamodel). The important properties of modularity and scalability are achieved for this model, emphasizing then the suitability of the paradigm. Comparison with NS-2 simulations and experimental results confirm the validity of the model on the considered topologies. As a byproduct, it is also shown that previous models from the literature may be viewed as approximations of the proposed model, or shown to be exact whenever conditions on the network topology are met. Finally, linearization of the building blocks offers an easy way for locally representing any network topology, locally understanding the behavior of blocks, and deriving local stability results in a very generic way.