International Graduate School on Control

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M01 – PARIS-SACLAY
15/01/2018-19/01/2018

Nonlinear Model Predictive Control

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Abstract of the course

Model predictive control (MPC), also called receding horizon control, is a very successful modern control technology. Its basic idea is as follows: at each sampling instant, the future behavior of the system is predicted over some finite horizon using some prediction model, and an open-loop optimal control problem is solved to determine the optimal input trajectory over this time horizon. Then, the first part of this optimal input is applied to the system until the next sampling instant, at which the horizon is shifted and the whole procedure is repeated again. The main advantages of MPC and the reasons for its widespread success include (i) guarantees for closed-loop satisfaction of hard input and state constraints, (ii) the possibility to directly include the optimization of some performance criterion in the controller design, and (iii) its applicability to nonlinear systems with possibly multiple inputs.

In recent years, significant progress has been made in establishing various guarantees of nonliner model predictive controllers such as closed-loop stability, robustness, and performance. The goal of this course is to give an introduction to the field of nonlinear model predictive control, covering both basic results as well as current reasearch topics such as economic and distributed MPC. The lectures will be accompanied by programming exercises.

Topics:

- Stability in MPC with terminal constraints
- Stability and performance in MPC without terminal constraints
- Robust MPC
- Economic MPC
- Distributed MPC

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M02 – PARIS-SACLAY 22/01/2018-26/02/2018	***Stability of Switched Linear Systems: Finite and Infinite Dimension***

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Abstract of the course

Switched systems have undergone major developments in the last decades. This course focuses on various stability concepts of linear switched systems, mainly in the continuous time framework. Our point of view puts the emphasis on the interplay between analytic properties of classes of switching rules and stability properties of corresponding linear switched systems. In particular, we address the issues raised by lack of concatenation inherent in many switching mechanisms such as dwell-time, persistent of excitation, etc. We extend these investigations to the probabilistic and infinite-dimensional settings (delay and networks).

The course is designed around the textbook: Y. Chitour, P. Mason and M. Sigalotti ``Dynamics and stability of continuous-time switched linear systems'', online on the webpages of the authors at most late October 2017

Topics

- Definition of linear switched systems (LSS) with discussion of most used classes of switching laws
- Fundamental tools: convexification, long-time approximation, block reduction, Lyapunov and Bohl exponents.
- Measures of stability for LSS: asymptotics of finite-time worst behavior versus infinite-time worst-case analysis, Fenichel's lemma, periodisation.
- Direct and converse Lyapunov techniques: common quadratic Lyapunov functions, converse Lyapunov constructions, universal classes of Lyapunov functions.
- Barabanov norms and applications: existence, extremal trajectories, joint spectral exponent theorem, resonance for marginal instability.
- Restrained switching signals: from common weak quadratic Lyapunovfunction to quasi-Barabanov norms.
- Controllability, observability and minimal realization for switched controlled dynamics.
- Intermittent control and persistence of excitation.
- Characterization of switched controlled dynamics with finite L_2 gain.
- Linear random dynamical systems: generalized pole placement, gap between probabilist and determinist measures of stability.
- Infinite-dimensional LSS: converse Lyapunov theorems, switched controlled dynamics on networks.

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M03 – PARIS-SACLAY 29/01/2018-02/02/2018	***The Scenario Approach for Systems, Control and Machine Learning***

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Abstract of the course

Control is the science of building automatic systems to regulate the behavior of other systems. It finds application to basically all human-created devices. Machine learning is a vast discipline where one learns how to classify new situations based on a record of previous cases. It has application in diverse fields including medicine, engineering and finance. Common to these fields is the need to make designs according to optimality principles. In the course, we shall give an in-depth - and yet gradual - presentation of the so-called "scenario approach", a methodology to do optimization grounded on empirical knowledge. The baseline of this methodology is that one collects previous cases and these are used to make an empirical design, while a powerful theory gives precise guarantees of performance. After presenting the fundamental elements of this theory, we shall show how the scenario approach can help solve problems in systems, control and machine learning.

