2020
International Graduate School on Control

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M01 – MUMBAI
27/01/2020-31/01/2020

From Data to Decisions: the Scenario Approach (Systems, Control, Machine Learning)

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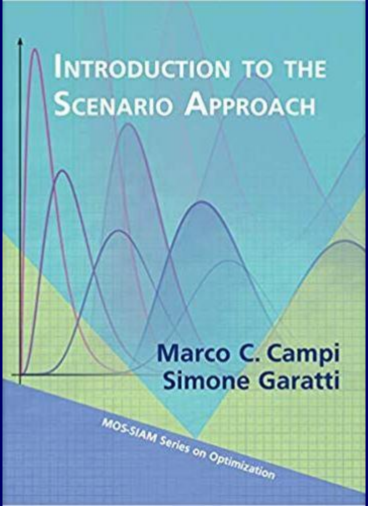
Abstract of the course

Data are pervasive in nowadays science and engineering. In this course, the attendee is introduced to the so-called "scenario approach", an emerging methodology for data-driven decision making. The course provides a broad overview of the topic and also presents the powerful generalization theory underlying this method. The scenario approach can help solve fundamental problems in system design, control and machine learning and various application domains will be also illustrated. A gradual presentation will allow for an easy comprehension of the delivered material.

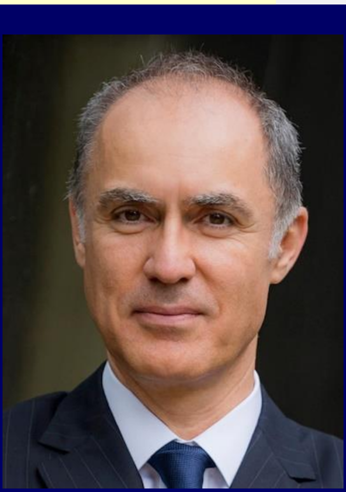


Topics:

- Scenario Approach
- Generalization theory
- Control and system design in the presence of uncertainty
- Supervised Learning
- Discussion of open problems that offer an opportunity for research

M02 – SAN DIEGO
03/02/2020-07/02/2020

Control of PDEs and Nonlinear Delay Systems



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Abstract of the course

In the 1990s, the recursive backstepping design revolutionized robust nonlinear control, enabling stabilization of systems with uncertain nonlinearities unmatched by control and of unlimited growth. In the 2000s, taking the backstepping recursion to the continuous limit produced a similar design methodology for boundary control of PDEs and for delay systems. This course starts with an introduction to control of PDEs based on the book Boundary Control of PDEs: A Course on Backstepping Designs (SIAM, 2008), continues on with a specialization of such control designs to nonlinear delay systems based on the book Nonlinear Control Under Nonconstant Delays (SIAM, 2013), and culminates with control designs for various types of interconnected PDE-ODE systems.

No a priori knowledge on control of delay/PDE systems is required and certain, central notions are reviewed. The practical significance of the methods and concepts is illustrated through various application examples from energy, manufacturing, aerospace, traffic, robotics, and petroleum engineering.

Topics

Lyapunov stability for PDEs; boundary control of parabolic (reaction-advection-diffusion) PDEs; observers with boundary sensing; wave and beam PDEs; first-order hyperbolic (transport-dominated) PDEs; basics of motion planning for PDEs; systems with input delay and predictor feedback; delay robustness of predictor feedback; time-varying input delay; stabilization of nonlinear systems with long input delays; predictor feedback for multi-input delay systems; inverse optimality of predictor feedback; distributed input delays; state- and input-dependent delays; control of interconnected transport/wave PDEs-ODEs; introduction to adaptive control of delay and PDE systems; introduction to control of nonlinear PDEs;

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M03 – EINDHOVEN
10/02/2020-14/02/2020

Networked Control of Multi-Agent Systems

Abstract of the course

Networked control uses the flexibility of digital communication systems to connect arbitrary components on demand, which makes novel control structures possible and poses fundamental research questions: Under what conditions should information be transferred from one control loop to another one? What is the minimum requirement on the communication structure to solve a control problem at hand? Why are certain information structures more favourable than others?

Starting with fundamental notions of algebraic graph theory, the course shows how graph theory and systems theory have to be combined to find networked controllers that make linear agents to synchronise or to follow set-point commands collectively. It presents a novel methodology for the selection of an appropriate communication structure for which all agents react on leader commands as quickly as possible. Furthermore, it shows how the agents can generate an overall system with a reasonable structure based only on their local information, such that the communication structure adapts to disturbances in a self-organised way.

The introduction of the main ideas is illustrated by numerous examples from diverse fields like vehicle platooning, networks of coupled oscillators or electrical power systems. The course participants should solve exercises, partly by using MATLAB, to learn more about the interesting dynamical phenomena that occur in networked systems.

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Topics

- Introduction to networked systems
- Algebraic graph theory
- Consensus in continuous-time and discrete-time systems
- Synchronisation of multi-agent systems with identical and individual dynamics
- Design of the communication structure of networked controllers
- Self-organisation in networked systems

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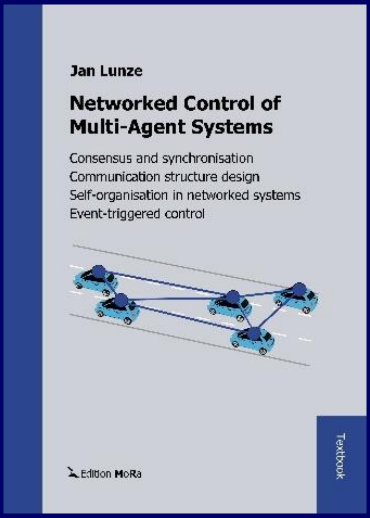
The course uses the **new textbook**

Jan Lunze:
Networked Control of Multi-Agent Systems
BookmundoDirect 2019
ISBN 9789463867139

which provides more than 100 exercises, some of which will be used in the course. Furthermore, the book gives supplementary material on matrix theory, probability theory and MATLAB functions for graphs.



