Universitatea POLITEHNICA din București

Facultatea de AUTOMATICĂ și CALCULATOARE

Master of Science
Advanced Techniques in Signals and Systems

Courses description

Nonlinear system identification

The main goal of Non Linear System Identification (NLSI) course is to introduce models and algorithmic methods to identify systems with non linear dynamic behaviour. Applications in various fields are concerned as well. The curriculum focuses on Volterra, Hammerstein, Wiener and Wiener-Hammerstein model classes. During the laboratory works, students have the opportunity to implement within Matlab programming environment some frequently employed algorithms, with fair complexity.

Numerical methods in control

The Numerical Methods in Control teaches a lesson of good practices in reliable numerical computation applied to problems arising in automatic control. It starts with algorithms for solving linear matrix equations, computing matrix functions and solving differential equations. Then it moves to the more specific problems of dynamical system representation and conversions between models. These representations are used for computing essential characteristics of the systems like time and frequency responses. The students' practical activities include implementing some of the methods in Matlab and an individual mini-project.

Robust SISO systems

This course deals with systems described by Single Input and Single Output (SISO) models that contain uncertainties, and presents the main robust control laws and techniques for this simple but fundamental class of systems. The applications try to familiarize the student with the content of basic libraries for robust control and their use for solving advanced control problems for real-life uncertain systems. Classical design is opposed to modern design to justify the necessity of a new fundamental approach based on norms. Several design methods are presented: optimal controller, model matching, Nevannlinna-Pick algorithm, robust performance based, stability margin optimization, S, T, and Q tuning.

Scientific computation

The main challenge of Scientific Computation is big data, which have to be processed in reasonable time. To this purpose one uses special computing architectures, needing special algorithms. The course focuses on two types of architectural principles: hierarchical memory and parallel processing. The first is at the origin of block level algorithms for matrix computations, of which are discussed the LU and QR factorizations. Among the several parallel processing models, the course is cantered on the "single program multiple data" paradigm and the Message Passing Interface (MPI) standard. The example algorithms belong to linear algebra and pave the way for the presentation of high performance computation libraries like BLAS, LAPACK and SCALAPACK. The students' main assignment is to write an MPI program, using a simulator; they also have the option to use OpenCL on GPU, using a graphic station.

Model order reduction

The principal aim of this course is to familiarize the student with the fundamental concepts of order reduction in science and engineering and the presentation of the principal techniques for dynamical systems. A thorough analysis is demonstrated on several relevant real-life examples by using several toolbox libraries from MATLAB. Two main classes of model order reduction techniques applicable for low to medium dimension models and based on different concepts are introduced: balanced truncation and Hankel norm approximation. The course presents also two classes of methods suited to large scale and very large scale systems: Krylov and Arnoldi methods. All theoretical results are illustrated by a great number of real engineering problems (e.g., the control of laser beam in modern CDs. weather prediction).

Nonlinear systems

The course is above all an introduction to the study of dynamical systems described by nonlinear differential equations, with emphasis on providing a qualitative description of the behaviour of such systems in the state space. Many examples are provided as an attempt to place as much as possible the theory of differential equations in the context of its applications in physics, biology, chemistry and engineering. The basic notions of equilibrium and periodic orbits are introduced, then the concepts of stability and linearization in the neighbourhood of these particular cases of orbits, which then opens the way to classifications of nonlinear dynamics. Lyapunov functions are introduced as a tool for stability analysis. The course also discusses the synthesis of control laws for nonlinear systems. Instruments such as input-output linearization and the technique of back stepping are introduced in this respect.

Robust MIMO systems

This course is a continuation of the course on robust SISO systems at another level of generality: systems having multiple inputs and multiple outputs. The representation of uncertainties based on normalized coprime factors is introduced as well as the notion of gap metric. Several modern techniques for robust MIMO systems design are presented based on nonconvex H2/H-infinity norm optimization. Several fundamental concepts like algebraic Riccati equations, spectral factorizations, entropy, miu synthesis, loopshaping based on SVD and miu-gap are introduced and studied. All these notions are presented from a theoretical viewpoint and exemplified on real-life case studies, e.g., modern reaction engines (Boeing Dreamliner and Airbus 380), the design of integrated third generation ESP, DCS and X-Drive systems for cars.

Numerical algorithms for control systems design

The aim of this course is to present modern methods for numerical computation in simulation and design of robust/optimal dynamical systems. The main chapters are: poles and zeros assignment, matrix pencil methods, numerical solution of matrix Lyapunov, Sylvester, and Riccati equations, both continuous and discrete-time, exact and iterative methods, numerical methods for solving optimal synthesis problems, numerical computation of Kalman, H-2/H-infinity optimal filters and compensators, algorithms for computing norms for signals and systems, singular perturbation techniques and their numerical implementation, LMI techniques in robust design.

Stochastic signals and systems

The course presents basic notions and methods for modelling and simulation of partially known processes that are subject to environmental exogenous factors that are unpredictable through classical methods. The course introduces the notion of random variable and stochastic process and signals, entropy and information, elements of estimation theory, e.g., quality criterions and indices, apriori information, construction of AR models and adaptive synthesis of signal filters. The systemic modelling of stochastic signals and the spectral factorization for real positive systems are used to design Kalman filters, LQG solution and, more general, for the control of stochastic systems. The course ends with a hindsight look into the difficulties of stochastic approach and several suggestions for alternative solutions.

