European Embedded Control Institute

EECI-HYCON2 Graduate School on Control

www.eeci-institute.eu/GSC2011

Spring 2011

15 INDEPENDENT MODULES *– one 21 hours module per week (3 ECTS)*

Lectures taught in English

Deadline for ADVANCE REGISTRATION to each module: 21/12/2010

Location: Supelec (South of Paris)

M1 17/01/2011 - 21/01/2011	*Flatness and Nonlinear Estimation Techniques*	**Michel Fliess**
M2 24/01/2011 - 28/01/2011	*Controlled Synchronisation of Dynamical Systems*	**Antonio Loria / Elena Panteley**
M3 31/01/2011 – 04/02/2011	*The Behavioral Approach to Modeling and Control*	**Harry L. Trentelman / Paolo Rapisarda**
M4 07/02/2011 – 11/02/2011	*LMI, Optimization and Polynomial Methods*	**Didier Henrion**
M5 14/02/2011 – 18/02/2011	*Optimization on Matrix Manifolds*	**Rodolphe Sepulchre / Pierre Antoine Absil**
M6 21/02/2011 – 25/02/2011	*Cooperative Navigation and Control of Multiple Robotic Vehicles*	**Antonio M. Pascoal / Antonio P. Aguiar**
M7 28/02/2011 - 04/03/2011	*Normal Forms for Nonlinear Control Systems*	**Witold Respondek**
M8 07/03/2011 – 11/03/2011	*High-Gain Observers in Nonlinear Feedback Control*	**Hassan Khalil**
M9 14/03/2011 – 18/03/2011	*An Introduction to Networked Control Systems*	**Karl Henrik Johansson / Vijay Gupta**
M10 21/03/2011 – 25/03/2011	*Specification, Design and Verification of Distributed Embedded Systems*	**Richard Murray / Ufuk Topcu**
M11 28/03/2011 – 01/04/2011	*Modeling and analysis of biological networks*	**Mustafa Khammash**
M12 04/04/2011 - 08/04/2011	*Control of Highly Nonlinear Systems*	**Claude Samson / Pascal Morin**
M13 26/04/2011 - 29/04/2011	*Model Predictive Control*	**Eduardo F. Camacho**
M14 02/05/2011 – 06/05/2011	*Robust Hybrid Control Systems*	**Ricardo G. Sanfelice**
M15 09/05/2011 – 13/05/2011	*Optimality, Stabilization, and Feedback in Nonlinear Control*	**Francis Clarke**

M1 17/01/2011 - 21/01/2011	*Flatness and* *Nonlinear Estimation Techniques*

Michel Fliess
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Abstract of the course:

Flat non-linear systems, which were introduced at the beginning of the 90s, provide a most efficient tool for the model-based control of many concrete finite-dimensional case-studies. This approach to nonlinear systems, which is now quite popular in industry, is taught here by revisiting the classic concept of *controllability via an algebraic setting which introduces modules over rings, resp.* differential fields, for linear, resp. nonlinear, systems. The same algebraic tools allow to revisit the concept of *observability and therefore to define also in a clearcut manner the notions of parameter* identifiability and of fault diagnosis. The corresponding estimators, which solve many pending questions in nonlinear system theory, are derived from a powerful numerical derivation of noisy signals, which will be analyzed and compared to nonlinear asymptotic observers. Numerous examples will be investigated during the lectures.

M2 24/01/2011 - 28/01/2011	*Controlled Synchronisation of Dynamical Systems*

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Abstract of the course: Synchronisation is the property by which several dynamical systems behave in a coordinated way. Controlled synchronisation is the ability to induce or to destroy synchronisation via an external force i.e., a control input. Study of synchronization is a broad domain of research and development which covers a number of disciplines such as (mathematical) physics, biology, engineering (electrical, electromechanical, electronic), applied mathematics, mechatronics, to mention a few. Two broad paradigms are open: analysis and design. Analysis is about understanding why and how synchronisation happens naturally. In Biology e.g., synchronisation is a phenomenon that appears in flocks of birds and schools of fish which migrate or travel in perfectly coordinated groups; the motion of each individual is synchronised with respect to both its neighbour's and the group itself. In Medicine, recent research and development (analysis and design) is targeted towards models of neuron cells with astonishing applications such as a cure for brain diseases such as Parkinson. Design is about controlling how synchronisation is willed to happen. An important R&D application field is Telecommunications: consider a transmitter which sends information to a receiver. Roughly, the scenario consists in implementing a chaotic transmitter which generates a chaotic signal that serves as carrier for valuable information. A receiver is controlled to mimic the behaviour of the transmitter to recover the encrypted information i.e., it must synchronise with the transmitter. Hence, if the receiver circuit is “tunned” to generate the same chaotic carrier as the transmitter, the data may be recovered by extracting the carrier from the transmitted signal. Controlled synchronisation has enormous impact in other aereas such as vehicle formation: ongoing ship replenishment, teleoperation and more generally, agents consensus: clusters of satellites ...

