1st DECOD Workshop

Delays and Constraints on Distributed Parameter Systems

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Incorporating Constraints on the Analysis of Distributed Parameter Systems

22nd-24th November 2017

CentraleSupélec, Paris, France.

1st DECOD Workshop

Delays and Constraints on Distributed Parameter Systems

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Scope

The 1st Workshop on **Delays and Constraints on Distributed Parameter Systems** emphasizing ***Incorporating Constraints on the Analysis of Distributed Parameter Systems*** focus on the recent developmes on the analysis and design of distributed parameter systems, network systems and delay systems.

The aim of the workshop is to bring together researchers from several universities over the world to discuss emerging topics related to Distributed Parameter Systems presenting Delays and Constraints. This workshop is organized within the ***International Scientific Research Network*** coordinated by ***CNRS***, ***"Spa-DisCo"*** which aims at establishing strong links between its members from France, Belgium, Italy, United Kingdom, Sweden, Czech Republic and Turkey.

Context

Distributed Parameter wide class of physical dynamical systems which appears in many fields as, for example, in biology, in mechanical or electrical engineering, in communication, in transportation to cite only a few. In practice the control of the above cited systems, naturally introduce delays, which appear as models of transport or interconnected systems where either information, matter or energy and introduce constraints such as input saturations and bandwidth limits on networked system. In this context, it naturally appears a real need of a *better understanding* of the *effects* caused by *these elements* on the dynamics of distributed parameter systems to improve the dynamical behavior using strategies adapted to the specific cases considered.

The *International Scientific Research Network* "SPaDisco" aims to promote the exchange on Distributed Parameter Systems with delays and constraints. It includes as goals, to *better structure* 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 covering the topics presented. 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 and to foster joint projects on the field.

Thematic areas

This first edition of the ***DECOD Workshop***, a particular focus on ***Incorporating Constraints on the Analysis of Distributed Parameter Systems*** will evolve around:

- ***Control Design for Distributed Parameter System***
- ***Delays and Constraints on Distributed Parameter Systems***
- ***Networked control systems***
- ***Numerical Methods for Analysis of Distributed Parameter Systems***

Participants

A total of 71 attendees participate on this edition, among which 15 PhD students and 2 number of Post-Doctoral researchers. The participating countries are Belgium, Brazil, Chile, Czech Republic, France, Hong Kong, Hungary, Italy, United Kingdom, United States of America, Mexico, Norway, Romania, Sweden and Turkey.

Sponsors

CNRS, L2S, LAAS, CentraleSupéléc, Univ. Paris-Sud, IPSA, Icode, Safran

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KU Leuven, Czech Technical University in Prague, Università degli Studi di Aquila, Università degli Studi di Udine, CINVESTAV, KTH, University of Oxford, Bilkent University, University of Craiova, Southern Illinois University.

Program

Wednesday, November 22nd

09.30-10.00: Registration and Welcome

10.00-12.00: Session 1

10.00-10.30: Stabilization of Delay Systems via PID Control: How Good Is it?

Dan Ma	City University of Hong Kong
Jie Chen	City University of Hong Kong

10.30-11.00: Integral Delay Equations

Sabine Mondié	CINVESTAV, Mexico
Saul del Valle	CINVESTAV, Mexico
Alexey Egorov	St. Petersburg State University

11.00-11.30: Agent Regrouping under Delays and Proximity Constraints

Rifat Sipahi	Northeastern University
Min Hyong Koh	Northeastern University

11.30-12.00: Global stabilization of a Korteweg-de Vries equation with saturating distributed control

Swann Marx	LAAS/CNRS
Eduardo Cerpa	Universidad Téc. Federico Santa Maria
Christophe Prieur	Gipsa-lab/CNRS
Vincent Andrieu	LAGEP/CNRS

12.00-13.30: Lunch

13.30-15.30: Session 2

13.30-14.00: Oscillatory dynamics of an intravenous glucose tolerance test model with delay interval

Yang Kuang	Arizona State University

14.00-14.30: Linearized systems of conservation laws - what can they give?

Daniela Danciu	University of Craiova
Vladimir Rasvan	University of Craiova

14.30-15.00: Stability analysis of mixed ODE-heat equation system

Lucie Baudouin	LAAS/CNRS
Alexandre Seuret	LAAS/CNRS
Frédéric Gouaisbaut	LAAS/CNRS

15.00-15.30: Stability of uncertain delay differential equations

Rossana Vermiglio	Università degli Studi di Udine
A Zamolo	Università degli Studi di Udine

15.30-16.00: Coffee Break

16.00-17.30: Session 3

16.00-16.30: Global and Semi-Global Stabilization by Sampled-Data Emulation of Global Stabilizers for Time-Delay Systems

Pierdomenico Pepe	University of L'Aquila
Mario Di Ferdinando	University of L'Aquila

16.30-17.00: Computing and optimizing system norms for delay equations

Wim Michiels	KU Leuven

17.00-18.00: Interactive Session

Stabilization of switched systems with time-varying delay using a trajectory based approach

Saeed Ahmed	Bilkent University
Frederic Mazenc	L2S, Inria
Hitay Ozbay	Bilkent University

Multi-dimensional delayed resonator - design objectives and first results

Matej Kure	Czech Technical University in Prague
Karel Kraus	Czech Technical University in Prague
Tomas Vyhlidal	Czech Technical University in Prague
Zbynek Sika	Czech Technical University in Prague

Computing distance to instability for large-scale delay systems with uncertainties in the system matrices and in the delay terms

