

International Graduate School on Control

Independent Graduate Modules – one 21 hours module per week (3 ECTS)

Different LOCATIONS	Deadline for advance registration to each module: 20/12/2014	
M1 – PARIS-SACLAY 19/01/2015 – 23/01/2015	<i>Advanced topics in the optimal control of economic systems</i>	Raouf Boucekkine, GREQAM, Aix-Marseille School of Economics, France
M2 – PARIS-SACLAY 26/01/2015 – 30/01/2015	<i>Moments, positive polynomials and LMIs for optimal control</i>	Didier Henrion & Jean-Bernard Lasserre CNRS LAAS, University of Toulouse, France
M3 – PARIS-SACLAY 02/02/2015 – 06/02/2015	<i>The scenario approach for robust control, identification, and machine learning</i>	Marco C. Campi, University of Brescia, Italy & Simone Garatti, Politecnico di Milano, Italy
M4 – PARIS-SACLAY 16/02/2015 – 20/02/2015	<i>Control-oriented modeling and system identification</i>	Emmanuel Witrant, University Joseph Fourier, GIPSA, Grenoble, France
M5 – PARIS-SACLAY 23/02/2015 – 27/02/2015	<i>Decentralized and distributed control</i>	Giancarlo Ferrari-Trecate, University of Pavia & Marcello Farina, Politecnico di Milano, Italy
M6 – PARIS-SACLAY 02/03/2015 – 06/03/2015	<i>Model Predictive Control</i>	Eduardo F. Camacho, University of Sevilla, Spain
M7 – STUTTGART 02/03/2015 – 06/03/2015	<i>Randomized algorithms for systems, control and networks</i>	Roberto Tempo & Fabrizio Dabbene CNR-IEIT, Politecnico di Torino, Italy
M8 – ISTANBUL 09/03/2015 – 13/03/2015	<i>Introduction to nonlinear systems analysis and nonlinear feedback control</i>	Hassan K. Khalil, Michigan State University, USA
M9 – BERLIN 16/03/2015 – 20/03/2015	<i>Nonlinear control for physical systems</i>	Roger W. Brockett, Harvard SEAS, USA & Alexandre L. Fradkov, RAS, St-Petersburg, Russia
M10 – BELGRADE 23/03/2015 – 27/03/2015	<i>Extremum seeking</i>	Miroslav Krstic, Univ. California, San Diego, USA
M11 – PARIS-SACLAY 23/03/2015 – 27/03/2015	<i>Feedback control of quantum systems</i>	Pierre Rouchon, Mines-ParisTech, France & Alain Sarlette, Ghent University, Belgium
M12 – PARIS-SACLAY 30/03/2015 – 03/04/2015	<i>Local methods for nonlinear systems and control</i>	Rodolphe Sepulchre, Univ. of Cambridge, UK
M13 – PARIS-SACLAY 06/04/2015 – 11/04/2015	<i>Sliding mode control and observation</i>	Christopher Edwards, Univ. of Exeter, UK
M14 – PARIS-SACLAY 13/04/2015 – 18/04/2015	<i>Attractive ellipsoid method in robust nonlinear control</i>	Alexander Poznyak, CINVESTAV-IPN, Mexico
M15 – ISTANBUL 13/04/2015 – 18/04/2015	<i>Advances in feedback design for MIMO nonlinear systems</i>	Alberto Isidori, University of Rome "La Sapienza", Italy
M16 – ST PETERSBURG 20/04/2015 – 25/04/2015	<i>Time-delay systems: Lyapunov functional and matrices</i>	Vladimir Kharitonov, St.-Petersburg State University, Russia
M17 – GRENOBLE 27/04/2015 – 31/04/2015	<i>Distributed control and computation</i>	A. Stephen Morse, Yale University, USA
M18 – GRENOBLE 04/05/2015 – 07/05/2015	<i>Identification in closed loop operation and controller reduction</i>	Ioan D. Landau, CNRS GIPSA-LAB, Grenoble, France & Alireza Karimi, EPFL, Switzerland
M19 – ISTANBUL 04/05/2015 – 08/05/2015	<i>Modeling and control of multiphysics systems</i>	Arjan van der Schaft, University of Groningen & Dimitri Jeltsema, TU Delft, The Netherlands
M20 – PARIS-SACLAY 11/05/2015 – 15/05/2015	<i>Hybrid systems : modeling, stability, robustness, and the math behind it</i>	Rafal K. Goebel, Loyola Univ. Chicago, IL, USA
M21 – PARIS-SACLAY 18/05/2015 – 22/05/2015	<i>Hybrid feedback control systems : analysis and design</i>	Ricardo G. Sanfelice, Univ. California at Santa Cruz, California, USA
M22 – PARIS-SACLAY 25/05/2015 – 29/05/2015	<i>Switched systems and control</i>	Daniel M. Liberzon, Univ. of Illinois, USA
M23 – PARIS-SACLAY 01/06/2015 – 05/06/2015	<i>Predictive and optimization based control for automotive and aerospace applications</i>	Ilya Kolmanovskiy, Univ. of Michigan, USA & Stefano Di Cairano, Mitsubishi Res. Lab Boston
M24 – PARIS-SACLAY 08/06/2015 – 12/06/2015	<i>Networked control with limited data rates</i>	Girish Nair, Univ. of Melbourne, Australia

M1 – PARIS-SACLAY

19/01/2015 – 23/01/2015

**Advanced topics in the optimal control
of economic systems**

Abstract of the course

This course reviews some selected advanced topics in the optimal control of economic and demo-economic systems. Three main topics will be studied. The first focus will be on age-structured models in economy and demography and the associated infinite-dimensional optimization problems. Adapted methods based on calculus of variations and dynamic programming will be presented and applied to a series of economic and demo-economic problems. The second topic concerns the optimal control of spatio-temporal systems typically governed by parabolic partial differential equations with an application to optimal economic growth. Finally, some recent optimal regime switching problems will be treated with applications to ecological economics.