Jan Lunze
Networked Control of Multi-Agent Systems
Consensus and synchronisation
Communication structure design
Self-organisation in networked systems
Event-triggered control
Edition MoRa
Textbook

www.atp.rub.de/Buch/NCS
publish.bookmundo.de/books/176262

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M04 – PARIS-SACLAY
17/02/2020-21/02/2020

Extremum Seeking Control:
Methods, Theory and Applications

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Abstract of the course

Extremum-seeking control (ESC) has grown to become the leading approach to solve real-time optimization problems. Following 20 years of research developments, this strikingly general and practically relevant control approach is now equipped with an established and well understood control theoretical framework. The objective of this course is to provide a detailed introduction to the most recent fundamental developments in this field for researchers, graduate students and practitioners. The focus of the course is on the design of ESC systems using various leading methodologies which include classical perturbation based methods, estimation based methods and Lie-bracket averaging techniques.

The first objective of the course is to present recent contributions to the design of fast ESC systems that can overcome the performance limitations of the classical approaches. The advent of fast techniques have sparked developments in new areas of applications such as distributed optimization, model-free control, observer design and deep learning. The second objective of the course is to present many important generalizations of ESC design techniques. These include the design of ESC for 1) multivariable systems, 2) systems subject to actuator limitations, 3) delay systems, 4) optimal output regulation, and 5) constrained optimization problems. The third objective of the course is to present several emerging applications of ESC in energy systems, biotechnology and power systems.

Outline of the course

1. Basic ESC Loop: Analysis and Performance
   - Perturbation based ESC
   - Estimation based ESC
   - Lie bracket averaging
2. Fast ESC: Methods and Analysis
   - Dual-mode ESC
   - Newton Seeking
3. ESC Generalizations: Challenges and Methods
4. ESC in practice: Applications and Case Studies
5. Beyond ESC: Adaptation and learning

For 2020: A book published by Springer that covers the main topics of the course will be made available to attendees.

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M05 – PARIS-SACLAY
24/02/2020-28/02/2020

Modeling and Control of Nonlinear and Distributed Parameter Systems: the Port Hamiltonian Approach

Abstract: This course presents a system control-oriented approach to modeling, analysis, and control of Non Linear and distributed parameter systems (DPS), i.e., systems governed by non linear ordinary differential equations and/or partial differential equations (PDEs). This class of systems is more and more encountered in control engineering due to the increased use of complex, heterogeneous and smart materials in applications. Analysis and control of this class of systems is thus of high theoretical and practical interest, especially when considering the evolution of computing capacities that allows to deal with very high order systems. The formalism used in this course is the port-Hamiltonian framework. It formalizes the basic interconnection laws together with the power-conserving elements by a geometric (interconnection) structure, and defines the Hamiltonian function as the total energy stored in a system. The aim of this course is to show how this formalism can be advantageously used to study stability and derive simple and physically consistent control laws for the stabilization of non linear and/or linear infinite dimensional systems. The different parts of this course are also illustrated through physical examples such as non linear electro-magnetic systems, transmission lines, beam equations, linearized shallow water equations, Korteweg-de Vries equations, reaction-transport problems including chemical processes, population dynamics, etc.

http://events.femto-st.fr/MCDPS-PHS/en

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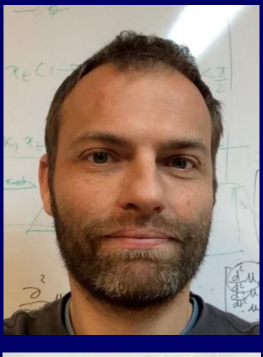

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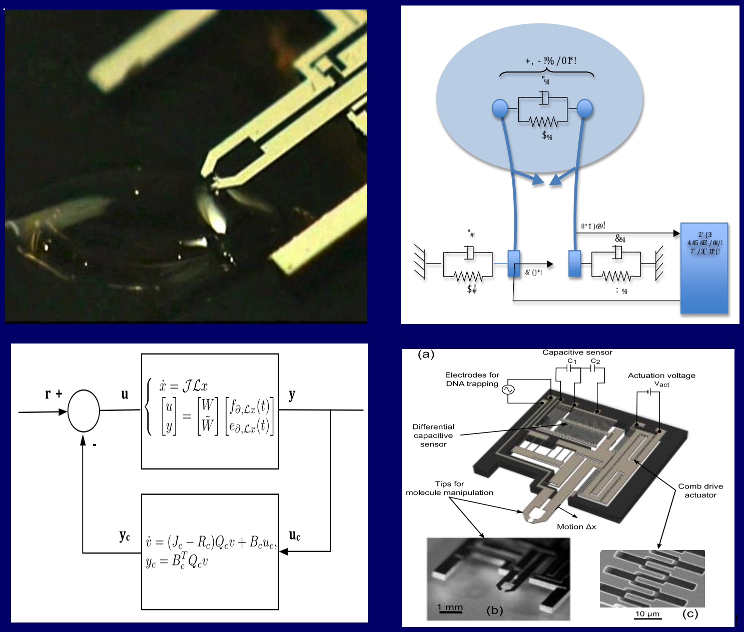

Fig: Modeling, simulation and control of flexible nanotweezers for DNA manipulation

Content: The first part of the course is devoted to geometric modelling of physical systems. It focuses on the derivation of structured models accounting for power exchanges occurring within the system and with its environment. It is shown how passivity and dissipativity can be advantageously used for control design in the non linear finite dimensional case.