Francesco Borgioli	KU Leuven
Wim Michiels	KU Leuven

Necessary and Sufficient conditions for the control of a logistic system subject to delays and constraints

Berna Bou Farraa	LS2N/Université de Bretagne Loire
Rosa Abbou	LS2N/Université de Bretagne Loire
Jean Jacques Loiseau	LS2N/Université de Bretagne Loire

Anti-windup Scheme Tuning for Flexible Mode Compensation Control Loop

Jaroslav Busek	Czech Technical University in Prague
Baran Alikoc	Czech Technical University in Prague
Pavel Zitek	Czech Technical University in Prague
Tomas Vyhlidal	Czech Technical University in Prague

Thursday, November **23rd**

08.30-10.00: Session 1

08.30-09.00: Saturated multiplicity inducing dominancy of spectral values of TDS: Application in active vibration control

Islam Boussaada	L2S/IPSA
Silviu-Iulian Niculescu	L2S/CNRS
Sami Tliba	L2S/Université Paris Sud

09.00-09.30: Converse Lyapunov theorems for uncertain retarded systems and application to the stability of interconnected systems

Ihab Haidar

Paolo Mason	L2S/CNRS
Mario Sigalotti	

09.30-10.00: Stability analysis of mathematical model of competition in a chain of chemostats in series with delay

Gonzalo Ricardo Robledo Veloso	Universidad de Chile
Silviu-Iulian Niculescu	L2S/CNRS
Fréderic Mazenc	L2S/Inria

10.00-10.30: Coffee Break

10.30-12.00: Session 2

10.30-11.00: Distributed Control and Abstraction for Multi-Agent Systems with Coupled Constraints

Dimitris Boskos	KTH
Dimos Dimarogonas	KTH

11.00-11.30: Flocking results for the Cucker-Smale model with time delay and hierarchical leadership

Christina Pignotti	Università degli Studi dell'Aquila
Irene Reche Vallejo	Università degli Studi dell'Aquila

11.30-12.00: Internally Positive Representations and Stability Analysis of Linear Delay Systems

Vittorio de Iulis	Università degli Studi dell'Aquila
Alfredo Germani	Università degli Studi dell'Aquila
Costanzo Manes	Università degli Studi dell'Aquila

12.00-13.30: Lunch

13.30-15.30: Session 3

13.30-15.30: Control by set invariance of a class of convolution systems

Berna Bou Farraa	Université de Nantes, France
Rosa Abou	Université de Nantes, France
Jean-Jacques Loiseau	Université de Nantes, France

14.00-14.30: Regional stability of nonlinear sampled-data control systems: a quasi-LPV approach

A. Palmeira	Universidade Federal do Rio Grande do Sul
J. M. Gomes da Silva	Universidade Federal do Rio Grande do Sul
J. F. Flores	Universidade Federal do Rio Grande do Sul

14.30-15.00: Global Dynamics of triangular difference equations and Hierarchical competition models

Saber Elaydi	Trinity University

15.00-15.30: Understanding Electrochemical PDE Models of Li-ion Batteries Using Feedback

Ross Drummond	University of Oxford
Adrien BIzeray	University of Oxford
David Howey	University of Oxford
Stephen Duncan	University of Oxford

15.30-16.00: Coffee Break

16.00-17.30: Session 4

16.00-16.30: Stability Analysis of Linear PDEs with Generalized Energy Functions

Giorgio Valmorbida	L2S/CentraleSupélec
Adithya Gawlahat	Ilinois Institute of Technology

16.30-17.00: Computing and optimizing system norms for delay equations

Wim Michiels	KU Leuven
Marco Gomez	CINVESTAV
Alexey Egorov	St Petersburg State University
Sabine Mondie	CINVESTAV
Elias Jarlebring	KTH
Suat Gumussoy	Mathworks

17.00-17.30: On the advantages of ODE-PDE modeling for the stability analysis of time-delay systems

Mohammad Safi	LAAS
Alexandre Seuret	LAAS/CNRS
Lucie Beaudouin	LAAS/CNRS

17.30-18.30: Interactive Session

Lyapunov stability analysis of a string equation coupled with an ordinary differential system

Matthieu Barreau	LAAS/CNRS
Alexandre Seuret	LAAS/CNRS
Frédéric Gouaisbaut	LAAS/CNRS
Lucie Beaudouin	LAAS/CNRS

Computing partial synchronization manifolds of delay-coupled systems

Libo Su	KU Leuven
Wim Michiels	KU Leuven
Erik Steur	Technische Universiteit Eindhoven
Henk Nijmeijer	Technische Universiteit Eindhoven

Signal shaping for drones with suspended load

David Osta	Czech Technical University in Prague
Jaroslav Busek	Czech Technical University in Prague
Tomas Vyhlidal	Czech Technical University in Prague

Constrained networked control systems stabilization: a λ-D-contractive set based approach

Mohammed Laraba	L2S
Sorin Olaru	L2S/CentraleSupélec
Silviu-Iulian Niculescu	L2S/CNRS

Symbolic definition of the flat output space for input-output constrained flat systems

Maria Bekcheva	L2S
Luca Greco	L2S/ Univ. Paris-Sud
Hugues Mounier	L2S/Univ. Paris-Sud

Friday, November **24th**

08.30-10.00: Session 1

08.30-09.00: Self-excited vibration frequencies of a continuum beam subjected to delayed feedback

Gabor Stepan	BME
Li Zhang	NUAA

09.00-09.30: 15 years or so of pseudospectral methods for delay equations

Dimitri Breda	Università degli Studi di Udine

9.30-10.00: Anthropomorphic image reconstruction via sub-Riemannian geometry and hypoelliptic diffusion