Outline



Raouf Boucekkine

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1. Optimal control of age-structured populations

- Examples
- A generic problem: Optimal replacement in the vintage capital growth model
- Case 1: state equations as functional integro-differential equations (delay or neutral)
- Case 2: state equations as partial differential equations
- Maximum principle and dynamic programming methods in infinite dimension

2. Optimal control of spatio-temporal dynamics

- A generic example: The spatial Ramsey model
- Optimal control of parabolic partial differential equations
- The dynamic programming approach

3. Optimal regime switching

- Examples from ecological economics
- Multi-stage optimal control: insight and limits

M2 – PARIS-SACLAY

26/01/2015 – 30/01/2015

*Moments, positive polynomials and
LMIs for optimal control*



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Abstract of the course:

In the 1960s, it was realized that many physically relevant problems of optimal control were inappropriately formulated in the sense that the optimum control law (a function of time and/or state) cannot be found if the admissible functional space is too small. This motivated the introduction of many concepts of functional analysis in control engineering, building up on the advances on mathematical control theory and calculus of variations. When formulated in a larger space, the decision variables are Borel measures subject to a finite number of linear constraints: the initial optimal control problem becomes a standard problem of moments. However, this approach is not frequently used by engineers, and in our opinion this may have been due to two main reasons. The first one is the technicality of the underlying concepts of functional analysis whereas the second one has been the absence (up to very recently) of numerical methods to deal satisfactorily with optimization problems in large functional spaces such as Banach spaces of measures.

Recent achievements of real algebraic geometry have provided powerful results for the representation of positive polynomials and its dual theory of moment problems. Moreover, such representation results are amenable to practical computation via linear matrix inequalities (LMIs) and semidefinite programming, a powerful technique from convex conic optimization. The conjunction of those two factors now provides the basis for a systematic and quite general methodology to solve moment problems with polynomial and semi-algebraic data.

The main purpose of this course is to introduce the basic concepts of this general methodology and detail its application for solving optimal control problems.

Elements of the course are posted at
<http://homepages.laas.fr/henrion/Papers/jncf2013-henrion.pdf>

M3 – PARIS-SACLAY

02/02/2015 – 06/02/2015

*The scenario approach for robust control, identification,
and machine learning*



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Abstract of the course

In this course, the student will be introduced to sample-based and randomized methods for uncertain optimization. Samples can be observations, and this covers data-based approaches in learning and identification, as well as extractions from a probabilistic mathematical model, as it is often the case in robust control.

The course will be focused on the scenario approach. The scenario approach is a key emerging methodology for uncertain optimization, which finds application in various fields including robust control, identification and machine learning. The presentation will be gradual to allow a progressive, in-depth understanding of the various concepts. Required preliminary knowledge is limited to fundamentals in probability theory. Practical examples will illustrate ideas.

- Topics:**
- Uncertain optimization
 - Monte-Carlo sampling
 - Scenario approach
 - Robust Control, Identification, Machine Learning
 - Discussion of open problems that offer an opportunity for research

M4 – PARIS-SACLAY

16/02/2015 – 20/02/2015

**Control-oriented modeling and
system identification**



Emmanuel Witrant

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Abstract of the course:

Feedback control design, diagnostic/supervision and process optimization typically require a specific modeling approach, which aims to capture the essential dynamics of the system while being computationally efficient. The first part of the class details the guiding principles that can be inferred from different physical domains and how multi-physics models can be obtained for complex dynamical systems while satisfying the principle of energy conservation. This leads to algebro-differential mathematical models that need to be computed with stability and computational efficiency constraints, which constitutes the second part of the class on the simulation of dynamical systems.

System identification is finally considered, to include knowledge inferred from experimental data in the input/output map set by the model. It provides methods to evaluate the model performance, to estimate parameters, to design "sufficiently informative" experiments and to build recursive algorithms for online estimation.

Topics :

PHYSICAL MODELING AND SIMULATION

- 1 Models and Physical Modeling
- 2 From Physical Relationships to Bond Graphs
- 3 Computer-Aided Modeling and Simulation

SYSTEM IDENTIFICATION

- 4 System Identification Principles and Model Validation
- 5 Signals for System Identification
- 6 Non-parametric Identification:
- 7 Parameter Estimation in Linear Models
- 8 Nonlinear Black-box Identification

TOWARDS PROCESS SUPERVISION AND DIAGNOSTIC

- 9 Recursive Estimation Methods

The attendants are expected to have a solid background on calculus, differential equations and frequency analysis (Laplace transforms).

M5 – PARIS-SACLAY

23/02/2015 – 27/02/2015

Decentralized and distributed control



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Abstract of the course

Advances in technology and telecommunications are steadily broadening the size of systems that can be controlled. Examples are smart grids, which are perceived as the future of power generation, and networks of sensors and actuators, which enable monitoring and control of processes spread over large geographical areas. As an alternative to centralized regulators, that are often impractical for large-scale systems, decentralized and distributed approaches to control have been developed since the 70's. Particular attention has been recently given to distributed control architectures based on model predictive control which are capable to cope with physical constraints.

The first part of the course will focus on classical results on stability analysis of large-scale systems, decentralized control and decentralized controllability. Then, distributed control design methods will be covered. In the last part of the course, more emphasis will be given on distributed regulators based on optimization and receding horizon control. Recent advances on decentralized and plug-and-play design of local controllers will be also presented, together with applications to power networks and microgrids.