The second part focusses on distributed parameter systems. Existence of solutions, boundary control, stability and stabilization of linear port-Hamiltonian systems are studied.
The third part is concerned with some extensions to interconnected systems (ODE+PDE) and numerical tool suitable for control implementation.

The course ends with a tutorial aiming at applying the different concepts on a practical and realistic example in order to illustrate with simulations the interest of such an approach.

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M06 – PARIS-SACLAY
02/03/2020-06/03/2020

Introduction to Nonlinear Systems & Control

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.

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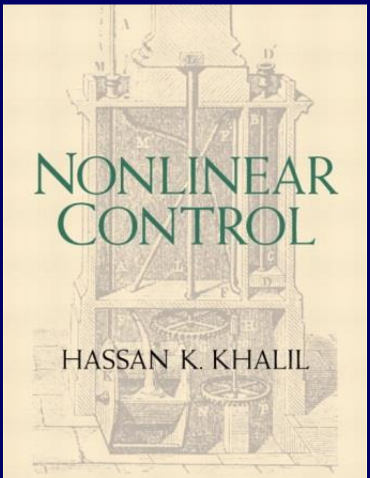

Outline

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

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M07 – ISTANBUL
09/03/2020-13/03/2020

Specification, Design, and Verification of Self-Driving Cars

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Summary 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 control protocols for autonomous systems, including self-driving cars. We combine methods from computer science (temporal logic, model checking, reactive synthesis) with those from control theory (abstraction methods, optimal control, invariants sets) 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, TuLiP, that is designed for analyzing and synthesizing hybrid control systems using temporal logic and robust performance specifications.

Topics

- Automata theory and formal methods for specification, verification, and synthesis
- Specifications of reactive control and decision-making systems using temporal logic
- Approximation of continuous systems using discrete abstractions
- Multi-layer architectures for control of autonomous vehicles
- Synthesis of control protocols, including reactive protocols, probabilistic synthesis, minimum-violation planning, and effects of machine learning-based classification systems
- Verification and testing of (asynchronous) control protocols
- Case studies in autonomous navigation, including two laboratory session covering PRISM, TuLiP

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M08 – PARIS-SACLAY
16/03/2020-20/03/2020

Cyber-Physical and data-driven Systems: Algebraic and Optimization techniques

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Abstract

Modern control systems are more and more complex. Not only are they impacted by increasingly involved and multiple constraints (sustainability, privacy, security, resilence, etc.), they are also subject to the increasingly complex nature of computation technology (embedded, decentralized, hybrid, crowdsourced,…). Such systems are often coined under the name of Cyber-Physical Systems.

Often, these nonidealities make the classical control techniques fail, either because they become poorly efficient, or because they simply do not work in these new environments. The course will survey several advanced techniques to tackle these new challenges. These techniques rely on deep theoretical bases from Mathematics or Computer Science.

We will survey both models and optimization/computation methods, which are well fit to cope with these nonidealities; finally we will see several important applications which exemplify well the introduced methods. An emphasis will be put on open problems and promising challenges for young researchers.

Outline

Models
- Switching systems
- Hybrid automata
- Graphs and Networks in control

Techniques
- LMI's, Sum-of-Squares,
- Tarski's procedure, s-procedure,
- Subgradient methods, Chance-constrained optimization
- Automata theoretic techniques for hybrid systems

Applications
- Analysis of black-box systems
- Wireless Control Networks

LNCIS
Lecture Notes in Control and Information Sciences
385
Raphaël Jungers
The Joint Spectral Radius
Theory and Applications
Springer

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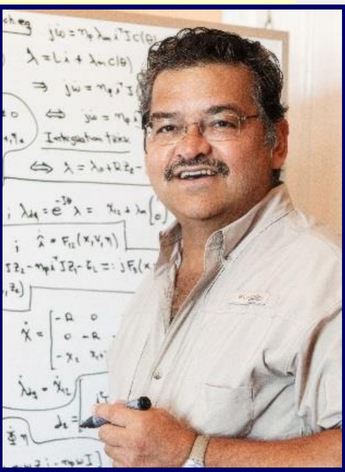
M09 – MONTERREY, MX
23/03/2020-27/03/2020

Energy-Based Control Design to Face the Challenges of Future Power Systems



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Abstract of the course:

The ongoing transition towards low-carbon power systems renders the current fit-and-forget strategy of renewable distributed generation deployment infeasible and challenges today's power system operation paradigms. In particular, modern power systems are characterized by an increasing number of active network elements with heterogeneous dynamics, resulting in complex networks with mutually interacting subsystems, instead of cause-effect, relations. As a consequence, the classical signal processing viewpoint of control, where the system and the controller are closed and isolated signal processors, and the control objectives are also expressed in terms of signals is highly inappropriate to provide the flexibility, modularity and scalability required in future power system operation.

Instead, to face these challenging problems a new control theory, focused on the energy and dissipation properties of the systems, has been developed in the last few years. The main articulating concepts of this new theory are the property of passivity, which is a reformulation of energy conservation, and the formulation of control as an interconnection of energy exchanging dynamical systems. The aim of these lectures is to introduce the basic concepts of this new theory and their application to emerging problems in low-inertia power systems along with their main components, i.e., power converters, motors, generators and alternative energy sources, such as wind power plants and solar panels.