Topics:

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

M04 – L'AQUILA
05/02/2018-09/02/2018

Time-Delay and Sampled-Data Systems

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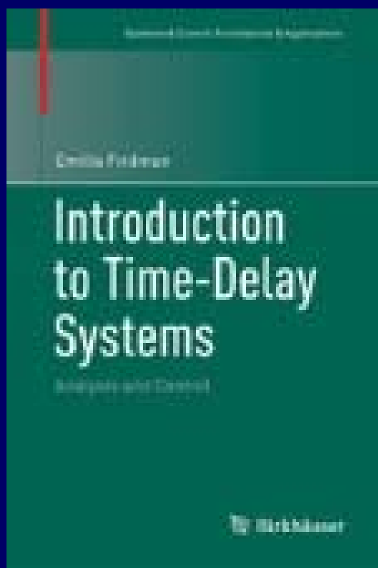
Abstract of the course

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.



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. 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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M05 – PARIS-SACLAY
12/02/2018-16/02/2018

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

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Abstract of the course

This course presents a system control-oriented approach to modeling, analysis, and control of distributed parameter systems (DPS), i.e., systems governed by 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 DPS 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. Well-known in control of nonlinear systems governed by ordinary differential equations, this formalism based on the notion of energy and power exchanges has been extended to distributed parameter systems. The aim of this course is to show how this formalism can be advantageously used to study stability and derive simple (boundary) control laws for the stabilization of un-(or weakly) damped (linear) distributed parameter systems

Topics

The first part of the course is devoted to modelling. More precisely, it focuses on the derivation of structured models accounting for power exchanges occurring within the system and with its environment. In the second part, existence of solutions, boundary control and stability of linear port-Hamiltonian systems are studied. The third part is concerned with control design. 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. The different parts of this course are also illustrated through physical examples such as transmission lines, beam equations, linearized shallow water equations, Korteweg-de Vries equations, reaction-transport problems including chemical processes, population dynamics, etc.

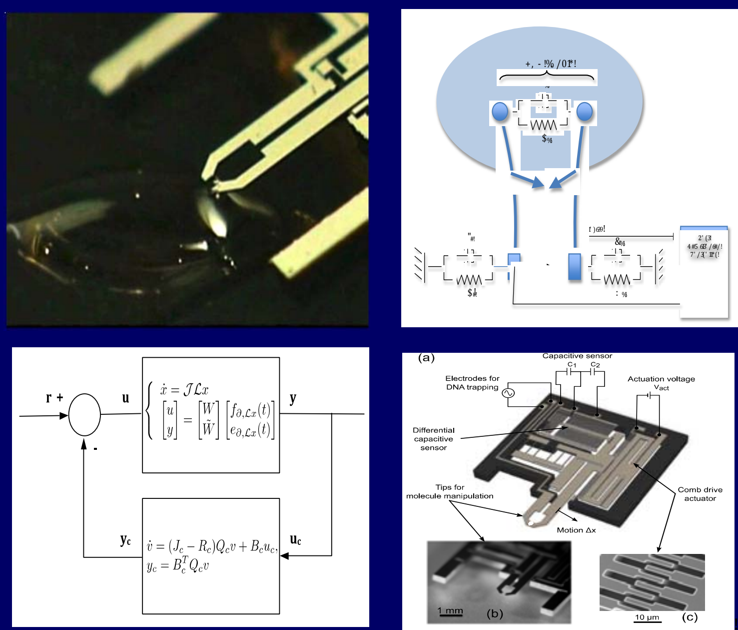

Fig: *Modeling, simulation and control of flexible nanotweezers for DNA manipulation*

Target audience

This course is devoted to engineers and applied mathematicians willing to have an introduction to the modelling and control of distributed parameters systems using the port-Hamiltonian framework.

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

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M06 – PARIS-SACLAY
19/02/2018-23/02/2018

Adaptive Extremum Seeking Control

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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 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. Several emerging applications of ESC will be presented including: distributed optimization, model-free control and observer design. The course will also include a hands-on computer session with Matlab.

Outline of the course

1. Basic ESC Loop
   - We present a stability analysis of classical ESC, estimation based technique and Lie-bracket techniques. The basic tools involve averaging and singular perturbation.
2. Performance Limitations
   - Pros and cons of each techniques are highlighted. Elements associated with excitation signal design, time-scale separation and tuning are presented.
   - Performance limitations of basic ESC is addressed using more advanced ESC formulations that extend existing techniques.
3. Applications and Generalizations of ESC
   - ESC output feedback control of unknown nonlinear systems
   - Distributed ESC on sensor networks
   - ESC Observer design
4. ESC in practice
   - Applications in biotechnology, cryogenic systems, HVAC systems and UAV formation systems
5. Beyond ESC: Adaptation and learning
6. Hands-on Computer Session

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M07 – PARIS-SACLAY
26/02/2018–02/03/2018