- Outline:**
- Introduction to large-scale systems and multivariable control
 - Decentralized control architectures
 - Stability analysis of large-scale systems
 - Decentralized controllability issues and design of decentralized control systems
 - Design of distributed control systems

M6 – PARIS-SACLAY

02/03/2015 – 06/03/2015

Model Predictive Control



Eduardo F. Camacho

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Abstract of the course:

Model Predictive Control (MPC) has developed considerably in the last decades both in industry and in academia. Although MPC is considered to be a mature discipline, the field has still many open problems and attracts the attention of many researchers. This course provides an extensive review concerning the theoretical and practical aspects of predictive controllers. It describes the most commonly used MPC strategies, showing both the theoretical properties and their practical implementation issues. As part of the course the students will program and simulate different MPC structures. Special focus is made in the control of a real solar energy plant that will serve as an application example of the different techniques reviewed in the course.

The course is designed around the text book:

E. F. Camacho and C. Bordons, Model Predictive Control, 2nd edition, Springer, 2004

Prerequisites: Undergraduate-level knowledge of differential equations and control systems.

Topics:

1. Introduction to MPC, process models, disturbance models, prediction equations.
2. MPC used in industry: FIR and step response based MPC. DMC.
3. MPC used in academy: GPC and State Space based MPC.
4. MPC of multivariable processes, dead time problems, choosing the control horizons, MPC and transmission zeros. Practical aspects for implementing multivariable MPC.
5. MPC and constraints: Handling constraints, QP and LP algorithms. Solving the constrained MPC, multi-parametric methods. Constrained and stability in MPC.
6. Nonlinear MPC, parametric models, local based function models, optimization methods.
7. Stability and robustness in MPC: Stability guaranteed MPCs, robust stability for MPC, robust constraint satisfaction, Min-max MPC.
8. Open issues: multi-objective MPC, MPC of hybrid systems, the tracking problem in MPC, distributed and hierarchical MPC, cooperative MPC.
9. MPC application to a solar power plant: plant models, MPC and intraday market, MPC and RTO: dynamical optimal set point determination, MPC for set point tracking. Choosing the appropriate models and horizon for each control level.

M7 - STUTT GART **Randomized algorithms for systems, control and networks**
 02/03/2015 – 06/03/2015



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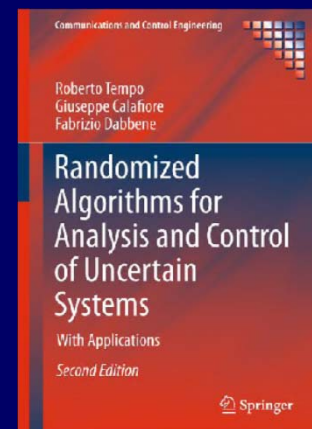
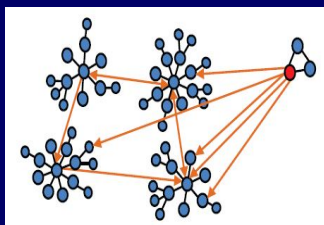
Abstract

In this course, we provide a perspective of the research area of randomization for systems, control and networks. In particular, we study several topics which are of interest when dealing with control of uncertain systems and networks described by graphs.

In these lectures, we demonstrate that randomization is a key tool to handle systems and control problems which can be solved only approximately due to partial or contaminated data, or because only local information about the network is available. Various techniques are developed to construct synchronous and asynchronous sequential algorithms for analysis and design. Convergence and optimality properties of these randomized algorithms are subsequently analyzed.

We also discuss several applications, which include the PageRank computation in the Google search engine, control design of unmanned aerial vehicles, clock synchronization of wireless networks and opinion dynamics in social networks. The course is based on the book by R. Tempo, G. Calafiore, F. Dabbene, "Randomized Algorithms for Analysis and Control of Uncertain Systems, with Applications," 2nd edition, Springer, London, 2013.

- Topics:**
- Uncertain systems, networks and graphs
 - Monte Carlo and Las Vegas algorithms
 - Random sampling techniques
 - Probabilistic methods for control design
 - Distributed randomized algorithms



M8 - ISTANBUL

09/03/2015 – 13/03/2015

Introduction to nonlinear systems analysis and nonlinear feedback control



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Abstract of the course

This is a first course in nonlinear control with the target audience being engineers from multiple disciplines (electrical, mechanical, aerospace, chemical, etc.) and applied mathematicians. The course is suitable for practicing engineers or graduate students who didn't take such introductory course in their programs.

Prerequisites: Undergraduate-level knowledge of differential equations and control systems.

The course is designed around the text book:

H.K. Khalil, Nonlinear Control, Pearson Education, 2015

Outline

1. Introduction and second-order systems (phase portraits; multiple equilibrium points; limit cycles)
2. Stability of equilibrium points (basics concepts; linearization; Lyapunov's method; the invariance principle; region of attraction; time-varying systems)
3. Perturbed systems; ultimate boundedness; input-to-state stability
4. Passivity and input-output stability
5. Stability of feedback systems (passivity theorems; the small-gain theorem; Circle & Popov criteria)
6. Normal and controller forms
7. Stabilization (concepts; linearization; feedback linearization; backstepping; passivity-based control)
8. Robust stabilization (sliding mode Control)
9. Observers (observers with linear-error dynamics; Extended Kalman Filter, high-gain observers)
10. Output feedback stabilization (linearization; passivity-based control; observer-based control; robust stabilization)
11. Tracking & regulation (feedback linearization; sliding mode Control; integral control)