M3 31/01/2011 – 04/02/2011	*Modeling, analysis and control of dissipative system behaviors*

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Harry L. Trentelman
Univ. of Groningen, NL
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Abstract of the course: The aim of this course is introduce modeling, analysis and control from the behavioral point of view, with special emphasis on dissipative systems.

The behavior of a dynamical system is the set consisting of all time-trajectories allowed by the laws governing the system. To obtain a mathematical description of a behavior, we view a complex system as the interconnection of subsystems, and we describe the subsystems and their interconnection. This procedure yields a model involving, besides the variables of interest, also auxiliary variables describing the interconnections, and comprising higher-order differential equations, often with algebraic constraints among the variables. In the behavioral setting, control is viewed as interconnecting a plant to a controller; thus we accommodate also those situations in which the usual point of view of the controller as a signal processor is not applicable, for example in passive control of mechanical systems. Stabilization and pole placement problems can be formulated concisely and effectively in this framework. A dissipative system is one which dissipates the energy supplied to it from the external world. When considering linear systems, quadratic functionals of the system variables and their derivatives measure the rate of energy supply and the rate of dissipation. The calculus of bilinear and quadratic differential forms provides an effective way of representing these functionals. Optimal- and H_∞- control problems can be formulated elegantly using this calculus.

The course will deal with the topics outlined on this page, and include exercise sessions aimed at familiarizing the attendees with the material illustrated during the lectures.

M4 07/02/2011 – 11/02/2011	*LMI, Optimization and Polynomial Methods*

Didier Henrion
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Fac. Elec. Engr., Czech Tech. Univ in Prague, Czech Rep.
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Abstract of the course: This is a course for graduate students of researchers with a background in linear algebra, convex optimization and some knowledge in linear control systems. The focus in on semidefinite programming (SDP), or linear matrix inequality (LMI) optimization, and its interplay with the problem of moments and semialgebraic geometry in the context of dynamical systems control.

The first part of the course describes fundamental mathematical features of LMIs, startingwith a historical survey. We review the notions of convexity, cones and duality. We classify convex semialgebraic sets that can be represented with LMIs, and we introduce the key notion of lifting variables allowing to represent convex semialgebraic sets as projections of LMIs. Then we show how these ideas can be exploited to provide constructive solutions to nonconvex polynomial optimization problems, including bilinear or polynomial matrix inequalities (PMIs), using a formulation as a primal problem of moments and a dual problem of finding sum-of-squares decomposition of polynomials nonnegative on semialgebraic sets. We also survey numerical and algorithmic aspects and latest software developments.

The second part of the course focuses on systems and control applications of these techniques, first in a classical state-space linear framework, explaining the connection with standard Lyapunov techniques and mainstream robust control techniques from the 1990s, and second in a polynomial framework, insisting on the notion of occupation measures for dynamical systems defined on polynomial vector fields.