Game Theory and Distributed Control

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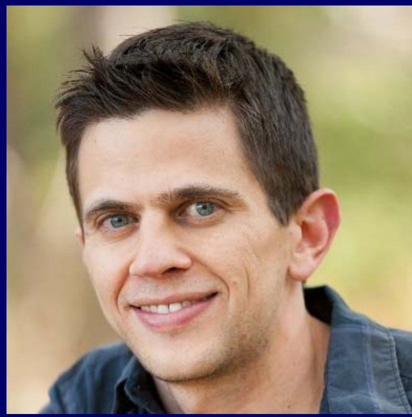

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Overview

Recent years have witnessed significant interest in the area of distributed architecture control systems, with applications ranging from autonomous vehicle teams to communication networks to smart grid. The general setup is a collection of multiple decision-making components interacting locally to achieve a common collective objective. Such architectures readily suggest game theory, which is the study of interconnected decision makers, as a relevant formalism. However, game theory is better known for its traditional role as a "descriptive" modeling framework in social sciences rather than a "prescriptive" design tool for engineered systems. This course presents an overview of how game theory can be used as an effective design approach for distributed architecture control systems, with illustrative examples of distributed coordination.

Outline:

- Elements of normal form games
- Nash equilibrium and generalized solution concepts
- Potential games and their variants
- Price-of-anarchy and price-of-stability
- Mechanism and utility design
- Multi-agent online learning algorithms
- Applications to distributed control problems

References

• J.R. Marden and J.S. Shamma, "Game theory and distributed control", *Handbook of Game Theory, v. 4*, H.P. Young and S. Zamir (eds), 2015.
• J.R. Marden and J.S. Shamma, "Game theoretic learning in distributed control", *Handbook of Dynamic Game Theory,* T. Basar and G. Zaccour (eds), forthcoming.

M08 – PARIS-SACLAY
05/03/2018 – 09/03/2018

Introduction to Nonlinear Systems and 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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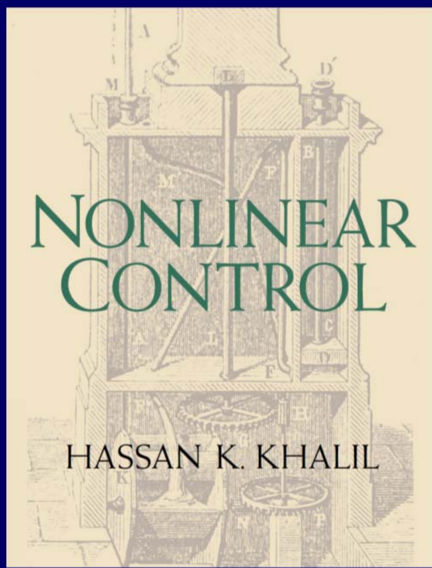


The course is designed around the text book:
H.K. Khalil, Nonlinear Control, Pearson Education, 2015

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 theorems; the small-gain theorem; Circle & Popov criteria)
- Normal and controller forms
- Stabilization (concepts; linearization; feedback linearization; backstepping; passivity-based control)
- Robust stabilization (sliding mode Control)
- 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)

M09 – PADOVA
12/03/2018 – 16/03/2018

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.

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.

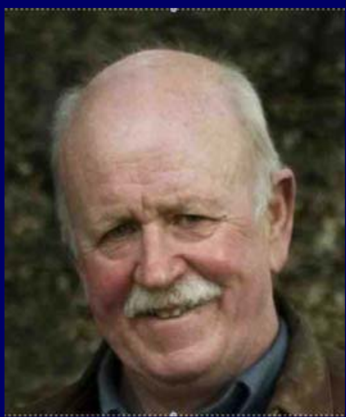
2. Lyapunov methods for verifying stability. Checking positivity by sum of squares and other methods.

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.