Dario Prandi	L2S/CNRS, France

10.00-10.30: Coffee Break

10.30-12.00: Session 2

10.30-11.00: Stability analysis of coupled differential-difference equations with uncertain feedback using multipliers

Haihong Wang	Southern Illinois University
Keqin Gu	Southern Illinois University

11.00-11.30: An algebraic analysis approach to linear differential time-varying delay systems

Alban Quadrat	Inria Lille
Rosane Ushirobira	Inria Lille

11.30-12.00: Time delay feedback in vibration suppression, with application example on damping pendulum oscillations

Tomáš Vyhlídal	Czech Tech. University in Prague
Silviu-Iulian Niculescu	L2S/CNRS
Milan Anderle	Czech Tech. University in Prague
Jaroslav Bušek	Czech Tech. University in Prague

12.00-13.30: Lunch

13.30-17.30: Tutorial - A guided tour on model order reduction for linear time-delay systems

Wim Michiels	KU Leuven

Book of abstracts

WEDNESDAY, NOVEMBER 22nd

SESSION 1

Title: Stabilization of Delay Systems via PID Control: How Good is it?

Author(s): Dan Ma, Jie Chen

Abstract: PID control is a time-honored control technique favored for its ease of implementation and undoubtedly, has been the most popular mechanism in controlling industrial processes with its unparallel simplicity and proven power. Issues exist, however, concerning its effectiveness and limitations. This talk addresses its effectiveness and limitations in countering delay effects, by studying the delay margin of linear time-invariant systems achievable by PID controllers. The basic issue under investigation addresses the question: What is the largest range of time delay so that there exists a single PID controller to stabilize the delay plants within the entire range? Delay margin is a fundamental measure of robust stabilization against uncertain time delays and poses a fundamental, longstanding problem that remains open except in simple, isolated cases. This talk shall present explicit expressions of the exact delay margin and its upper bounds achievable by PID control for low-order delay systems, notably the first- and second-order unstable systems with unknown constant and time-varying delays. Other than furnishing fundamental limits on the delay margin, our results should also provide useful guidelines in tuning PID parameters and in the analytical design of PID controllers.

Title: Integral delay equation

Author(s): Sabine Mondié, Saul del Valle, Alexey Egorov

Abstract: Differential models of retarded, neutral or distributed type are in general used to describe the dependence of present states on past ones. However, the dependence on the past can also be addressed with non-differential systems. A first possibility is to use difference equations in continuous time where the present state, not its derivative, depends on states at past instants. A second one, which is more appropriate when the dependence on past states is not at pointwise delays, but at delays weighted by some distribution on a given interval, is to use integral delay equations.
These equations appear as mathematical objects in a number of delay problems: In the study of neutral delay systems they represent the difference operator whose stability is a necessary condition for the stability of the system. They correspond to additional dynamics introduced by some system transformations, and they describe the internal stability of predictor-based control laws for input delay systems. Integral delay equations can be used in modelling processes such as exhaust gas re-circulation, material transport models such as plug flow vessels or crushing-mill process, age-structured population models or propagation phenomena in excitable media. Moreover, they have been shown to be closely connected to first order hyperbolic partial differential equations. In this talk, we discuss ongoing research on a class of integral delay equations in the context of converse stability theorems. The main definitions and properties of the fundamental matrix and Cauchy formula are given. A new Lyapunov delay matrix is introduced, that characterizes a new functional that admits a quadratic lower bound when the system is stable. These results allow proving novel necessary stability conditions.

Title: Agent Regrouping under Delays and Proximity Constraints

Author(s): Rifat Sipahi, Min Hyong Koh

Abstract: In this talk, we consider a class of multi-agent systems interacting with each other under proximity constraints and with delays. We show that under certain conditions, the

unstable system can break into sub-networks where each sub-network is stable - a way the system's agents regroup to achieve stability. Next, we show how link losses due to proximity constraint can promote stability, which then explains the underlying principles of stabilization through agent regrouping.

Title: Global stabilization of a Korteweg-de Vries equation with saturating distributed control

Author(s): Swann Marx, Eduardo Cerpa, Christophe Prieur and Vincent Andrieu

Abstract: A particular nonlinear partial differential equation is studied, namely the Korteweg-de Vries equation, that models long waves in water of relatively shallow depth. A control actuating on a small part of the channel will be considered. This control will be modified with two different types of saturations. The attractivity result will be proved by using Lyapunov argument and a contradiction argument. Finally, the results will be illustrated with some numerical simulations.

SESSION 2

Title: Oscillatory dynamics of an intravenous glucose tolerance test model with delay interval

Author(s): Yang Kuang

Abstract: Type 2 diabetes mellitus (T2DM) has become prevalent pandemic disease largely due to the modern life style. The intravenous glucose tolerance test (IVGTT) is an effective protocol to determine the insulin sensitivity, glucose effectiveness and pancreatic β-cell functionality, through the analysis and parameter estimation of a proper differential equation model.In this talk we propose a novel approach to model the time delay in IVGTT modeling.This approach uses two parameters to simulate not only both discrete time delay and distributed time delay in the past interval, but also the time delay distributed in a past sub-interval. Longer time delay, either a discrete or distributed delay, often destabilize a system. This may not be true for time delay over a sub-interval. We present analytically some basic model properties which are desirable biologically and mathematically.
We show that this relatively simple model provides good fit to fluctuating patient data sets and reveals some intriguing dynamics.
Moreover, our numerical simulation results indicate that our model may remove the defect in well known Minimal Model which often overestimates the glucose effectiveness index.