Theoretical topics:

- Euler-Lagrange and port-Hamiltonian models
- Control by interconnection and PID-Passivity-based Control of nonlinear systems
- Adaptive control of nonlinear and nonlinearly parameterized systems

Practical examples:

- Power electronic systems: power converters and power factor compensation for nonlinear loads
- Control of alternative energy generating systems (wind power plants, fuel-cells and PV units)
- Power systems and microgrids: stabilization of low-inertia systems, distributed passivity-based control applications
- Electromechanical systems: sensorless control of motors, doubly-fed induction generators
- Energy management via control by interconnection

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M10 – PARIS-SACLAY
30/03/2020-03/04/2020

Model Predictive Control

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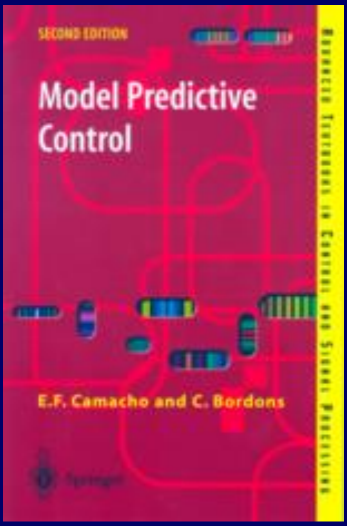
Abstract of the course:

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 courses 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.

M11 – STOCKHOLM
13/04/2020-17/04/2020

Control and Optimization of Autonomous Power Systems

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Abstract of the course

The electric power system is currently undergoing a period of unprecedented changes. Centralized bulk generation based on fossil fuel and interfaced with synchronous machines is substituted by distributed generation based on renewables and interfaced with power converters. Accordingly, the entire operation of power systems is undergoing several major paradigm shifts spanning decentralized device-level control, distributed coordination of energy sources, and real-time system-level optimization. In this course, we give a tutorial introduction to new and emerging thrusts in analysis, control, and optimization of future, smart, and cyber-enabled power systems. The solutions that we present tap into some recent methodological advances in control and optimization, with a focus on scalable and distributed solutions, multi-agent decision problems, feedback control for real-time optimization, (almost) model-free design,

Topics:

- Power system modeling, dynamics, & stability analysis
- Decentralized control of power converters & synchronous generators
- Real-time control of distribution networks and microgrids
- Feedback strategies for power balancing and frequency regulation
- Autonomous power system operation for congestion relief

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M12 – PARIS-SACLAY
20/04/2020-24/04/2020

An Introduction to Financial Markets for the Uninitiated: New Research Directions for Engineers

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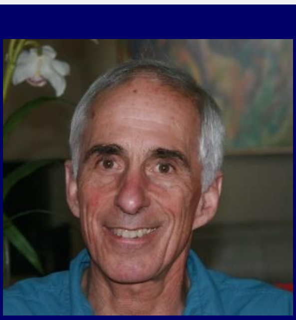

Course Plan: This short course is targeted at graduate students, faculty and other professionals with little or no background in financial engineering. The main topics, stock trading algorithms, modern portfolio theory and options, will be covered with emphasis on applications rather than esoteric mathematics. The highlights of the course will be the Nobel Prize winning ideas of Markowitz, Black, Scholes, Merton and Sharpe. In the discussion surrounding the presentation of course material, many research opportunities, will be described—particularly in areas of control, systems engineering and signal processing as well as optimization and operations research. This will include an introduction to research on algorithmic trading.

Course Topics: View of financial engineering, stock market preliminaries, world markets, stock purchase mechanics, short selling, technical analysis, market psychology, price modelling, geometric Brownian motion, binary lattices, risk-reward and mean-variance considerations, coin flipping as a stepping stone to generation of the feasible set for a portfolio, diversification and portfolio diagrams, the notion of efficiency, the Markowitz theory, the One and Two Fund Theorems, motivation for options, option terminology, the profit-loss diagram, option-price modelling, puts and calls, options as building blocks, straddles, spreads, butterflies, covered calls, iron condors, the Black-Scholes formula, Merton's dividend adjustment, properties of options, arbitrage and related puzzles, course takeaways and conclusions, new research directions for graduate students with interest in financial markets.

Exercises and Matlab Simulations: About one third of the course will be devoted to mastery of the basic skills needed for a graduate student to start working in the area. To this end, afternoons will involve the instructor interacting with students solving application problems often with Monte Carlo methods.

Prerequisites: As far as prerequisites are concerned, only undergraduate basics in calculus, matrix algebra, discrete probability and Matlab are assumed.

Reference Textbook: D. G. Luenberger, Investment Science, second edition, Oxford University Press, 2014.

M13 – PADOVA
20/04/2020-24/04/2020

Distributed Computation and Control

Over the past fifteen years there has been growing in interest in distributed control problems of all types. Among these are consensus problems including flocking and distributed averaging, the multi-agent 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, adaptive control theory, and linear system theory will be covered. Among the topics discussed are the following.

Flocking: Graph-theoretic results will be presented which are 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.

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.

Distributed State Estimation: Despite the longstanding interest in the problem of estimating the state of a distributed linear system, only recently have provably correct estimation algorithms emerged which accomplish this under reasonably non-restrictive assumptions. For time-invariant networks, the estimators are time - invariant linear systems while for time - varying networks, the estimators are hybrid dynamical systems. Conditions will be discussed under which both types of estimators can obtain asymptotically correct state estimates.