M9 – BERLIN

16/03/2015 – 20/03/2015

Nonlinear control for physical systems

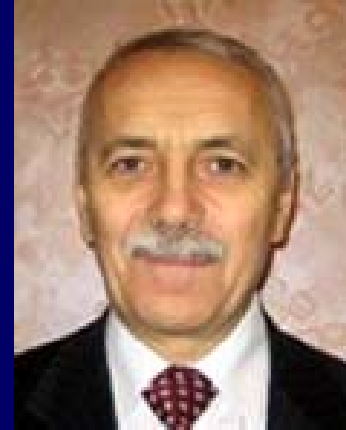


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Abstract of the course

Technological developments have led to a new, exciting and powerful synthesis of physics and control, building on the classical work of notable physicists such as Huygens, Carnot, Szilard, and Kapitza. Examples as diverse as managing electric power grids and optimizing inputs for magnet resonance spectroscopy, noise cancellation and vibration technologies are among topics of current interest. Of course, most of these interesting problems fall well outside the usual linear, quadratic, Gaussian framework.

In this course, the unifying principles coming from the consideration of energy, momentum, and reduction principles will be extended to include control terms. Emphasis will be placed on the role of geometrical ideas such as metrics, symplectic structures, Poisson and Lie brackets, etc., when they serve to best explain matters. Examples will be drawn from cyber-physical systems of current interest and the type of control mechanisms that have proven to be effective in this setting.

Topics will include:

Control of conservative systems; Control of dissipative systems; Synchronization and control of chaos; The Lyapunov-Krasovskii functionals and Demidovich condition; Statistical Mechanics and Learning Theory, Quantum control and Quantum information.

M10 - BELGRADE

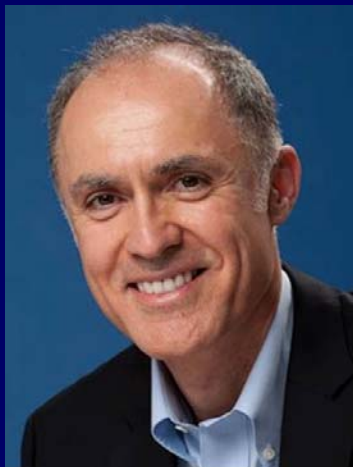
23/03/2015 – 27/03/2015

Extremum seeking

Abstract of the course

Extremum seeking (ES) is a collection of methods for model-free real-time optimization. Invented around 1920 and revived around 2000, ES has witnessed an explosive recent growth in applications and theoretical advances, with about 3,000 new papers over the last dozen years. This course will be based on the instructor's books *Real-Time Optimization by Extremum Seeking* (2003) and *Stochastic Averaging and Stochastic Extremum Seeking* (2012), as well as on various papers.

Topics



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1. History; basic idea; braking application; basic stability proof for single-input and multivariable ES
2. Basic continuous applications of ES: bioreactors, compressors, formation flight, flow control, wind power generation
3. Modification of basic ES: slope seeking, time-varying maps, performance improvement, limit cycles; application to combustion instabilities
4. Discrete-time ES; PID tuning; accelerator beam matching
5. GPS-free source seeking: fully actuated vehicles; tuning of forward velocity; tuning of heading; 3D extension; fish locomotion and scent seeking
6. Newton-based ES; application to solar energy
7. Noncooperative games – Nash equilibrium seeking: finitely many players; continuum of players
8. Stochastic ES: stochastic averaging, bacterial chemotaxis, Newton-based stochastic ES, stochastic Nash seeking
9. ES for finite-time optimal control: analysis for LQ case; accelerator high-voltage converter tuning, laser pulse shaping
10. Minimum seeking: CLF-based model-free nonlinear stabilization; ES with bounded updates; nonholonomic vehicle application
11. Delay compensation for ES

M11 – PARIS-SACLAY

23/03/2015 – 27/03/2015

Feedback control of quantum systems



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Alain Sarlette

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Abstract of the course

Quantum control is an emerging research subject with an increasing role in technologies related to high precision metrology, quantum information and communication. Its development requires to reconsider how measurement, control, and interactions fundamentally affect a system --- in particular, the intrinsic invasive character of measurements. This course presents some modern tools for controlling quantum systems, i.e. steering a system to a quantum state and stabilizing it against decoherence (dissipation of quantum information through the coupling of the system to its uncontrolled environment). These tools will be illustrated by recent feedback experiments in cavity and circuit quantum electrodynamics. The context throughout is that of systems of ordinary and stochastic differential equations and the level will be that of a graduate course intended for a general control audience without any prerequisites in quantum mechanics.

Topics:

1. Introduction to quantum mechanics based on the two-level system (quantum bit) and the harmonic oscillator.
2. Different dynamical models: Markov chains, Kraus maps, quantum stochastic master equations and Lindblad differential equations.
3. Stabilization scheme relying on measurement-based feedback and Lyapunov techniques.
4. Stabilization scheme relying on dissipation engineering and coherent feedback..

M12 – PARIS-SACLAY

30/03/2015 – 03/04/2015

Local methods

for nonlinear systems and control



Rodolphe Sepulchre

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Linear modeling is both the success and the limitation of engineering: local methods are analytically and computationally efficient but a thousand linearized models do not necessarily account for a global phenomenon. The course will present a theory of non-local phenomena that can be analyzed by means of local methods, with the aim of enlarging the modeling and design principles of nonlinear control science. The emphasis will be on the role of symmetry and feedback in “localizing” architectures.

Topics

Lecture 1: **Local and global analysis.**

The principle of linearization. Review of local and global analysis methods. Motivations for local methods in global analysis.

Lecture 2: **The line, the half-line, and the circle.**

Nonlinear spaces that possess efficient linearizations. Elements of differential geometry and Lie group theory.