Title: Linearized systems of conservation laws what can they give?

Author(s): Daniela Danciu, Vladimir Rasvan

Abstract: The systems of conservation laws describe systems with distributed parameters that are essentially nonlinear i.e. modeled by some special partial differential equations. These equations display several "unpleasant phenomena"' from the point of view of the control: propagation of the discontinuities, compression and rarefaction waves, shock waves. On the other hand the control and stabilization of the operating points of any technical system aims at avoiding the aforementioned phenomena. The present research has as motivation and/or ``rough material'' three classes of systems with distributed parameters described by conservation laws and belonging to the field of energy production and management: hydroelectric power plants under waterhammer; thermal power plants for co-generation; controlled water channels (shallow water). In all these cases the boundary conditions are non-standard (i.e. in ``feedback connection'' with a subsystem described by ordinary differential equations). There are however some differences between these three structures: in the first two cases the linearization is ``physical'' - the nonlinear terms are rather small and negligible in all regimes i.e. the models in current use are always linear. For the third model (shallow water) the assumption is no longer true but one might perform linearization around some operating point.

Now, the linearized models allow association of some functional differential equations (in most cases of neutral type). At their turn these equations are used for basic theory, controller synthesis as well as for ``guessing'' suitable Lyapunov functionals. As in all linear cases, a quite complete theory can be built which contains valuable hints for the nonlinear case. We list some of them: basic theory by successive approximations; suggestions for specific Lyapunov functionals; small parameter constructions; computational approaches and their foundations, based on comparison and small parameters. Some of these ideas are illustrated throughout the paper.

Title: Stability analysis of mixed ODE-heat equation system

Author(s): Lucie Baudouin, Alexandre Seuret, Frédéric Gouaisbaut

Abstract: This talk will address the stability of a system of ordinary differential equations coupled with a classic heat equation on a bounded domain, the coupling acting through the boundary. Using a Lyapunov functional technique and inspired from recent developments in the area of time delay systems, a new methodology to study the stability of such a class of distributed parameter systems will be presented. The idea is to use a polynomial approximation of the infinite dimensional state of the heat equation in order to build an enriched energy functional, allowing to obtain stability conditions expressed in terms of linear matrix inequalities. The efficiency of our approach will be illustrated on academic examples.

Title: Stability of uncertain delay differential equations

Author(s): Rossana Vermiglio, A. Zamolo

Abstract: Differential equations of retarded type arise to model a variety of problems in science, engineering, and medicine, where there is a time lag or after-effect. Such evolution equations describe an infinite-dimensional dynamical systems and, in this context, the first key question is the understanding of the linear case, since the local stability of equilibria, according to the principle of linearized stability, can be inferred from the zero-solution stability of the linearized system. Another important aspect to take into account in practical applications is the specification of initial conditions, model constants and parameters. In many situations, due to limitations in available experimental data, in measurement or identification of model constants, the input data cannot be exactly specified and, as a consequence, the analysis of the effect of data uncertainty on the stability of linear delay differential equations is a crucial question. The uncertain parameters are often modeled as random quantities in a suitable probabilistic framework and, within this context, the Polynomial Chaos Expansions (PCEs) have been successfully applied to represent random variables [4] and for sensitivity and uncertainty analyses in many applications [2]. The PC theory provides the basis for the definition of delay differential equations with uncertain parameters, here called uncertain delay differential equations [3] and for the Sobol sensitivity analysis of the stability indicator [5]. We propose a numerical approach which combines the spectral discretization of the infinitesimal generator [1] with non-intrusive methods [2]. Numerical results complete the talk.

References:
[1] Breda D., Maset S. and Vermiglio R. Stability of Linear Delay Differential Equations - A Numerical Approach with MATLAB, Springer (2015).
[2] Le Maître O. P., Knio O. M. Spectral Methods for Uncertainty Quantification, Springer (2010).
[3] Vermiglio R., Polynomial Chaos expansions for the stability analysis of uncertain delay differential equations, SIAM/ASA J. Uncertainty Quantification, 5(1), (2017) pp. 278-303.
[4] Wiener N., The Homogeneous Chaos. American Journal of Mathematics 60 (4)(1938) pp. 897-936.
[5] Zamolo A. Polynomial Chaos Expansions with applications to delay differential equations, Master's Thesis in Mathematics, (2017).

SESSION 3

Title: Global and Semi-Global Stabilization by Sampled-Data Emulation of Global Stabilizers for Time-Delay Systems

Author(s): Pierdomenico Pepe, Mario Di Ferdinando

Abstract: Sufficient conditions, in terms of suitable Lyapunov-Krasovskii functionals, are given such that a finite dimensional, spline approximated, non-smooth state feedback provides stabilization in the sample-and-hold sense. It is assumed that the state feedback satisfies a Lipschitz property in any bounded subset of the state space, whenever couples of states are considered which have the same value at zero. Insights for observer-based sampled-data stabilizers are provided. It is shown, for the class of globally Lipschitz systems, that the global exponential stability is preserved, by Euler emulation, whenever the dynamics describing the observer and the observed-state feedback are globally Lipschitz.

Title: Computing and optimizing system norms for delay equations

Author(s): Wim Michiels, M. Gomez, A. Egorov, S. Mondie, E. Jarlebring, S. Gumussoy

Abstract: In this talk we address the computation of two commonly used system norms, the H-2 and the H-infinity norm, for linear time delay systems, as well as their optimization as a function of system or controller parameters. We show how basic properties of these norms lead to fundamentally different algorithms for the evaluation and optimization. The presented algorithms are illustrated by means of two applications: the design of robust fixed-order controllers, and the computation of approximate models of reduced dimension.