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. Asynchronous behavior
7. Consensus-based approach to solving a linear and nonlinear equation
8. Stochastic matrices, graph composition, rigid graphs
9. Distributed state estimation

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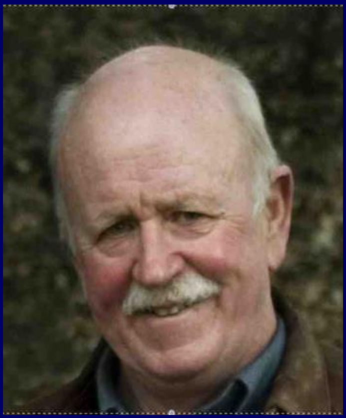
M14 – LONDON
27/04/2020-01/05/2020

Computational Issues in Nonlinear Control and Estimation

Summary of the course

Over the past several decades there has been substantial progress in the development of the theory for control and estimation of nonlinear systems. But implementation of these ideas has lagged behind because of the lack of effective and portable computational tools. Computational nonlinear control is in a similar stage of development that computational linear control was in the early 1980s. At that time there was a well developed theory of linear control and estimation but computational tools lagged behind. Soon after comprehensive tools such as Matlab and Matrix X were developed and put to great use in implementing the linear theory.

Advancements in numerical methods together with the exponential increase in computational power have made it possible to solve complex nonlinear problems. Developing portable and efficient computational algorithms and software tools for nonlinear control and estimation are necessary for the application of the theory. This course will briefly introduce the theoretical methods and then focus on their computational implementation in Matlab or an equivalent language.



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Outline

1. Feedback stabilization of a nonlinear system to an an operating point. Comparison of various methods, feedback linearization, backstepping, optimal stabilization, model predictive control.

2. Lyapunov methods for verifying stability. Checking positivity by sum of squares and other methods.

3. Numerical calculation of optimal trajectories. Indirect and direct methods, pseudospectral methods

4. Trajectory tracking and disturbance rejection. Nonlinear regulation

5. Estimation for nonlinear systems. The unsolvability of the Duncan-Mortenson-Zakai PDE, minimum energy estimation, extended Kalman filtering, unscented Kalman filtering, moving horizon estimation, moderate and high gain observers, particle filters

6. Nonlinear Systems Tool Box. A Matlab toolbox for nonlinear control and estimation.

2020
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M15 – ISTANBUL
27/04/2020-01/05/2020

Stability and Stabilisation of Nonlinear Time-Varying Systems: Applications to Multi-Agent systems

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Abstract of the course:

In common engineering systems it is never possible to reproduce an experiment twice under the same conditions and, therefore, to obtain exactly the same results. Stability theory provides the tools to measure how (un)successful an experiment is, relative to a desired behaviour. For its breadth and rigour, Lyapunov's direct method is one of the pillars of stability theory and control design. However, it is often difficult to employ in concrete engineering problems. Indeed, whether in the context of adaptive control and identification of the most innocuous linear time-invariant plant or in that of tracking control of complex nonlinear systems such as robots or autonomous vehicles, we are often ineluctably confronted to analysing the stability of *nonlinear time-varying* systems. This poses significant challenges to the construction of Lyapunov functions hence, alternative methods to Lyapunov's are most desirable.

In this course, we revise several methods of analysis and design that build upon structural properties of physical systems and we apply them in contemporary control problems in the realm of multi-agent systems. Primarily, we study passivity-based control methods for adaptive and tracking control of electromechanical systems. We also revise trajectory-based methods that rely on the notion of persistency of excitation and we study methods of analysis that lead to separation-principle-based control.

Theoretical topics:

- Revision of notions of stability and robustness
- Passivity-based controlled systems
- Adaptive control of linear and nonlinear systems
- Tracking control and dynamic feedback stabilisation
- Cascades-based (output feedback) control
- Analysis of synchronisation and consensus problems

Practical examples:

- Formation control and synchronisation of multiagent systems
- Adaptive control of Euler-Lagrange systems
- Tracking control and stabilisation of autonomous (nonholonomic) vehicles
- Sensorless control of electromechanical motors

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M16 – MUMBAI
04/05/2020-08/05/2020

Homogeneity Based Design of Sliding Mode Controllers

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The sliding mode methodology has proved to be effective in dealing with complex dynamical systems affected by disturbances, uncertainties and unmodeled dynamics. These robustness properties have also been exploited in the development of nonlinear observers for state and unknown input estimation. In conventional (first-order) sliding modes a “sliding function” (typically an algebraic function of the states) is forced to zero in finite time and maintained at zero for all subsequent time. Recently, higher-order sliding mode controllers have been developed to force the switching function and *a number of its time derivatives* to zero in finite time.

Specific features of the course

Proposed course will present a homogeneity based Lyapunov approach for the design of first-, second- and higher-order Sliding Modes Controllers (SMC), including sliding mode controllers producing continuous control signals, and some of its applications.