Convex optimization

Convex Optimization course concentrates on recognizing and solving convex optimization problems that arise in applications. The course introduces first the basic notions from convex analysis: convex sets and functions. Then, it defines the basics of convex optimization (optimality conditions, duality theory and theorems of alternative) and numerical optimization algorithms (gradient methods, interior-point methods, decomposition methods). Finally, the course provides applications from control, signal processing, statistics and machine learning, digital and analogue circuit design, and finance. The main objectives of the course are: to give students the tools to recognize convex optimization problems that arise in applications, to give students a thorough understanding of how such problems are solved, and to give students the background required to use the methods in their own research work or applications.

Time-Frequency Analysis with Wavelets

The main goal of Time-Frequency Analysis with Wavelets (TFAW) course is to introduce the basic concepts and the specific terminology of mono or multivariable non stationary signals processing by means of time-frequency-scale analysis tools and especially wavelets. Applications in various fields are concerned as well. The curriculum focuses on time-frequency-scale analysis gravitating around orthogonal and finite length discrete time wavelets. During the laboratory works, students have the opportunity to implement within Matlab programming environment some frequently employed algorithms based on Daubechies' class of wavelets.

Discrete dynamical systems with applications in fractal geometry

The course introduces the concepts of discrete dynamical system, iterated function system, Hutchinson operator, the study of fractals as attractors of iterative systems, classical fractals, and Julia and Mandelbrot sets. Several different notions of fractal dimension are studied systematically together with appropriate numerical algorithms for its computation. Although the whole course is built on rigorous abstract mathematical concepts, these are everywhere illustrated with nice applications like Cantor sets, Sierpinski triangle and carpet, Koch curve, Barnsley fern fractal or by some modern applications in engineer as nonlinear video analysis based on algorithms for fractal generation and approximate calculus of fractal dimension by compass and Box-Counting methods.

Advanced signal processing

The Advanced Signal Processing course aims to extend the basic notions acquired at undergraduate level in several directions. The studied topics include filter banks, spectral estimation, sparse representations, vector quantization and a few notions of image processing. The course presents mainly algorithms, some of them classic like those for filter bank design or non-parametric spectrum estimation, but also very modern like orthogonal matching pursuit or basis pursuit. While all students are expected to attain a certain level in all directions, the diversity of topics is also meant for them to choose one for deeper study in an individual project based on recently published methods.

Nonconvex optimization

The principal aim of this course is to familiarize the student with advanced methods for optimization of nonconvex functions subject to structural constraints, as they occur in systems theory and electrical engineering in general, and in control in particular. After a brief review of the necessary mathematical notions, the course focuses on the following important classes of methods: primal, penalty and barrier, dual and cutting plane, and Lagrange. The course accent lies on the soundness of the associated numerical methods, on how to formulate a well-posed problem and to implement numerically stable algorithms, and how to apply the methods in practical problems in engineering.

Optional course

We alternatively offer several optional courses, among which:

- Decentralised systems (Conf. I. Necoara – UPB/FA&C);
- Signals, systems, and optimization: an integrated approach (Prof. Petre Stoica – Uppsala University/Sweden);
- Delay systems (Dr. Silviu Niculescu – Supelec Paris/Franța);
- Genomic signals (Prof. Ioan Tăbuş – Tampere University/Finland);
- Optimal systems (Prof. Cristian Oară);
- Writing a scientific article (Prof. B. Dumitrescu).

The main objective of the course on decentralised systems is to present theoretical and practical tools to address the control of complex processes. The course presents first the main decentralized control strategies and defines methodologies for determining the configuration of multivariable process control loops and resolution of conflicts arising from interactions between control loops. Finally, the course presents the practical methods of decentralized control for multivariable processes: setting control objectives, setting the proper inputs and outputs, setting the configuration of control loops for decentralized control architecture, stationary decoupling, control laws and algorithms of multivariable PI and PID and implement these decentralized techniques on several relevant applications (interconnected power systems, chemical processes).

Scientific research

The master program Advanced Techniques in Signal and Systems (ATSS) presents state-of-the-art methods in its courses and hence places a high importance in the research activity of its students, with the declared purpose that most of them will follow their education with doctoral studies. Depending on his/her preferred topic, each student chooses a guiding professor and together they select a research theme, which can evolve during the two years of the program. Whenever possible, the students are involved in the research projects directed by the ATSS professors. While some details can vary, the general framework for the research activity is as follows. During the first year, the student aims to get acquainted with the research problem by reading scientific articles related to it and especially by implementing and testing existing methods for solving it, using real or simulated data. Thus, the students enhance their ability to understand the formalisms for presenting scientific results, to go quickly from theory to practice and to critically evaluate different approaches for solving a problem. In the second year, or even earlier if possible, the main purpose of the research activity is to develop specific creativity, insisting on the innovations that the students can identify, implement and prove. Each semester, the student's present research reports, that is also a training opportunity for writing technical and scientific papers. Ideally, the dissertation project is a natural follow-up of these reports and an overall result of the whole research activity.