INTERACTIVE SESSION

Title: Stabilization of switched systems with time-varying delay using a trajectory based approach

Author(s): Saeed Ahmed, Frédéric Mazenc, Hitay Ozbay

Abstract: We present a trajectory based approach for stabilization of switched linear systems with a time-varying delay. Our approach does not require finding common Lyapunov function or multiple Lyapunov functions for establishing the stability of the closed-loop switched system. Moreover, our main result does not require stabilizability of all of the constituent subsystems of the switched system and it does not require the switching signal to be known. Moreover, no assumption is needed about the differentiability of the delay and no constraint is imposed on the upper bound of the delay derivative.

Title: Multi-dimensional delayed resonator - design objectives and first results

Author(s): Matej Kure, Karel Kraus, Tomas Vyhlidal, Zbynek Sika

Abstract: First results achieved in the subject of extending the delayed resonator concept to suppress vibrations in multiple dimensions will be presented. First, a two dimensional problem will be solved by application of two delayed resonators. Secondly, considerably more difficult task of designing a single three-dimensional vibration absorber for a primary structure vibrating in two translational and one rotational degree of freedom will be introduced. Designing an active time delay feedback to this multi-dimensional absorber is the key challenge for future research.

Title: Computing distance to instability for large-scale delay systems with uncertainties in the system matrices and in the delay terms

Author(s): Francesco Borgioli, Wim Michiels

Abstract: We propose an algorithm to compute the distance to instability of a linear system of delay differential equations (DDEs) containing uncertainties in the delay terms as well as in

matrices coefficients. For what regards the system matrices, any structure on the perturbation can be considered in order to allow only specific parameters to change; moreover, real-valued matrix perturbations are taken into account. The algorithm relies on the computation of the pseudospectral abscissa of the system and performs a bisection-Newton's method to find the minimum size of the perturbation that generates instability. A few illustrative examples finally show the correctness and the efficiency of the method, including a model for a rotating cutting machine.

Title: Necessary and sufficient conditions for the control of a logistic system subject to delays and constraints

Author(s): Berna Bou Farraa, Rosa Abbou, Jean Jacques Loiseau

We consider the classical model of an elementary production system, with a loss term. This system is subject to a delay in the control, that corresponds to the production time, and to a demand, that is assumed to be variable in a given range. It is also subject to strict constraints, since the production level and inventory level are bounded. Using Artstein transform, an equivalent system without delay is obtained. Using invariance principle, we express necessary and sufficient conditions, such that the constraints are met by the closed-loop system. We also derive conditions for the initial system. These conditions are expressed in terms of affine inequalities. By projection, we obtain necessary and sufficient conditions for the existence of a control law such that the constraints are met, whatever be the demand varying in the given range. The result is compared with various existing results.

Title: Anti-windup Scheme Tuning for Flexible Mode Compensation Control Loop

Author(s): Jaroslav Busek, Baran Alikoc, Pavel Zitek, Tomas Vyhlidal

An observer-based anti-windup compensator for a flexible mode compensation control loop including inverse delay-based signal shaper in the feedback path is presented. Because the classical shaper design can not suppress the oscillations fully when the saturation effect on control action exists the compensator with emphasis to simple tuning is proposed.

THURSDAY, NOVEMBER 23rd

SESSION 1

Title: Saturated multiplicity-inducing dominancy of spectral values of TDS: Application in active vibration control

Author(s): Islam Boussaada, Silviu-Iulian Niculescu, Sami Tliba

Abstract: For linear delay-differential equations, a question of ongoing interest is to determine conditions on the equation parameters that guarantee exponential stability of solutions. The building blocks of this talk are unexpected recent results showing a link between the stable manifold and the variety characterizing multiple characteristic spectral values allowing to the right-most root assignment. It starts by motivating the tracking of multiple spectral values for analysis/control perspectives. Then, some existing links with classical mathematical results are stressed. Namely, Birkhoff interpolation problem as well as a result due to Pólya and Szegö on the number of quasipolynomial's roots in some horizontal strip will be revisited. Later, an analytic proof of the dominancy of quasiploynomial's root will be presented. A standard reduced order model arizing from mechanical engineering problems will illustrate the proposed control approach.

Title: Converse Lyapunov theorems for uncertain retarded systems and application to the stability of interconnected systems

Author(s): Ihab Haidar, Paolo Mason, Mario Sigalotti

Abstract: In this talk I will first present a collection of converse Lyapunov-Krasovskii results for uncertain linear retarded systems. Based on these results, the preservation of the stability under Small perturbations and in the case of interconnected stable subsystems will be shown.

Title: Stability analysis of mathematical model of competition in a chain of chemostats in series with delay

Author(s): Gonzalo Robledo, Silviu-Iulian Niculescu, Frédéric Mazenc

Abstract: We study a system of nonlinear differential delay equations that describes the model of a chain of two chemostats, where one contains two microbial species in competition for a single limiting nutrient and receives an external input of the less advantaged competitor, which is cultivated in an external chemostat. We obtain sufficient conditions ensuring the coexistence of all the species in competition, summarized by upper delay bounds.