Outline of the course

Introduction

- Solutions of equations with discontinuous right hand sides. Finite- and fixed- time convergence
- Homogeneity, weighted homogeneity
- Lyapunov design of first-order sliding modes. Smooth and Lipschitz Lyapunov Functions. Unit Control
- Regular form. Sliding surfaces design
- Lyapunov based redesign
- Integral sliding modes

Lypunov based Second-Oder Sliding Modes Controller (SOSMC) Design

- Lyapunov-based design for twisting and terminal algorithms
- Lyapunov-based design for super-twisting controller

Lyapunov based Higher-Oder Sliding Modes Controllers (HOSMC)

- Lyapunov- based design for HOSMC (continuous and discontinuous)

Gain design for HOSMC. Some Alternatives:

- Nonlinear inequalities
- Pòlya’s theorem
- Sum of Squares method

Sliding Mode Observation and identification

- Lyapunov-based design of arbitrary-order exact differentiators
- HOSM based robust- exact observers
- HOSM based parameter identification
- Output feedback HOSMC

M17– TOULOUSE
11/05/2020-15/05/2020

Sparsity and Big Data in Control, Systems Identification and Machine Learning

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Abstract of the course

One of the hardest challenges faced by the systems community stems from the exponential explosion of data, fueled by recent advances in sensing technology. During the past few years a large research effort has been devoted to developing computationally tractable methods that seek to mitigate the ``curse of dimensionality" by exploiting sparsity.

The goals of this course are:

1) provide a quick introduction to the subject for people in the systems community faced with ``big data" and scaling problems, and

2) serve as a ``quick reference" guide for researchers, summarizing the state of the art .

Part I of the course covers the issue of handling large data sets and sparsity priors in systems identification, model (in)validation and control. presenting recently developed techniques that exploit a deep connection to semi-algebraic geometry, rank minimization and matrix completion.

Part II of the course focuses on applications, including control and filter design subject to information flow constraints, subspace clustering and classification on Riemannian manifolds, and time-series classification, including activity recognition and anomaly detection.

Topics include:

- Review of convex optimization and Linear Matrix Inequalities
- Promoting sparsity via convex optimization. Convex surrogates for cardinality and rank
- Fast algorithms for rank and cardinality minimization
- Fast, scalable algorithms for Semi-Definite Programs that exploit sparsity
- Sparsity in Systems Identification:
  - Identification of LTI systems with missing data and outliers
  - Identification of Switched Linear and Wiener Systems
  - Identification of sparse networks
- Sparsity in Control: Synthesis of controllers subject to information flow constraints
- Connections to Machine Learning: subspace clustering and manifold embedding
- Applications: Time series classification from video data, fault detection, actionalble information extraction from large data sets, nonlinear dimensionality reduction, finding causal interactions in multi-agent systems.

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M18 – SHANGHAI
18/05/2020-22/05/2020

Hybrid Control Design

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Course Overview:

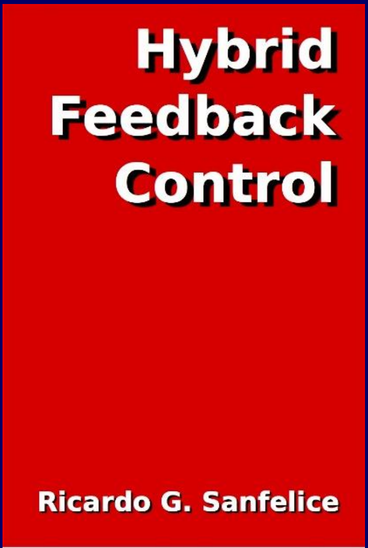
Hybrid dynamical systems, when broadly understood, encompass dynamical systems where states or dynamics can change continuously as well as instantaneously. Hybrid control systems arise when hybrid control algorithms — algorithms which involve logic, timers, clocks, and other digital devices — are applied to classical dynamical systems or systems that are themselves hybrid. Hybrid control may be used for improved performance and robustness properties compared to classical control, and hybrid dynamics may be unavoidable due to the interplay between digital and analog components of a system.

The course has two main parts. The first part presents various modeling approaches to hybrid dynamics, focuses on a particular framework which combines differential equations with difference equations (or inclusions), and present key analysis tools. The ideas are illustrated in several applications. The second part presents control design methods for such rich class of hybrid dynamical systems, such as supervisory control, CLF-based control, invariance-based control, and passivity. A particular goal of the course is to reveal the key steps in carrying over such methodologies to the hybrid dynamics setting. Each proposed module/lecture is designed to present key theoretical concepts as well as applications of hybrid control of current relevance.

Course Outline:

- **Part 1: Introduction, examples, and modeling.**
  - Theoretical topics: hybrid inclusions; solution concept, existence, and uniqueness.
  - Applications: hybrid automata, networked systems, and cyber-physical systems.
- **Part 2: Dynamical properties.**
  - Theoretical topics: continuous dependence of solutions, Lyapunov stability notion and sufficient conditions, invariance principles, and converse theorem.
  - Applications: synchronization of timers and state estimation over a network.
- **Part 3: Supervisory control, uniting control, throw-catch, and event-triggered control.**
  - Theoretical topics: logic-based switching, uniting control, throw-and-catch control, supervisory control, and event-triggered control.
  - Applications: aggressive control for aerial vehicles, control of the pendubot, obstacle avoidance, control of robotic manipulators.
- **Part 4: Synergistic control, CLF-based control, invariance-based control, passivity-based control, and hybrid model predictive control**
  - Theoretical topics: synergistic control, control Lyapunov functions, stabilizability, Sontag-like universal formula for hybrid systems, selection theorems, invariance and invariance-based control, passivity-based control, and hybrid model predictive control.
  - Applications: control for DC/DC conversion and for mechanical systems with impacts.

References available at https://hybrid.soe.ucsc.edu/biblio and upcoming book to appear late 2019.