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INTERNATIONAL FEDERATION OF AUTOMATIC CONTROL

M10 – PARIS-SACLAY 19/03/2018-23/03/2018	***Model-Based Fault Diagnosis –*** ***A Linear Synthesis Framework using MATLAB***

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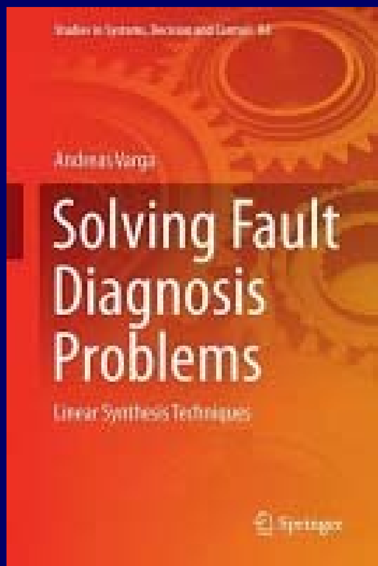
Summary of the course:

The model-based approach to fault detection and diagnosis has been the subject of ongoing research for the past few decades. The aim of this course is to describe the recent developments in the synthesis procedures of fault detection and isolation filters relying on computational approaches suitable to solve the basic synthesis problems in the most general setting. Freely available MATLAB-based software will serve as basis of computational synthesis experiments.

The course is centred on chapters 1– 8 of the recent book:

A. Varga, Solving Fault Diagnosis Problems –
Linear Synthesis Techniques, Springer, 2017.

The computational experiments are performed using MATLAB-based software developed in conjunction with this book.



Covered topics:

- Modelling systems with faults
- Basic problems of linear model-based fault diagnosis
- Nullspace-based synthesis paradigm
- Solution of synthesis problems of fault detection and isolation filters
- Solution of synthesis problems of model-detection filters using multiple-model-based techniques
- Computational issues in solving the synthesis problems
- Computational synthesis experiments using MATLAB

Prerequisites:

Undergraduate-level knowledge of linear systems (described by linear systems of differential equations and transfer-function matrix based input-output descriptions) and basic knowledge of the Control System Toolbox of MATLAB.

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M11 – BERLIN
19/03/2018–23/03/2018

Control of Timed and Untimed Discrete Events Systems

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Abstract

In many areas of application, properties that are interesting from a control point of view are naturally characterised via (timed or untimed) sequences of discrete events. This is true for many manufacturing and transportation systems, but also holds for processes from other application domains on certain levels of abstraction. The dynamic behaviour of such processes is described by Discrete Event Systems (DES). This course will provide an introduction to DES and does not require any background knowledge on this subject. We will address modelling, analysis and (optimal) control aspects. The course will cover language and behavioural models, characterising DES by sets of finite or infinite strings of discrete events, and their realisations in terms of Petri net and finite automaton, or state machine, models. It will discuss the basic ideas of Supervisory Control Theory, aiming at providing minimally restrictive control for problems where both the plant and the specification can be modelled by finite automata. The optimal (just-in-time) feedforward and feedback control for a subclass of Timed Petri nets that describe synchronisation phenomena will be addressed. State estimation for such systems will also be covered. Finally, we will address the question whether finite state abstractions can be used to design control for infinite state systems. .

Topics

1. Introduction
2. Petri Nets: Petri Net Graphs; Petri Net Dynamics; Special Classes of Petri Nets; Analysis of Petri Nets; Control of Petri Nets; Timed Petri Nets
3. Dioid Algebras – Basics: Timed Event Graphs (TEGs) with Holding Times; The Max-Plus Algebra and Residuation Theory; State Equations for TEGs in the Max-Plus Algebra
4. Control of DES in Dioid Algebras: Optimal Feedforward Control (Just-in-Time Control); Optimal Feedback Control; State Estimation
5. Supervisory Control Theory: Languages and Automata; Maximally Permissive Control; Control Implementation by Finite Automata
6. Abstraction Based Control

M12 – PARIS-SACLAY
26/03/2018 - 30/03/2018

Sliding Mode Control and Observation

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/citations?user=cKPYylQAAAAJ&hl=en

Abstract

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. In particular recent a Lyapunov based analysis of such systems will be introduced.

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. Results from recent piloted flight tests of a sliding mode fault tolerant controller undertaken as part of the H2020/Japan collaborative project "VISION" will be presented.

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
- Lyapunov analysis of 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
- marine contour following case study

M13 – PARIS-SACLAY 26/03/2018 - 30/03/2018

Cyber-Physical Systems control: 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

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M14 – PARIS-SACLAY 09/04/2018-13/04/2018	***Modeling, Analysis and Design of Wireless Sensor and Actuator Networks***

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Abstract of the course

Cyber-physical systems such as Smart Grids, Internet of Things Networks, and Intelligent Transport Systems, are supported by three main engineering components: sensing/actuating, networking, and automatic decision making. These components can be generally abstracted as a wireless network of sensors and actuators (WSANs). In WSANs, the new interaction of sensing/actuating, networking, and decision making is demanding the development of novel fundamental design principles, so to reliably observe the physical world, interconnect its units, analyze data and perform control actions, even with resilience, privacy and security guarantees.