SESSION 2

Tiltle: Distributed Control and Abstraction for Multi-Agent Systems with Coupled Constraints

Author(s): Dimitris Boskos, Dimos Dimarogonas

Abstract: Multi-agent planning and control constitute active research areas with numerous applications in fields such as robotics, power systems and sensor networks. For the coordination of multi-robot teams, it is in principle required that the agents satisfy certain relative state constraints. These can provide guarantees for collision avoidance and network connectivity, by appropriately incorporating the agent's volume and sensing/communication

ranges, respectively. Towards this goal we provide a distributed control scheme which establishes robust connectivity maintenance of a multi-agent network. This is accomplished by means of bounded control laws and ensures that connectivity is preserved robustly with respect to bounded additive inputs. The latter provide to the agents control freedom to perform high level tasks, by using discrete representations (abstractions) of their dynamic behavior and appropriate algorithmic tools. We therefore derive distributed symbolic models for the agents, through space-time discretizations which establish that each agent's abstraction has at least one outgoing transition from every discrete state. The symbolic model of each agent is based on the knowledge of its neighbors' discrete positions and the transitions are performed through hybrid control laws, which can drive the agent to its possible successor states. This framework is additionally modified towards the derivation of online abstractions, by discretizing overapproximations of the agents' reachable sets over a bounded time horizon.

Title: Flocking results for the Cucker-Smale model with time delay and hierarchical leadership

Author(s): Cristina Pignotti, Irene Reche Vallejo

Abstract: The celebrated Cucker-Smale model has been introduced in 2007 as a model for flocking, namely for phenomena where autonomous agents reach a consensus based on limited environmental information. We will consider the so called Cucker-Smale model with hierarchical leadership introduced by J. Shen (SIAM J. Appl. Math. 2007/08), i.e. the agents are ordered in a specific way, depending on which other agents they are leaders or lead by. In particular, we are interested in the asymptotic analysis of such a model in presence of a time delay. We will present convergence to consensus results for every positive time lag. These results seem to point out an advantage of the hierarchical structure in order to contrast time delay effects that often appear in real situations.

Title: Internally Positive Representations and Stability Analysis of Linear Delay Systems

Author(s): Vittorio De Iuliis, Alfredo Germani, Costanzo Manes

Abstract: As shown in recent works, the availability of results on positive systems naturally encourages investigating whether such special properties lead to corresponding results on arbitrary (i.e. not necessarily positive) systems. This is the core idea behind the Internally Positive Representation (IPR) of systems, a technique that associates to an arbitrary system an internally positive one, and a set of transformations from the original system to its positive counterpart (and viceversa). This work presents the Internally Positive Representation of three classes of linear time-delay systems: differential systems, difference systems, and coupled differential-difference systems. We illustrate how the IPR method allows to obtain delay-independent sufficient conditions for the stability of arbitrary delay systems of those classes. The results are discussed and compared to similar conditions proposed in the literature, and finally validated by means of numerical examples.

SESSION 3

Title: Control by set invariance of a class of convolution systems

Author(s): Berna Bou Farraa, Rosa Abbou, Jean-Jacques Loiseau

Abstract: We consider the control of a class of convolution systems subject to constraints on the state and the control, using the search of invariant sets. Our motivations come from production management.

Title: Regional stability of nonlinear sampled-data control systems: a quasi-LPV approach

Author(s): A. Palmeira, J.M. Gomes da Silva Jr., J.F. Flores

Abstract: This work addresses the stability analysis of sampled-data control for a class of continuous-time nonlinear systems. The proposed approach is based on a local quasi-LPV model for the nonlinear system and the use of a parameter dependent looped-functional to deal with the aperiodic sampling effects. From these ingredients, conditions in an LMI form are proposed to assess local stability. These conditions are then incorporated in convex optimization problems aiming at obtaining maximized estimates of the region of attraction of the origin or maximizing the intersampling time for which the stability is ensured regionally. A numerical example illustrates the proposed methodology.

Title: **Global Dynamics of triangular difference equations and Hierarchical competition models**

Author(s): Saber Elaydi

Abstract: We will investigate the global dynamics of a special class of maps whose Jacobian matrix is triangular. These maps give rise to triangular discrete dynamical systems/difference equations. It is shown that under mild conditions, for compact spaces or systems with bounded orbits, every orbit must converge to a fixed point. Hence global stability is attained if there is a unique attracting fixed point. Such maps model hierarchical competition models, in which species are in a networked hierarchy of state variables rather than the random parameter models of statistics.

Title: Understanding Electrochemical PDE Models of Li-ion Batteries Using Feedback

Author(s): Ross Drummond, Adrien Bizeray, David Howey, Stephen Duncan

Abstract: This talk proposes a method to analyse nonlinear electrochemical PDE models of Li-ion batteries using feedback. More specifically, it is shown that the benchmark Newman model can be framed as a feedback system when fast capacitance dynamics are included. This opens the door for a rigorous analysis of this model, which will lead to improved observers and parameter estimates and, in turn, improved state-of-charge and state-of-health knowledge.

SESSION 4

Title: On the advantages of ODE-PDE modeling for the stability analysis of time-delay systems

Author(s): Mohammad Safi, Alexandre Seuret and Lucie Baudouin

Abstract: This presentation deals with the stability analysis of a system of fi nite dimension coupled to a vectorial transport equation, which includes as a particular case usual time-delay systems. We develop here a new method to study the stability of such a system, coupling ordinary and partial differential equations, using linear matrix inequalities led by the choice of an appropriate Lyapunov functional. To this end, we exploit Legendre polynomials and their properties, and use a Bessel inequality to measure the contribution of our approximation. The exponential stability of a wide class of delay systems is a direct consequence of this study, but above all, we are detailing here a new approach in the consideration of systems coupling in finite and fi nite dimensional dynamics. The coupling with a vectorial transport equation is a first step that already prove the interest of the method, bringing hierarchized conditions for stability. Based on this first general result, an emphasis on the non unique ODE-PDE representation of a time-delay system is provided and brgins some relevant indication of discretized Lyapunov functionals. Our approach will finally be tested on several academic examples.