Lecture 3: **Local calculus made non-local.**

Averaging, filtering, and interpolating in nonlinear spaces.

Lecture 4: **Zooming in and zooming out.**

A feedback principle of localization and an architecture for multiresolution behaviors

Lecture 5: **Local rulers of non-local dynamical behaviors**

Sensitivity analysis of switches and clocks. Elements of singularity theory.

Lecture 6: **The power of linearization**

Nonlinear behaviors that possess informative linearizations

M13 – PARIS-SACLAY

06/04/2015 – 11/04/2015

Sliding mode control and observation

Abstract of the course



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The sliding mode methodology has been proved to be effective in dealing with complex dynamical systems affected by disturbances, uncertainties and un-modelled dynamics. Robust controllers can be developed exploiting the well known insensitivity properties of sliding modes to so-called matched uncertainties. These robustness properties have also been exploited in the development of nonlinear observers for state and unknown input estimation. In conventional sliding modes a 'switching function' (typically an algebraic function of the states) is forced to zero in finite time and maintained at zero for all subsequent time. However, more recently so-called higher-order sliding modes have been developed to force the switching function and a number of its time derivatives to zero in finite time.

The course will begin with an introduction to conventional sliding modes - typically for uncertain linear systems and will demonstrate the properties exhibited by sliding mode controllers and observers. The course will then examine more recent developments in terms of higher-order sliding modes - particularly 2nd order sliding modes. Throughout the course a number of practical engineering examples will be considered to demonstrate the features and advantages of using sliding modes. The results of implementations of these ideas will be presented and discussed. In addition several detailed case studies will be presented demonstrating the use of sliding mode ideas for fault detection and fault tolerant control in aerospace systems.

Topics will include:

- a motivating overview of sliding modes and their properties
- conventional sliding mode controllers and their design for uncertain linear systems
- conventional sliding mode observers and their properties
- 2nd order sliding mode controllers and observers
- general higher-order controllers and differentiators
- sliding modes for fault detection and fault tolerant control
- aerospace case studies

M14 – PARIS-SACLAY

13/04/2015 – 18/04/2015

Attractive ellipsoid method in robust nonlinear control

Abstract of the course

This course introduces a newly developed robust-control design technique for a wide class of continuous-time nonlinear dynamical systems. Along with a coherent introduction to the proposed control design and related topics, nonlinear affine control systems in the presence of model uncertainties and external bounded perturbations are studied. Linear-style feedback control synthesis is discussed. The development and physical implementation of high-performance robust-feedback controllers that work in the absence of complete model information is addressed, with numerous examples to illustrate how to apply the Attractive Ellipsoid Method (AEM) to mechanical and electromechanical systems. While theorems are proved systematically, the emphasis is on understanding and applying the theory to real-world situations.



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Outline

1. Mathematical background: LMI's, the Schur's compliment, S-procedure, Quasi-Lipschits nonlinearities.
2. Linear Differential inequalities, Zone-convergence and practical stability.
3. Robust feedback design: state, output observer-based and k -order dynamic feedbacks.
4. Robust control with sample-data output quantizing measurements.
5. Feedback design for implicit systems.
6. AEM in Sliding Mode Control.
7. Robust stabilization of time-delay systems.
8. Feedback controllers for switched systems.
9. Design of bounded robust controllers.
10. Adaptive version of robust feedbacks.

M15 – ISTANBUL

13/04/2015 – 18/04/2015

**Advances in feedback design
for MIMO nonlinear systems**



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Abstract of the course

The control of multi-input multi-output (MIMO) nonlinear systems is a problem of major practical relevance. However, despite of a consistent corpus of results concerning the internal structure such systems, design methods are still at an early stage of development. The extension of design methods developed for single-input single-output (SISO) is relatively trivial if the system has a well-defined 'vector relative degree' and possesses a well-defined global 'normal form'. However, if the system is only 'invertible', from an input-output viewpoint (which is known to be a property that does not require the existence of a vector relative degree), or does not possess a normal form (which is the generic case, since the existence of such form requires certain vector fields to commute) systematic methods for (robust) global stabilization and/or asymptotic rejection of exogenous disturbances are not available. The purpose of these lectures is to present recent advances in the design of feedback laws for such broader classes of MIMO nonlinear systems.

The course will begin with a review of the property of invertibility, of the so-called structure algorithm, of the zero-dynamics algorithms and of the special version of such algorithms for systems that are input-output linearizable. Then, the issue of characterizing in coordinate free-terms the property that the inverse system is input-to-state stable is addressed. This makes it possible to develop robust (and coordinate free) design methods for asymptotic stabilization and disturbance rejection via partial-state and/or observer-based output feedback. In this setting, it also is show how the notion of 'extended observer' can be used in order to cope with uncertainties in the so-called 'high-frequency gain matrix'.

Topics will include:

- a motivating example: an invertible MIMO system that does not have a vector relative degree
- review of the structure algorithm for system inversion
- input-output linearizable systems
- a coordinate-free characterization of 'strongly minimum-phase' systems
- stabilization via partial-state feedback
- high-gain partial-state observers
- performance recovery via extended observers
- asymptotic rejection of exogenous disturbances

M16 – ST PETERSBURG

20/04/2015 – 25/04/2015

Time-delay systems:

Lyapunov functional and matrices

Abstract of the course

In this course we consider the class of retarded type linear systems with one delay. We introduce the fundamental matrix of such a system, and provide an explicit expression for the solution of an initial value problem. Exponential stability conditions both in terms of characteristic eigenvalues of the system, and in terms of Lyapunov functionals are presented. The general scheme for the computation of quadratic functionals with prescribed time derivatives along the solutions of the time-delay system is explained in detail. It is demonstrated that these functionals are defined by special Lyapunov matrices. The matrices are natural counterpart of the classical Lyapunov matrices that appear in the computation of a Lyapunov quadratic forms for a delay free linear system. A substantial part of the course is devoted to analysis of basic properties of the Lyapunov matrices. Then, Lyapunov complete type functionals that admit various quadratic lower and upper bounds are introduced. Finally, we make use of the complete type functionals in order to derive exponential estimates of the solutions of time- delay systems, robustness bounds for perturbed systems, evaluation of quadratic performance indices.