This course presents the most relevant design principles of WSANs.

Topics:

- Mathematical modeling of networks and networked control systems;
- Resilient and secure methodologies for control-networking co-design;
- Networked optimization for WSANs;
- Mixed data- and model-based optimal control for large-scale WSANs;
- Experimental case studies on energy efficient buildings;
- Discussion of open problems and opportunities for research.

Registration: http://eeciinstitute.web-events.net/registration/
(Advance registration before 28 December, 2017)

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M15 – L'AQUILA
09/04/2018-13/04/2018

Nonlinear Control Design via Lyapunov Functions and Positivity-Based Techniques

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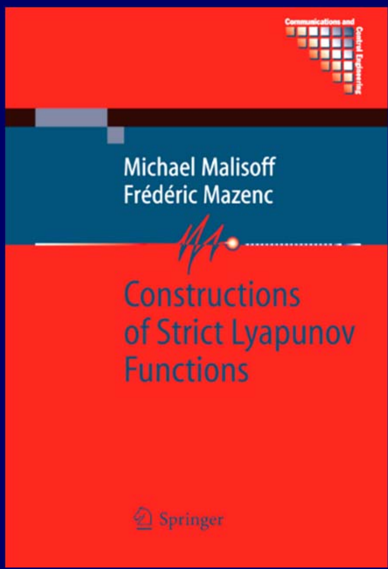
Abstract

We will present fundamental results pertaining to ordinary differential equations, discrete-time systems and nonlinear control theory. In particular, we will review the notion of Lyapunov function, the LaSalle Invariance Principle, the Jurdjevic-Quinn's theorem and the techniques called backstepping and forwarding. We will perform construction of strict Lyapunov functions. We will study the notion of positive systems. We will study several applied problems (chemostats, PVTOL, cart-pendulum system).

The module is partially based on the research monograph: M. Malisoff, F. Mazenc, Constructions of Strict Lyapunov Functions, Spinger-Verlag, serie : Communications and Control Engineering, 2009

Outline

- **Introduction to dynamical systems:** Ordinary Differential Equations, discrete-time systems, time-varying systems, basic notions (existence and uniqueness of solutions, finite escape time phenomenon). Notions of stability (local, global, basin of attraction), notion of input-to-state stability.
- **Fundamental results: Linear systems:** stability analysis, linearization. Hartman-Grobman Theorem, Two dimentional systems : Poincaré–Bendixson theorem. Dulac's criterion, properties of ω-limit sets.
- **Lyapunov functions:** Lyapunov theorem, converse Lyapunov theorem, LaSalle Invariance Principle. Weak Lyapunov functions, strict Lyapunov functions, Matrosov Theorem. Construction of strict Lyapunov functions. Determination of an estimate of a basin of attraction via a strict Lyapunov functions. Notion of ISS Lyapunov function.
- **Control design:** Lyapunov design, Jurdjevic-Quinn theorem, classical backstepping, bounded backstepping, backstepping for time-varying systems, stabilization and tracking though forwarding, Sontag's formula.
- **Positive systems:** Cooperative nonlinear systems, linear positive systems, linear Lyapunov function. Notion of interval observer.



http://www.springerlink.com/content/978-1-84882-534-5

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M16 – PADOVA
16/04/2018-20/04/2018

Lyapunov Stability and Stabilisation without Lyapunov Functions

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Abstract of the course
yapunov's direct method is widely regarded as the spine of stability theory; it is omnipresent in the analysis and design of control systems. Because it is inspired by the energy conservation laws and Lagrange's theorems on stability of mechanical systems, Lyapunov's method is appealing. In control of physical systems, such as robots, autonomous vehicles, and motors, however, realistic scenarios impose uncertainties in the parameters and the impossibility of measuring the whole system's state. Solving such problems through systematic Lyapunov-based design may rapidly become intractable only because of our inability to find appropriate Lyapunov functions.