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M5
14/02/2011 – 18/02/2011

Optimization on Matrix Manifolds

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Abstract of the course: The recent years have witnessed an increasing interest in the development of efficient optimization algorithms defined on special nonlinear spaces, in particular embedded and quotient matrix manifolds. Applications abound in numerical linear algebra (eigenproblems), statistical analysis (Principal and Independent Component analysis), large-scale optimization (sparse and rank-constrained problems), signal processing (blind source separation, subspace tracking), machine learning (clustering, regression on nonlinear spaces), computer vision (pose estimation), to name a few. Good algorithms result from the combination of insights from differential geometry, optimization and numerical analysis. The purpose of the course is to provide a tutorial introduction to this rich field of applied mathematics with a parsimonious selection of topics in differential geometry and in numerical algebra, and with an illustration of engineering problems where the theory is currently applied. The course will provide the participants with the basic concepts of differential geometry instrumental to algorithmic development. It will illustrate why differential geometry provides a natural foundation for the development of efficient numerical algorithms for many equality-constrained optimization problems. Several well-known optimization techniques, such as steepest descent, conjugate gradients, trust-region and Newton-type methods, are generalized to the manifold setting. A generic development of each of these methods is provided, building upon the geometric material. The participants are then guided through the constructions and computations that turn these geometrically formulated methods into concrete numerical algorithms. The techniques are general and are illustrated on several problems in linear algebra, signal processing, data mining, optimization, computer vision, and statistical analysis. Specific lectures will be devoted to specific applications. Matlab sessions will allow the students to experience the step-by-step implementation of illustrative algorithms. The course material will be based on the freely downloadable monograph "Optimization Algorithms on Matrix Manifolds" (Princeton University Press, 2008).

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M6 21/02/2011 – 25/02/2011	*Cooperative Navigation and Control of Multiple Robotic Vehicles*

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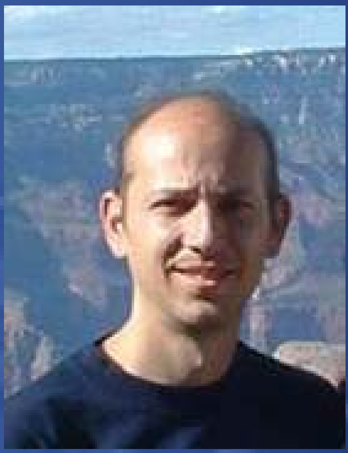
http://welcome.isr.ist.utl.pt/people/index.asp?accao=showpeople&id_people=35



Antonio P. Aguiar
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Abstract of the course: This course focuses on the theme of cooperative control of multiple autonomous vehicles. It is organized around the following themes: 1) Mission scenarios: description of scientific mission scenarios that require the use of multiple autonomous vehicles. 2) Theoretical Foundations: covering a whole spectrum of issues related to vehicle modeling in the presence of environmental disturbances, single vehicle navigation and control, cooperative navigation and control, and networked control in general in the face of stringent communication constraints. 3) Practical Issues: how to go from theory to practice; lessons learned from experiments with real vehicles.

Outline:

1. Introduction: An historical perspective; Practical motivation and mission scenarios
2. Autonomous Vehicles Models: Hovercraft; Autonomous surface craft; Autonomous underwater vehicle; Unmanned aerial vehicle
3. Nonlinear Control theory (a brief review): Lyapunov Stability; Input to state stability; Lyapunov based analysis and design tools
4. Dynamic positioning of autonomous vehicles: Point-stabilization; Positioning in the presence of external disturbances
5. Trajectory-tracking and path-following of autonomous vehicles: Problem statement; Trajectory-tracking controller design; Path-following controller design; Dealing with parametric uncertainty; Performance limitations

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M7
28/02/2011 - 04/03/2011

Normal Forms for Nonlinear Control Systems

Abstract of the course: The aim of this course is to present a fairly complete list of normal forms for various classes of nonlinear control systems. Such forms have been obtained during the last 30 years for various purposes: classification, stabilization, tracking, motion planning, observation etc. We will attempt to present them in a systematic way, by providing normal forms, necessary and sufficient conditions for equivalence to them, and (whenever they exist) algorithmic procedures for obtaining them. We will show usefulness of the presented forms in various nonlinear control problems: linearization, flatness, stabilization, output and trajectory tracking, and nonlinear observers.

Witold Respondek
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Outline:
1. Feedback and state equivalence.
2. Feedback linearizable systems.
3. Globally feedback linearizable systems.
4. Partial feedback linearization.
5. Special classes of control systems.
   5a. Systems on R2
   5b. Locally simple systems.
6. Triangular forms.
   6a. Lower triangular forms and feedback linearizability.
   6b. p-normal forms.
   6c. Upper triangular forms and feedforward systems.
   6d. Linearizable feedforward systems
7. Formal feedback and formal normal forms.
   7a. General systems.
   7b. Feedforward systems.
8. Normal forms for driftless systems
   8a. Chained forms
   8b. Locally simple driftless systems
9. Normal forms for observed dynamics.
10. Nonlinear control systems with observations.
   10a. Local normal forms.
   10b. Global normal forms

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M8 07/03/2011 – 11/03/2011	*High-Gain Observers in Nonlinear Feedback Control*

Hassan Khalil
Dept. Electrical & Computer Engineering
Michigan State University , USA
http://www.egr.msu.edu/~khalil/

Abstract of the course:

The theory of high-gain observers has been developed for about twenty years. In this module, we introduce the theory with emphasis on the peaking phenomenon, the role of control saturation in dealing with it, and the nonlinear separation principle. We present results on the use of high-gain observers in various nonlinear feedback control problems, including stabilization, tracking, regulation, and adaptive control. We examine performance in the presence of measurement noise, sampled-data control, and observers with time-varying and nonlinear gains. We show a connection with the Extended Kalman Filter and present recent results on extended high-gain observers.