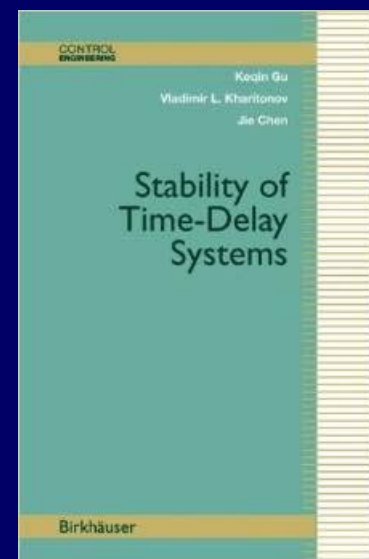


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Topics :

1. Linear time-delay systems: fundamental matrix, Cauchy formula, characteristic function, stability conditions;
2. Lyapunov functionals with a prescribed time derivative;
3. Lyapunov matrices for time-delay systems: definition, basic properties, existence and uniqueness;
4. Complete type functionals: definition, upper and lower quadratic bounds;
5. Application of the complete type functionals.

M17 – GRENOBLE

27/04/2015 – 31/04/2015

Distributed Control



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Abstract of the course

Over the past decade there has been growing in interest in distributed control problems of all types. Among these are consensus problems including flocking and distributed averaging, the multiagent rendezvous problem, and the distributed control of multi-agent formations. The aim of these lectures is to explain what these problems are and to discuss their solutions. Related concepts from spectral graph theory, rigid graph theory, nonhomogeneous Markov chain theory, stability theory, and linear system theory will be covered. Among the topics discussed are the following.

Flocking: We will present graph-theoretic results appropriate to the analysis of a variety of consensus problems cast in dynamically changing environments. The concepts of rooted, strongly rooted, and neighbor -shared graphs will be defined, and conditions will be derived for compositions of sequences of directed graphs to be of these types. As an illustration of the use of the concepts covered, graph theoretic conditions will be derived which address the convergence question for the widely studied flocking problem in which there are measurement delays, asynchronous events, or a group leader.

Distributed Averaging: By the distributed averaging problem is meant the problem of computing the average value of a set of numbers possessed by the agents in a distributed network using only communication between neighboring agents. We will discuss a variety of double linear iterations and deadlock-free, deterministic gossiping protocols for doing distributed averaging.

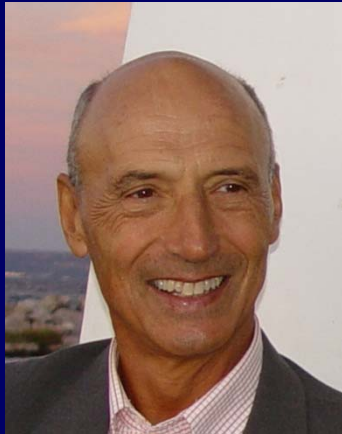
Formation Control: We will review recent results concerned with the maintenance of formations of mobile autonomous agents {eg robots} based on the idea of a rigid framework. We will talk briefly about certain classes of “directed” rigid formations for which there is a moderately complete methodology. We will describe recently devised potential function based gradient laws for asymptotically stabilizing “undirected” rigid formations and we will illustrate and explain what happens when neighboring agents using such gradient laws have slightly different understandings of what the desired distance between them is suppose to be.

Topics will include:

1. Flocking and consensus
2. Distributed averaging via broadcasting
3. Gossiping and double linear iterations
4. Multi-agent rendezvous
5. Control of formations
6. Convergence rates
7. Asynchronous behavior
8. Consensus-based approach to solving a linear equation
9. Stochastic matrices, graph composition, rigid graphsperformance recovery via

M17 - GRENOBLE**Identification in closed loop operation and controller reduction**

04/05/2015 – 07/05/2015



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Abstract of the course

System identification in closed loop operation has known a very important development in the recent years. This development has been driven on one hand by the frequent practical requirement for system identification in closed loop (either because the system is unstable or have important drift in open loop operation or because a controller exists already) and on the other hand by the important discovery, that models for control design identified in closed loop are in general better than those identified in open loop (provided that appropriate algorithms are used). Identification in closed loop is also a very useful tool for controller reduction.

In this course the basic principles, the algorithms and their properties as well as the full methodology for identification in closed loop operation and controller reduction will be covered. The presentation will be made in connection with a number of applications and bench tests located at GIPSA-LAB Grenoble.