Title: Stability Analysis of Linear PDEs with Generalized Energy Functions

Author(s): Aditya Gahlawat, Giorgio Valmorbida

Abstract: We present a method for the stability analysis of a large class of linear Partial Differential Equations (PDEs) in one spatial dimension. We rely on Lyapunov analysis to establish the exponential stability of the systems under consideration. The proposed test for the verification of the underlying Lyapunov inequalities relies on the existence of solutions of a system of coupled differential equations. We illustrate the application of this method using a PDE actuated by a backstepping computed feedback law. Furthermore, for the case of PDEs defined by polynomial data, we formulate a numerical methodology to solve these inequalities. More importantly, this numerical method can be cast as a convex optimization problem which can be solved algorithmically. We show the efficacy of the proposed numerical methodology using various examples of different types of PDEs.

INTERACTIVE SESSION

Title: Signal shaping for drones with suspended load

Author(s): David Osta, Jaroslav Busek, Tomas Vyhlidal

Abstract: This work deals with application of input command shapers for control of quadcopters with a suspended load. Signal shaper technique is applied in order to reduce residual oscillations of the suspended load. Simulation results are presented for a free 2DoF quadcopter. The control system is based on a novel control architecture, which consists of inverse form of zero vibration shaper with distributed time-delay in the feedback loop and classical PID controller. Properties of the resulting control law are presented and further research proposals are elaborated.

Title: Lyapunov stability analysis of a string equation coupled with an ordinary differential system

Author(s): Matthieu Barreau, Alexandre Seuret, Frédéric Gouaisbaut, Lucie Baudouin

Abstract: We will consider the stability problem of a linear time invariant system of finite dimension in feedback with a string equation. A new Lyapunov functional candidate is proposed using augmented states which enriches and encompasses the classical functionals proposed in the literature. It results in tractable stability conditions expressed in terms of linear matrix inequalities. This methodology follows from the application of the Bessel inequality together with Legendre polynomials. The outline of the presentation is as follow. First, some known results about time-delay systems are reminded. Then, the problem is proposed and the well-posedness is briefly discussed. After some result in Riemann invariant, a first stability analysis is proposed. Based on the results in time-delay systems, an extension is also provided. Finally, some numerical examples illustrate the potential of our approach through three scenari: a stable ODE perturbed by the PDE, an unstable open-loop ODE and an unstable closed-loop ODE stabilized by the PDE.

Title: Computing partial synchronization manifolds of delay-coupled systems

Author(s): Libo Su, Wim Michiels, Erik Steur, Henk Nijmeijer

Abstract: Due to weak couplings, large time-delays, etc., a network of interconnected dynamical systems may exhibit a phenomenon of incomplete synchronization where some but not all systems behave synchronously. The phenomenon is called partial synchronization or cluster synchronization. To describe the pattern of partial synchronization, so-called partial synchronization manifolds are used, which are linear invariant subspaces of C, the state space of the network of systems. Here, we focus on partial synchronization manifolds in networks of identical systems interacting via linear diffusive coupling with inclusion of time-delays. Based on

a recently proposed existence criterion for partial synchronization manifolds in terms of the block structure of a reordered adjacency matrix, we present an improved algorithm for computing partial synchronization manifolds, particularly, for networks with invasive delayed coupling whose coupling term does not vanish when relevant systems are synchronized. It is shown that the computational cost is largely reduced using the improved algorithm when computing the partial synchronization manifolds of networks with invasive coupling.

Title: Constrained networked control systems stabilization: a λ-D-contractive set based approach

Author(s): Mohamed Laraba, Sorin Olaru, Silviu-Iulian Niculescu

Abstract: In this talk the stabilization problem of Networked Control Systems 'NCSs' with a specific attention to linear dynamical systems affected by uncertain, possibly time-varying, network-induced delays in the presence of input and state constraints is discussed. Two main theoretical results are presented. First, we address the computation of a polyhedral control Lyapunov-Razumikhin Function 'pcLRF' using 1-step controllability sets. Furthermore, we show that adopting 'pcLRF' instead of quadratic control Lyapunov-Razumikhin Function 'qcLRF' reduces the conservativeness of 'LRF' based control design. Secondly, based on the first result, we show that polyhedral λ-D-contractive sets can be used as a target set in a Set Induced Lyapunov Function 'SILF' control fashion where a simple Linear Programming 'LP' problem is required to be solved at each sampling instance. We prove that the proposed controller, under mild assumptions, is able to handle state/input constraints, and ensures asymptotic stability for all initial states belonging to a predefined set.

Title: **Symbolic definition of the flat output space for input-output constrained flat systems**

Author(s): Maria Bekcheva, Hugues Mounier, Luca Greco

Abstract: This communication presents an approach to embed the input and output constraints into the trajectory design for differentially flat systems. For that purpose, we specialize the flat outputs (or the reference trajectories) as Bezier curves. Using the flatness property, we show that the system's inputs/states, can be expressed as a combination of Bezier curves. In this approach, we explicitly obtain the symbolic expressions of the control points of the inputs/states Bezier curves. By applying desired constraints to the latter control points, we find regions for the outputs (reference trajectories) Bezier control points, thus allowing a better choice of reference trajectory. We illustrate the approach by an example on simplified non-linear vehicle model.