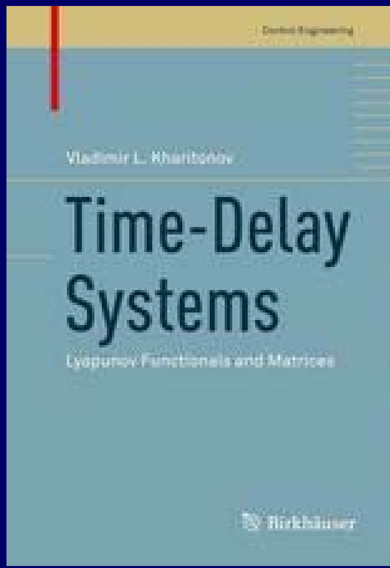
In this course we study methods of stability analysis and control design to construct controllers that guarantee robust Lyapunov stability for time-varying systems that appear, *e.g.*, in adaptive control, tracking control, and several other dynamic-feedback stabilisation scenarios. Overall, we learn how to circumvent the classical Lyapunov's first method through alternative conditions which guide nonlinear control design for complex, interconnected, possibly large-scale and networked, systems. Our theoretical tools are presented streamlined by significant control problems of physical systems that include robot manipulators, autonomous vehicles, and electromechanical systems.

Topics:

- **Diverse classes of systems:**
  - passive systems;
  - networked systems;
  - cascade-interconnected systems;
- **Analysis and design methods:**
  - integrability conditions;
  - Matrosov's theorems and invariance principles;
  - persistency-of-excitation conditions and adaptive control.
- **Control problems:**
  - output-feedback;
  - tracking and formation control;
  - consensus and synchronisation.

M17 – PARIS-SACLAY
16/04/2018 – 20/04/2018

Time Delay Systems: Lyapunov Functionals and Matrices



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Summary of the course

In this lecture course we consider the class of retarded type linear systems with one delay. There are several reasons to address this class of time-delay systems:

- from a methodological point of view it seems that dealing with one delay systems simplifies the understanding of basic concepts, and creates a firm basis for the extension of the presented results to the case of more general classes of time-delay systems;
- for the case of one delay systems we often obtain more complete results than that in more general settings;
- results for the one delay case are not so cumbersome as that for the more general classes of time-delay systems.

The initial value problem for time-delay systems is discussed. The fundamental matrix of such a system is defined, and the variation-of-constants formula for the solution of the initial value problem is derived. The notion of exponential stability for time-delay systems is introduced, and stability criterion in terms of the system's eigenvalues is proven. General scheme for the computation of a quadratic functional with a prescribed time derivative is presented. Lyapunov matrices for time-delay systems are defined and the basic properties of the matrices are studied. Existence and uniqueness issues of the time-delay Lyapunov matrices are discussed, and a numerical scheme for the computation of the matrices is provided.. The class of complete type functional is introduced and the computation of lower and upper estimates for the functionals is studied. The complete type functionals are applied to derive robustness bounds, and exponential estimates for the solutions of a time-delay system.

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INTERNATIONAL FEDERATION OF AUTOMATIC CONTROL

M18 – PARIS-SACLAY
23/04/2018 – 27/04/2018

Model Predictive Control

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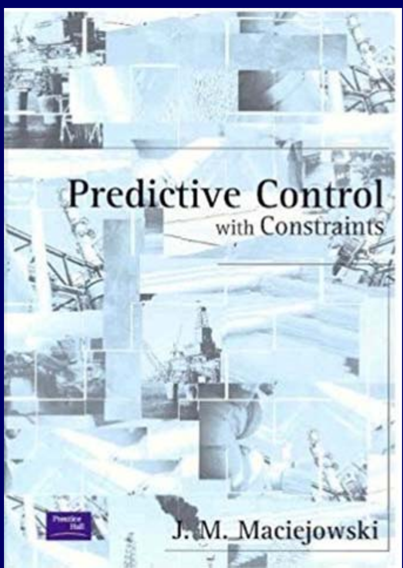
Abstract of the course

Model Predictive Control (MPC) is a model-based method which uses online optimization in real time to determine control signals. It is the only practical control method that takes account of system constraints explicitly, and the only 'advanced control' method to have been adopted widely in industry, particularly in petrochemicals and other process industries. There is intense interest in it for a variety of other applications, including automotive, aerospace, electric drives, smart grid and paper-making. This course covers the theory from basics through to current research concerns, as well as practical aspects. It includes paper-and-pencil and *Matlab*-based exercises. The course has been given in various universities since 2001, and has recently been comprehensively revised and updated.