Topics:

<ul style="list-style-type: none"> - Identification in closed loop. Why? - Review of identification in open loop - Review of robust digital control - Algorithms for identification in closed loop - Validation of models identified in closed loop - Iterative identification in closed loop and controller re-design - Experimental results (flexible transmission, active suspension) 	<ul style="list-style-type: none"> - Reduction of the controller complexity. Why? - Direct controller reduction by identification in closed loop - Basic schemes and algorithms - Properties of reduced order controllers - Coherence of identification in closed loop and direct controller reduction - Experimental results (active suspension system, flexible transmission)
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M19 - ISTANBUL

04/05/2015 – 08/05/2015

Modeling and control of multiphysics systems



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Dimitri Jeltsema

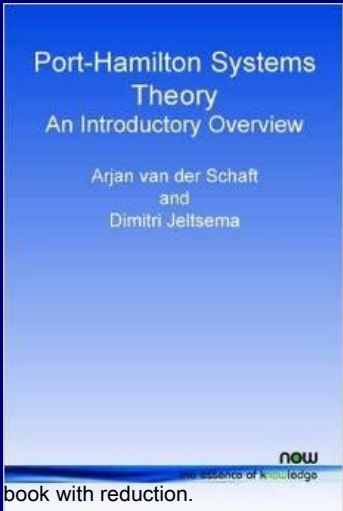
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Abstract of the course

This course presents a variety of modeling techniques that uses energy as a starting point. Apart from the fact that energy is a fundamental concept in physics, there are several motivations for adopting an energy-based perspective in modeling physical systems. First, since a physical system can be viewed as a set of simpler subsystems that exchange energy among themselves and the environment, it is common to view dynamical systems as energy-transformation devices. Secondly, energy is neither allied to a particular physical domain nor restricted to linear elements and systems. In fact, energies from different domains can be combined simply by adding up the individual energy contributions. Thirdly, energy can serve as a lingua franca to facilitate communication among scientists and engineers from different fields. Lastly, the role of energy and the interconnections between subsystems provide the basis for various control strategies.

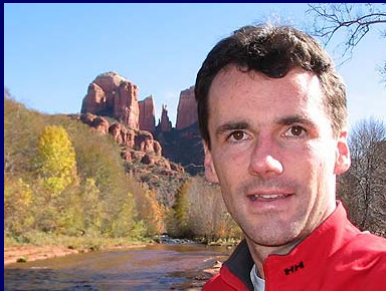
Topics: First we start with the basic concepts of port-based network modeling, where complex lumped-parameter multiphysics systems are systematically modeled as networks of ideal components linked by energy-flow. We show how this immediately leads to a differential equation representation that is in generalized Hamiltonian form, including the standard conservative Hamiltonian systems based on the exchange of energy between different energy storages; e.g., in the mechanical domain between potential and kinetic energy.

Furthermore, we discuss how the port-Hamiltonian representation leads to other useful representations such as the Brayton-Moser equations. We show how port-Hamiltonian models not only reflect the energy flow in the system, but also capture the other basic physical conservation laws, such as conservation of momentum or charge. This will be amply illustrated on a number of applications stemming from mechanics, mechatronics, hydraulic systems, MEMS, and power systems. We also show how distributed-parameter (partial-differential equation) components are incorporated in this broadly applicable modeling approach to nonlinear multi-physics systems.



M20 – PARIS-SACLAY
11/05/2015 – 15/05/2015

**Hybrid systems: modeling, stability, robustness,
and the math behind it**



Rafal K. Goebel

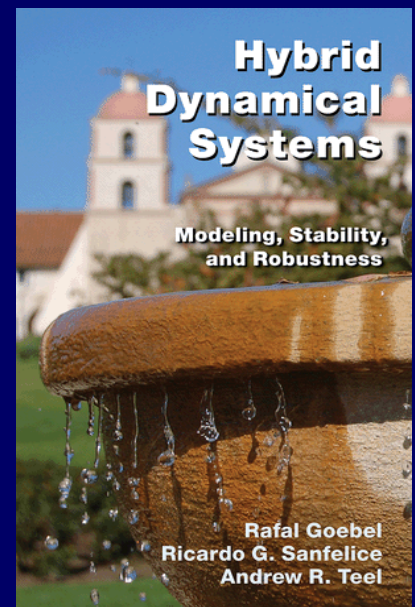
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Course Summary: The course is an introduction to hybrid inclusions, a framework for modeling and analysis of hybrid dynamical systems. Hybrid dynamical systems exhibit features typical of continuous-time dynamical systems and of discrete-time dynamical systems. They are ubiquitous in applications where mechanical systems meet digital and logic-based controllers, where impacts and switching occurs, etc. Hybrid inclusions model such dynamical systems with a combination of differential equations or inclusions, of difference equations or inclusions, and of constraints on the continuous or instantaneous change. The hybrid inclusions framework has a broad modeling power and, despite this, admits an elegant asymptotic stability theory that resembles what a control student is used to. The modern mathematical tools that make this work include elements of set-valued analysis, differential inclusions theory, generalized concepts of convergence, etc.

Outline:

- Modeling hybrid dynamical behavior with hybrid inclusions.
- Solutions to hybrid inclusions, their existence and dependence on initial conditions and perturbations.
- Sensitivity to perturbations and its relation to multi-valued dynamics.
- Asymptotic stability theory for hybrid inclusions: necessary and sufficient Lyapunov conditions, invariance principles, uniformity of convergence, robustness, etc.
- Elements of set-valued analysis: set convergence, set-valued mappings, graphical convergence, etc.