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M19 – PARIS-SACLAY
25/05/2020-29/05/2020

Time-Delay and Sampled-Data Systems

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Abstract of the course

Time-delay appears naturally in many control systems. It is frequently a source of instability although, in some systems, it may have a stabilizing effect. A time-delay approach to sampled- data control, which models the closed-loop system as continuous-time with delayed input/output, has become popular in networked control systems (where the plant and the controller exchange data via communication network). The beginning of the 21st century can be characterized as the "time-delay boom" leading to numerous important results. The aim of this course is to give an introduction to systems affected by time-delays, in both the linear and the nonlinear framework. The emphasis of the course is on the Lyapunov-based analysis and design for time-delay, sampled-data and networked control systems.

Introduction to Time-Delay Systems

Topics

Models of systems with time-delay and basic theory. Sampled-data and networked-control systems. LTI systems with delay: characteristic equation. Stability and performance analysis. Direct Lyapunov approach: Krasovskii and Razumikhin methods. An LMI approach to stability and performance. Control design: predictor-based control, LQR problem. LMI approach to robust stabilization and H infinity control. Stabilization by using delay. Systems with saturated actuators. Discrete-time delay systems. Sampled-data and networked control systems: a time-delay approach. Nonlinear retarded systems with inputs: basic theory, stability, input-to-state stability. Stabilization by means of control Lyapunov-Krasovskii functionals. Universal stabilizers. Sampled-data stabilization of nonlinear retarded systems.

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M20 – LAUSANNE
01/06/2020-05/06/2020

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 scalable design approaches of local controllers will be also presented, together with applications to microgrids.

Outline:

- Introduction to large-scale systems and multivariable control
- Stability analysis of large-scale systems
- Design of decentralized and distributed controllers for unconstrained systems
- Decentralized and distributed model predictive controllers
- Approaches to the scalable design of control architectures

The course includes MATLAB sessions: students are required to bring their own laptop.

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M21 – MARSEILLE
08/06/2020-12/06/2020

Introduction to Discrete Event Systems

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Course summary:

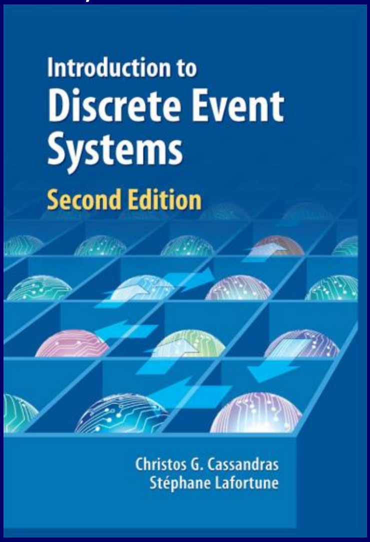
Discrete event systems are dynamic systems with discrete state spaces and event-driven dynamics. They arise when modeling the high-level behavior of cyber-physical systems or when modeling computing and software systems. Discrete event models can be purely logical, or they may include timing and stochastic information. This course will have two parts.

In the first half, we will study logical discrete event systems, focusing primarily on automata models. We will consider estimation, diagnosability, and opacity analysis for partially-observed systems, then supervisory control under full and partial observation. In the second half, we will study the performance analysis, control, and optimization of timed DES, using stochastic timed automata models. We will describe the use of discrete event simulation and review elementary queueing theory and Markov Decision Processes used to study stochastic timed DES. We with then present Perturbation Analysis (PA) theory as a method to control and optimize common performance metrics for DES. Finally, we will explain how to extend DES into Hybrid Systems, limiting ourselves to basic modeling and simple extensions of PA theory.

No prior knowledge of discrete event systems will be assumed. The course will rely on the textbook co-authored by the instructors.

Course outline:

0. Overview of DES and contrast to time-driven systems
1. Introduction to discrete event modeling formalisms
2. Analysis of logical discrete event systems
3. Supervisory control under full and partial observation
4. Timed Models of DES
5. DES (Monte Carlo) computer simulation
6. Review of queueing theory and Markov Decision Processes
7. Perturbation Analysis and Rapid Learning methods
8. From DES to Hybrid Systems



Introduction to
Discrete Event Systems
Second Edition

Christos G. Cassandras
Stéphane Lafortune

2020
International Graduate School on Control

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M22 – LONDON
15/06/2020-19/06/2020

Introduction to Optimal and Stochastic Control

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Abstract of the course

Optimal Control and Stochastic Control are two central topics to control engineering.

- Optimal Control aims at designing feedback laws satisfying a used-selected performance criterion. It relies on the solution of a certain partial differential equation or of a two-point boundary value problem. Since these problems are difficult to solve in general, approximation methods will be discussed and a curse-of-dimensionality-free algorithm will be presented.
- Control of stochastic differential equations (SDEs) has been successfully used in a variety of theoretical and applied scientific fields, such as system biology and finance. One way to view SDEs is to interpret the stochastic processes in the equations as a means to model uncertainty. In this sense, stochastic systems offer a powerful modelling framework for engineering applications. The course will provide an introduction to stochastic control.

The course will initially develop these topics in two independent units which will be merged towards the end of the course.

Outline

- Introduction to Optimal Control (~10.5 hours)

  The aim of this unit is to present the basic tools for the solution of classes of nonlinear optimal control problems. We will then discuss minimax problems, problems with constraints and numerical methods for obtaining approximate solutions. We will discuss both the minimum principle and the dynamic programming approach, highlighting the differences between these two approaches and showing that a combination of the two allows to determine approximate solutions to a class of optimal control problems with very limited computational complexity.