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M9 14/03/2011 – 18/03/2011	*An Introduction to Networked Control Systems*

Karl Henrik Johansson
ACCESS Linnaeus Centre
School of Electrical Engineering
KTH, Stockholm, Sweden
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Vijay Gupta
Department of Electrical Engineering
University of Notre Dame, USA
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Abstract of the course:

Networked control systems have emerged as a major research area in recent years as components of a dynamical system have been equipped with processing and communication capabilities. Analysis and design of such systems requires a fusion of tools from various information sciences, such as information theory, control, distributed processing, and so on. This set of lectures will provide an introduction to the theory and tools for building such systems.

Topics:
1. Markov jump linear systems
2. Estimation and control in the presence of delay and packet loss
3. Effects of quantization
4. Information patterns
5. Distributed estimation and sensor fusion
6. Consensus and distributed control
7. Event based control
8. Applications in cooperative control

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M10 21/03/2011 – 25/03/2011	*Specification, Design and Verification of Distributed Embedded Systems*

Richard Murray
California Institute of Technology, USA
http://www.cds.caltech.edu/~murray/wiki/Main_Page

Ufuk Topcu
California Institute of Technology, USA
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Abstract of the course:

Increases in fast and inexpensive computing and communications have enabled a new generation of information-rich control systems that rely on multi-threaded networked execution, distributed optimization, sensor fusion and protocol stacks in increasingly sophisticated ways. This course will provide working knowledge of a collection of methods and tools for specifying, designing and verifying distributed embedded systems. We combine methods from computer science (temporal logic, model checking, synthesis of control protocols) with those from dynamical systems and control (Lyapunov functions, sum-of-squares certificates, receding horizon control) to analyze and design partially asynchronous control protocols for continuous systems. In addition to introducing the mathematical techniques required to formulate problems and prove properties, we also describe a software toolbox that is designed for analyzing and synthesizing hybrid control systems using linear temporal logic and robust performance specifications. The following topics will be covered in the course:

* Transition systems and hybrid I/O automata
* Specification of behavior using linear temporal logic
* Algebraic certificates for continuous and hybrid systems
* Approximation of continuous systems using discrete abstractions
* Verification of (asynchronous) control protocols using model checking
* Receding horizon temporal logic planning

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M11 28/03/2011 – 01/04/2011	*Modeling and analysis of biological networks*

Mustafa Khammash
University of California
at Santa Barbara, USA
http://www.engineering.ucsb.edu/~khammash/

Abstract of the course: Regulation is a running theme throughout biology. At every level of organization, living systems use feedback control strategies to regulate their internal milieu in order to withstand the constant changes in their external environment. In this course we will develop the modeling and analysis tools necessary for exploring regulatory mechanisms in biology. We use these tools to study some examples of intricate biological control mechanisms at the molecular level and at the system level, showing how they achieve robustness and performance and drawing analogies with engineering control systems. We will also highlight some of the unique operating conditions under which biological systems achieve their function. Among these is the ever-present noise at the cellular level.

A key source of this noise is the randomness that characterizes the motion of cellular constituents at the molecular level. Cellular noise not only results in random fluctuations (over time) within individual cells, but it is also a source of phenotypic variability among clonal cellular populations. Researchers are just now beginning to understand that the richness of stochastic phenomena in biology depends directly upon the interactions of dynamics and noise and upon the mechanisms through which these interactions occur. We review a number of approaches for the analysis of stochastic fluctuation in gene expression. We will explore analytical and computational methods for the analysis of stochasticity in living cells, and demonstrate these techniques using examples of gene regulatory networks that suppress or exploit noise.