The course is based on the textbook
Predictive Control with Constraints, by J.M. Maciejowski, Prentice-Hall, 2002.
http://www.amazon.co.uk/Predictive-Control-Constraints-Jan-Maciejowski/dp/0201398230

Topics will include:

- Various formulations of MPC
- Solution methods for MPC
- Stability and recursive feasibility
- Tuning MPC and reverse engineering
- Robust MPC
- Explicit MPC
- Nonlinear MPC
- 'Economic' MPC
- Case studies and applications

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M19 – ST PETERSBURG
23/04/2018 – 27/04/2018

Convergence Theory for Observers: Necessary, and Sufficient Conditions

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Abstract of the course

Observers are objects delivering estimation of variables which cannot be directly measured. The access to such "hidden" variables is made possible by combining modeling and measurements. But this is bringing face to face real world and its abstraction with as a result the need for dealing with uncertainties. The corresponding theoretical observers are consequently very complex, multivalued and often extremely difficult to implement. This implies that approximations and simplifications are involved with, as a consequence, convergence problems.

Content:

As introduction we state the observation problem in its full generality and mention possible theoretical answers. This shows that an observer is nothing but a dynamical system with measurements as inputs and estimates as outputs. We restrict ourselves with the case where this system is finite dimensional and when there is no uncertainty. We concentrate our attention on the convergence aspect with first giving necessary condition and then sufficient conditions. Particular emphasis is given to general purpose observers as high gains observers and nonlinear Luenberger observers.

Prerequisites:

This course is intended to PhD students or Doctors with a sound background on Analysis and Dynamical systems theory.

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M20 – ZURICH
07/05/2018-11/05/2018

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

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M21 – PARIS-SACLAY
14/05/2018 – 19/05/2018

Big Data and Sparsity 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
- 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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M22 – PARIS-SACLAY 14/05/2018 – 19/05/2018	*Formal Methods for Discrete-Time Dynamical Systems*

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Summary of the course

In control theory, complex models of physical processes, such as systems of differential or difference equations, are usually checked against simple specifica- tions, such as stability and set invariance. In formal methods, rich specifications, such as languages and formulas of temporal logics, are checked against simple models of software programs and digital circuits, such as finite transition systems. With the development and integration of cyber-physical and safety-critical systems, there is an increasing need for computational tools for verification and control of complex systems from rich, temporal logic specifications.

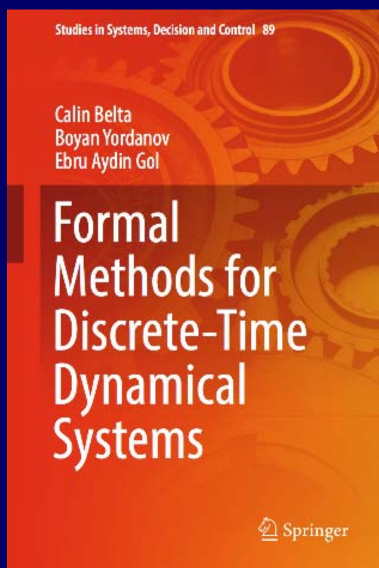
The main objective of this course is to present formal verification and control algorithms for a class of discrete-time systems generically referred to as linear.

Most of the results are formulated for piecewise linear (or affine) systems, which are described by a collection of linear (affine) dynamics associated to the regions of a polytopic partition of the state space. Such systems are quite general, as they have been shown to approximate nonlinear system with arbitrary accuracy.

This course is self-contained. While some level of mathematical maturity is expected, no mathematical background in control or automata theory is necessary. Most of the formal definitions and algorithms are explained in plain language and illustrated with several examples. Most examples include explanatory illustrations.

Outline

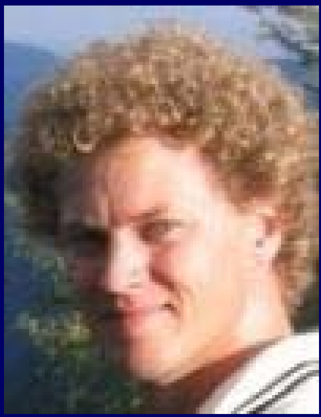
1. The need for formal methods in dynamical systems
2. Transition systems, automata, and temporal logics
3. Analysis and control of finite transition systems
    - 3.1 Model checking
    - 3.2 Largest finite satisfying region
    - 3.3 Finite temporal logic control
4. Analysis and control of discrete-time dynamical systems
    - 4.1 Discrete-time dynamical systems
    - 4.2 Largest satisfying region
    - 4.3 Temporal logic control
    - 4.4 Finite bisimulations
    - 4.5 Language-guided control systems
    - 4.6 Optimal temporal logic control



The course is based on the textbook
Formal Methods for Discrete-Time Dynamical Systems, Springer, 2017,
by Calin Belta, Boyan Yordanov, and Ebru Aydin Gol,
https://link.springer.com/book/10.1007/978-3-319-50763-7

M23 – ISTANBUL
21/05/2018 – 25/05/2018

Control-Oriented Modeling and System Identification



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Objectives and overview

Feedback control, diagnostic and supervision require specific modeling strategies, which capture the essential dynamics of the system while being computationally efficient. Similar constraints are set by process optimization, where the model is simulated by numerous optimization loops.