- Introduction to Stochastic Control (~10.5 hours)

  This unit will assume no prior knowledge of stochastic control and stochastic differential equations. The aim of the unit is to develop a working knowledge of control of stochastic differential equation. The unit will start by quickly introducing some elements of measure theory and probability which are instrumental for the development of the course. We will then construct the Brownian motion and discuss its relation with white noise. We will then cover the notion of stochastic integral and topics related to SDEs, such as existence and uniqueness of the solution, linear SDEs and simulation of SDEs. We will then cover a selection of advanced topics: various concept of stability and elements of optimal control (connecting with the other unit of the course). Recent research topics, such as stochastic regulation and stochastic zero dynamics, may be covered depending on time.

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M23 – ROME
22/06/2020-26/06/2020

Dynamic Control Allocation

Abstract

Several modern control applications involve a large number of actuators and sensors, typically chosen with the objective of ensuring a certain level of redundancy and reliability. Such a redundancy is a challenge as well as a valuable opportunity for the designer. The aim of this course is to introduce the student to the framework of dynamic control allocation, which constitutes an effective strategy for addressing and tackling such scenarios. In particular, the topics discussed in the course range from the analysis of allocated control schemes (with points of view borrowed from different contexts, such as geometric tools or frequency-domain approaches) to detailed synthesis algorithms (based on advanced hybrid and optimization techniques or viable also in the presence of uncertain systems). Moreover, links to intimately connected topics, such as anti-windup control and the output regulation problem, are introduced and further explored.

Outline

I. Introduction to Dynamic Control Allocation
  1. Motivating examples
  2. Objectives and main assumptions
  3. Characterization of input redundancy

II. Dynamic Control Allocation Framework
  4. Main control scheme
  5. Complementarity with anti-windup techniques
  6. Comparison with static control allocation

III. Structural Insights on Allocated Control Schemes
  7. The geometric control point of view
  8. The frequency-domain approach
  9. Connections with the output regulation problem
  10. Revisiting the key building blocks: annihilators, optimizers and steady-state generators

IV. Advanced Topics
  11. MPC-based strategies and reference governor
  12. Hybrid control allocation for output regulation
  13. Data-driven control allocation
  14. Extensions to nonlinear systems

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M24 – PRAGUE 29/06/2020-03/07/2020	*LMIs for Optimization and Control*

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LMIs, linear matrix inequalities, have been studied extensively since the 1990s in connection with Lyapunov techniques for ensuring stability and performance of linear and nonlinear control systems. This approach to systems control constantly benefits from developments and improvements of efficient interior-point primal-dual algorithms for conic optimization by the mathematical programming community.

Recent achievements of real algebraic geometry have provided powerful results for the representation of positive polynomials as sum-of-squares (SOS) and its dual theory of moment problems. Many difficult nonlinear nonconvex optimization and control problems can now be solved numerically and efficiently by moment-SOS LMI hierarchies, with mathematically sound convergence guarantees and explicit certificates of global optimality. Our public-domain Matlab package GloptiPoly, developed since 2002, implements many of these techniques and ideas.

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

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M25 – BERLIN
06/07/2020-10/07/2020

Robust and Adaptive Output Regulation of Multivariable and Hybrid Systems

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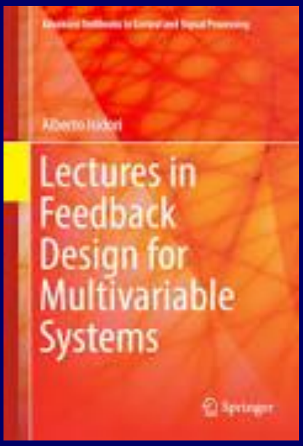
Outline

The problem of output regulation, the design feedback control laws so as to asymptotically track/reject exogenous inputs, is one of the defining problems in control theory. In the case of MIMO linear systems the problem was solved in full generality several decades ago, but only very recently systematic methods for dealing with uncertain exosystems has been developed. In the case of MIMO nonlinear systems, the solution of this problem presumes the availability of methods for feedback stabilization. Only very recently methods for handling such problem have been developed, for broad classes of systems, such as systems that do not have vector relative degree but are only assumed to be right-invertible. These methods require the development of suitable normal forms, the extension of the concept of minimum-phase, the investigation of the relation between right-invertibility and observability and lead to the design of dynamic output-feedback stabilizing laws. Such concepts are instrumental in the solution of the problem of output regulation.

The problem of output regulation has been also extended to the class of systems and exosystems with hybrid dynamics combining continuous-time and discrete-time behaviors. The generalization of the theory to this class of systems necessarily asks for an appropriate extension of key concepts and tools well known for continuous-time systems, such as the concept of steady-state response, of regulator equations and the internal model property. Furthermore, the design of internal models that are robust with respect to system and exosystem uncertainties asks for different adaptive design paradigms.

Topics

1. Adaptive output regulation of MIMO linear systems in the case of uncertain exosystems : an LMI-based approach.
2. Methods for robust feedback stabilization of MIMO nonlinear systems : normal forms for right-invertible systems, observability and observers.
3. Robust output regulation for MIMO nonlinear systems. Pre-processing internal models and post-processing internal models. The concept of robust minimum-phase and its use in the design of regulators.
4. The problem of output regulation for hybrid systems: Hybrid steady state and hybrid regulator equations as main tools.
5. Isolating invisible dynamics and implementing the visible ones in the design of hybrid internal models.
6. The issue of robustness to parametric uncertainties in the system and exosystem.



Alberto Isidori

Lectures in Feedback Design for Multivariable Systems

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