Tentative syllabus:

- Introduction to gene expression and gene regulatory networks.
- Deterministic vs. stochastic models.
- Mass-action kinetics. Michaelis-Menton kinetics. Reaction rate equations.
- Deterministic modeling at the system and cellular levels.
- Feedback and feedforward strategies.
- Biological oscillations.
- The stochastic chemical kinetics framework.
- A rigorous derivation of the chemical master equation. Moment computations.
- Linear vs. nonlinear propensities.

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M12 04/04/2011 - 08/04/2011	*Control of Highly Nonlinear Systems*

Claude Samson
INRIA, France
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Pascal Morin
INRIA, France

Abstract of the course:

The course in an introduction to the Transverse Function approach recently developed by P. Morin and C. Samson to control nonlinear systems that are locally controllable at equilibria but whose linear approximation is not. Such systems are sometimes referred to as "critical" systems, and the fact that they are not state-feedback linearizable explains in part the difficulty posed by their control. The non-existence of asymptotical stabilizers in the form of continuous pure-state feedback controllers, as pointed out by a Brockett's theorem for a large subclass of critical systems, and the non-existence of "universal" feedbacks capable of stabilizing all feasible state-trajectories asymptotically, as proved in a work by Lizzaraga, are also incentives for the development of control solutions that depart from "classical" nonlinear control theory. The practical stabilization of non-feasible trajectories, a preoccupation little addressed in the control literature, constitutes a complementary incentive. Beyond these theoretical aspects, an important motivation for the control engineer also arises from the fact that many physical systems can be modeled as critical systems. Such is the case, for instance, of nonholonomic mechanical systems (like most mobile vehicles on wheels, ranging from common car-like vehicles to ondulatory wheeled-snake robots) and of many underactuated vehicles (like ships, submarines, hovercrafts, blimps). Asynchronous electrical motors also belong to this category.

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M13 26/04/2011 - 29/04/2011	*Model Predictive Control*

Eduardo F. Camacho

Dpto. Ingeniería de Sistemas y Automática

Escuela Superior de Ingenieros, Sevilla, Spain

http://www.esi2.us.es/~eduardo/home_i.html

Abstract of the course:

Model Predictive Control (MPC) has developed considerably in the last decades both in industry and in academia. This success is due to the fact that Model Predictive Control is perhaps the most general way of posing the control problem in the time domain and its ability to handle constraints and multivariable processes. Although the technique originated in industry, the academic research community has contributed, during the last two decades, important results, specially in the stability domain. Although MPC is considered to be a mature discipline, the field has still many open problems and attracts the attention of many researchers.

This courses provides an extensive review concerning the theoretical and practical aspects of predictive controllers. It describes the most commonly used MPC strategies, especially, showing both the theoretical properties and their practical implementation issues. Topics such as multivariable MPC, constraints handling, stability and robustness properties, fast realizations, tracking, multi-objective, hybrid and stochastic MPC are dealt with in the course.

M14
02/05/2011 – 06/05/2011

Robust Hybrid Control Systems

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& Mechanical Engineering
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Abstract of the course:

Hybrid control systems arise when 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 when controlling systems that are themselves hybrid. Recent technological 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. In the workshop, we will present recent advances in the theory and design of hybrid control systems, with focus on robustness properties. In this course, we will present a general modeling framework for hybrid systems and relevant modern mathematical tools. Next, we will introduce asymptotic stability and its robustness, and describe systematic tools like Lyapunov functions and invariance principles. The power of hybrid control for (robust) stabilization of general nonlinear systems will be displayed in applications including control of robotic manipulators, autonomous vehicles, and juggling systems.

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M15 09/05/2011 – 13/05/2011	*Optimality, Stabilization, and Feedback in Nonlinear Control*

Francis Clarke
Institut Camille Jordan
Université Claude Bernard Lyon 1
http://math.univ-lyon1.fr/~clarke/

Abstract of the course:

This course presents some modern tools for treating truly nonlinear control problems, including nonsmooth calculus and discontinuous feedback. The need for such tools will be motivated, and applications will be made to central issues in optimal and stabilizing control. The context throughout is that of systems of ordinary differential equations, and the level will be that of a graduate course intended for a general control audience.

Topics include:

1. Dynamic optimization: from the calculus of variations to the Pontryagin Maximum Principle
2. Some constructs of nonsmooth analysis, and why we need them
3. Lyapunov functions, classical to modern
4. Discontinuous feedback for stabilization
5. Sliding modes and hybrid systems