Contrarily to the classical physical models that reproduce the system behavior with a high precision, a control-oriented model should contain the minimum complexity that can reflect the system trends in response to a given input/stimulus. The structure of the model is designed according to the available data or sensors and includes data assimilation strategies to adapt to processes with a (possibly large) degree of uncertainty.

The first part of the class provides 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 (e.g. Bond graph models). This leads to algebro-differential mathematical models that need to be computed with stability and computational efficiency constraints: this 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 structure. It provides methods to evaluate the model performance, to estimate parameters, to design "sufficiently informative" experiments and to build recursive algorithms for online estimation.

Expected background

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

Main references

- L. Ljung and T. Glad, "Modeling of Dynamic Systems", *Prentice Hall PTR*, 1994.
- S. Stramigioli, "Modeling and IPC Control of Interactive Mechanical Systems: A Coordinate-free Approach", *Springer*, LNCIS 266, 2001.
- S. Campbell, J-P. Chancelier and R. Nikoukhah, "Modeling and Simulation in Scilab/Scicos", *Springer*, 2005.
- L. Ljung, "System Identification: Theory for the User", 2nd Edition, *Information and System Sciences, (Upper Saddle River, NJ: PTR Prentice Hall)*, 1999.

M24 – PARIS-SACLAY
28/05/2018-01/06/2018

Switched Systems and Control

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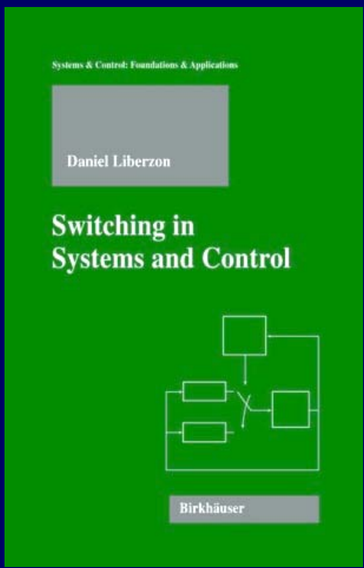
Abstract of the course:

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



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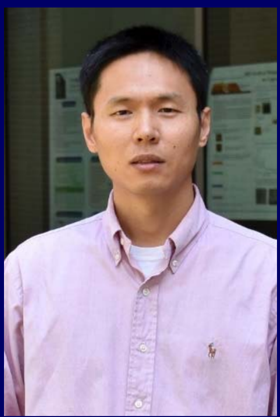
M25 – BERLIN
04/06/2018 – 08/06/2018

Distributed Coordination of Multi-Agent Systems

Abstract of the course

While autonomous agents that perform solo missions can yield significant benefits, greater efficiency and operational capability will be realized from teams of autonomous agents operating in a coordinated fashion. Potential applications for networked multiple autonomous agents include environmental monitoring, search and rescue, space-based interferometers, hazardous material handling, and combat, surveillance, and reconnaissance systems. Networked multi-agent systems place high demands on features such as low cost, high adaptivity and scalability, increased flexibility, great robustness, and easy maintenance.

To meet these demands, the current trend is to design distributed coordination algorithms that rely on only local interaction to achieve global group behavior. The objective of this course is to introduce some recent results in the field of distributed coordination of multi-agent systems. Topics covered include consensus seeking, motion coordination, distributed average tracking, distributed optimization, and distributed estimation as well as their applications in multi-vehicle cooperative control (e.g., ground robots, UAVs, spacecraft, robotic arms, sensor networks).



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Outline

1. Overview of recent research in multi-agent coordination and control
2. Distributed consensus in multi-agent systems (fundamental continuous- and discrete-time local averaging algorithms, consensus for agents with linear or nonlinear dynamics, applications)
3. Distributed motion coordination (periodic motion patterns, single-leader coordinated tracking, multi-leader multi-follower containment control)
4. Distributed average tracking of multiple time-varying references
5. Distributed continuous-time optimization with local information and interaction
6. Distributed estimation with multiple communicating sensors