*The course is based on the book "Hybrid Dynamical Systems: Modeling, Stability, and Robustness" by Goebel, Sanfelice, and Teel. A natural continuation of this course is the course "Hybrid Feedback Control Systems: Analysis and Design" by R. Sanfelice, taught as **module M21 in the following week.***



M21 – PARIS-SACLAY
 18/05/2015 – 22/05/2015

**Hybrid feedback control systems :
 analysis and design**



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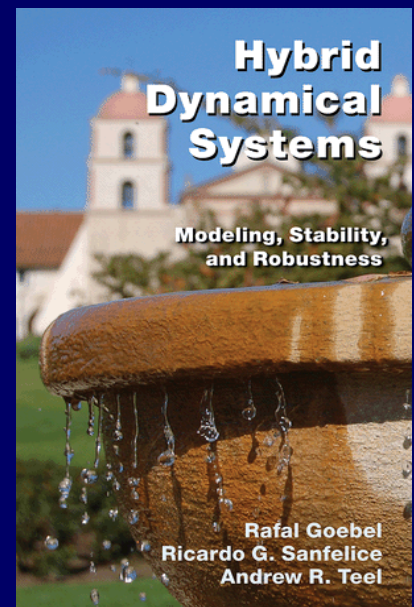
Course Summary: Hybrid control systems arise from controlling nonlinear systems with hybrid control algorithms - algorithms that involve logic variables, timers, computer program, and in general, states experiencing jumps at certain events – and also from controlling systems that are themselves hybrid, such as computer networks, power systems, and nonsmooth mechanical systems. Recent techno-logical advances allowing for and utilizing the interplay between digital systems with the analog world (e.g., embedded computers, sensor networks, etc.) have increased the demand for a theory applicable to the resulting systems, which are of hybrid nature, and for design techniques that may guarantee, through hybrid control, performance, safety, and recovery specifications even in the presence of uncertainty. This course presents recent advances in the analysis and design of hybrid control systems from a control theory viewpoint.

Outline:

- Modeling of hybrid control systems with hybrid inclusions.
- Solutions to hybrid inclusions with inputs and their interconnections.
- Input/output stability notions.
- Control Lyapunov functions.
- Minimum-norm control.
- Tracking control.
- Passivity-based control.
- Backstepping..

The power of hybrid feedback control for robust stabilization will be displayed in several applications including power systems, robotic networks, underactuated rigid bodies, integrate-and-re oscillators, neurons, and genetic networks.

This course is a natural follow-up to the introductory course on hybrid dynamical systems, to be taught in the preceding week by R. Goebel as module M20. Similar introductory courses have been offered through EECI and HYCON previously by A.R. Teel in 2010 and R.G. Sanfelice in 2011, 2013, and 2014.





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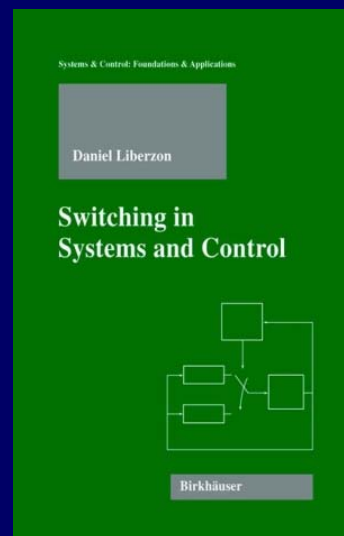
Abstract of the course:

Switched systems are dynamical systems described by a family of continuous-time systems and a rule that orchestrates the switching between them. Such systems are interesting objects for theoretical study and provide realistic models suitable for many applications.

This course will examine switched systems from a control-theoretic perspective. The main focus will be on stability analysis and control synthesis of systems that combine continuous dynamics with switching events. In the analysis part of the course, we will develop stability theory for switched systems; properties beyond traditional stability, such as invertibility and input-to-state stability, will also be discussed. In the synthesis part, we will investigate several important classes of control problems for which the logic-based switching paradigm emerges as a natural solution.

Topics include:

- Single and multiple Lyapunov functions
- Stability criteria based on commutation relations
- Stability under slow switching
- Switched systems with inputs and outputs
- Control of nonholonomic systems
- Quantized feedback control
- Switching adaptive control



M23 – PARIS-SACLAY
01/06/2015-05/06/2015

***Predictive and optimization based control for
automotive and aerospace applications***



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Ilya Kolmanovsky

The University of Michigan, USA
www.engin.umich.edu/aero/people/faculty/ilya-kolmanovsky
ilya@umich.edu

Abstract of the course

This course will focus on predictive and optimization-based control for constrained systems, and its applications to automotive and aerospace systems. The fundamentals of optimization and optimal control, Model Predictive Control and constrained control will be reviewed with the focus on the theory and computations. Ancillary schemes needed for controller implementation such as state estimators and disturbance input observers will be introduced. Several automotive and aerospace applications will be considered in detail with the introduction to the underlying technologies, system modeling, constrained control design and experimental implementation.

The topics covered will include:

1. Optimization and optimal control
2. Model Predictive Control: theory and computations
3. Governor schemes for constrained control
4. Applications to automotive gasoline and diesel engine control
5. Applications to Hybrid Electric Vehicles energy management
6. Applications to control of vehicle dynamics
7. Limit protection in aircraft gas turbine engines
8. Applications to spacecraft rendezvous and docking
9. Applications to spacecraft attitude control
10. Advanced topics in automotive and aerospace control – as time permits

M24 – PARIS-SACLAY

08/06/2015 – 12/06/2015

Networked control with limited data rates



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Abstract of the course

In modern control systems, components such as sensors, controllers and actuators are often connected to one another by digital channels of finite communication capacity. At their limits of performance, such systems exhibit important properties that can be understood only by examining their control and communication aspects jointly.

This course introduces some of the main concepts and theoretical results governing the analysis and design of networked control systems with limited data rates, based on techniques from control, quantisation theory, information theory and dynamical systems. No background knowledge is assumed, apart from basic control theory.

Topics will include:

1. Stochastic linear systems controlled via a digital channel – minimal data rates and universal performance bounds via information theory; construction and analysis of stabilising policies that approach minimum rate
2. Nonlinear systems controlled via a digital channel- topological feedback entropy; minimal data rates for set invariance
3. Distributed linear systems connected by a digital network - network information theory; when is information a fluid flow; conditions for system stability
4. An introduction to nonstochastic information and directed nonstochastic information for worst-case estimation and control.