FRIDAY, NOVEMBER 24th

SESSION 1

Title: Self-excited vibration frequencies of a continuum beam subjected to delayed feedback

Author(s): Gabor Stépan, Li Zhang

Abstract: The mechanical model of a basic problem of electroacoustics is considered. The governing PDE is a 1D wave equation with delayed boundary conditions. The exact stability chart is constructed analytically in the parameter plane of the gain parameter and the ratio of the delays related to the travelling waves in the electrical and the mechanical parts of the model. The physical relevance of this peculiar stability chart is highlighted in undamped and damped cases from the view-point of engineering relevance, while the difficulties of finite dimensional numerical approximations are also discussed. The vibration frequencies of periodic and quasi-periodic oscillations are identified at the Hopf and double-Hopf bifurcations in the system, which leads to certain conclusions regarding the squeal phenomenon in public address systems.

Title: 15 years or so of pseudospectral methods for delay equations

Author(s): Dimitri Breda

Abstract: Problems involving time delays generate dynamical systems on infinite-dimensional state spaces. Still much of the properties of ODEs hold. The celebrated principle of linearized stability is an example: hyperbolic equilibria or periodic orbits of nonlinear models inherit the stability features of the corresponding linearizations. The latter are based on spectral properties of certain linear operators, whose infinite dimension asks for numerical treatment. In this talk we review the basics of pseudospectral methods as applied to approximate the stability determining eigenvalues. Starting from the original problem of the characteristic roots of equilibria of delay differential equations, we arrive at the most recent developments concerning multipliers of periodic orbits of renewal equations, as well as the direct application to nonlinear retarded systems in view of bifurcation analysis.

Title: Anthropomorphic image reconstruction via sub-Riemannian geometry and hypoelliptic diffusion

Author(s): Dario Prandi

Abstract: In this talk I will present an algorithm of image reconstruction based on a model of geometry of vision started with the works of Hubel and Wiesel at the end of the 50s, up to the works by Petitot, Citti and Sarti and our research group. One of the main features of this model is that the primary visual cortex V1 lifts an image from the plane to the bundle of directions of the plane. Neurons are grouped into orientation columns, each of them corresponding to a point of this bundle. In this model a corrupted level set of an image is reconstructed by minimizing the energy necessary for the activation of the orientation columns corresponding to regions in which the image is corrupted gives rise to a sub-Riemannian problem. To this sub-Riemannian problem is naturally associated an hypoelliptic heat equation on the bundle of directions of the plane that can be used to reconstruct a "natural" image. One of the main difficulties is the numerical integration of such a diffusion equation that being highly non-isotropic contains two different diffusion scales. We solve this problem by using techniques of non-commutative Fourier analysis on a suitable semi-discretization the group of rototranslations of the plane. The use of the knowledge of "where" the image is corrupted permits to reconstruct images with 97% of corruption obtaining result at the state of the art in image processing

SESSION 2

Title: Stability analysis of coupled differential-difference equations with uncertain feedback using multipliers

Author(s): Haihong Wang, Keqin Gu

Abstract: Uncertainties are often modeled either as a bounded or positive real feedback. Multiplier method is an effective method to take advantage of known information of uncertainties to reduce conservatism. When the nominal system is coupled differential difference equations, the traditional Lyapunov-Krasovskii formulation leads to BOI (bilinear operator inequality). However, based on an abstract differential equation formulation, the Lyapunov-Krasovskii functional is associated with a linear operator. It is shown that the formulation based on the inverse of this operator leads to a linear operator inequality. This can be discretized to obtain a linear matrix inequality.

Title: An algebraic analysis approach to linear differential time-varying delay systems

Author(s): Alban Quadrat, Rosane Ushirobira

Abstract: In this talk, we propose an algebraic analysis approach to linear differential time-varying delay systems. This approach is based on the construction of an Ore extension for the ring of differential time-varying delay operators. We investigate the properties of this ring. Finally, we study built-in properties of linear differential time-varying delay systems by means of module theory and homological algebra.

Title: Time delay feedback in vibration suppression, with application example on damping pendulum oscillations

Author(s): Tomáš Vyhlídal, Silviu-Iulian Niculescu, Milan Anderle, Jaroslav Bušek

Abstract: Time delay feedback has proven beneficial in a number of applications in vibration suppression or oscillation damping. The talk will start with recalling fundamental design ideas of two key applications: i) delayed resonator, and ii) input shaping. In both these applications, including the delay directly related to the oscillation period brings considerable benefits to the algorithm performance. As a new application example where time delay feedback is beneficial, the recently proposed method [1] to damp oscillations of a pendulum by adjusting a cable length will be presented. Next to derivation of the nonlinear time delay algorithm and both simulation and experimental validation, open problems mainly concerning the stability proof will be highlighted.

[1] Vyhlídal T., Anderle M., Bušek J, Niculescu S.I. Time-Delay Algorithms for Damping Oscillations of Suspended Payload by Adjusting the Cable Length. IEEE/ASME Transactions on Mechatronics, 2017, 22.5: 2319-2329.

TUTORIAL

Title: A guided tour on model order reduction for linear time-delay systems

Instructor(s): Wim Michiels

Abstract: The aim of the lectures is to present an overview of model reduction techniques for large-scale time-delay systems, focusing on their main principles and properties. After discussing fundamental properties of delay systems, I outline how approaches based on moment matching (Krylov and data driven variants) and approaches based on balanced truncation can be generalized from LTI systems to time-delay systems. Both reduction methods where the reduced model is in the form a standard LTI system, and structure preserving methods, where the reduced model has the same, delay structure as the large-scale system, are considered.