CENTRALE NANTES

# MASTER OF SCIENCE, TECHNOLOGY AND HEALTH

2023-2024

YEAR 2

## CONTROL AND ROBOTICS

## CONTROL SYSTEMS

PROGRAMME SUPERVISOR(S):
Ina TARALOVA

# YEAR 2 - Autumn Semester

## CORE COURSES

| Course code | Title | ECTS Credits |
|---|---|---|
| CONF | Conferences | - |
| MAMO | Mathematical Modeling | 4 |
| MEREC | Project | 2 |
| OBSEDIA | Observation and Diagnostic | 5 |
| OPTIMI | Optimization | 4 |
| ROBOC | Robust and Optimal Control | 4 |
| SGTVS | Analysis and Control methodologies: Standard, Generalized and Time-Varying Systems | 5 |
| SYCOMP | Complex Systems | 4 |

# YEAR 2 - Spring Semester

## CORE COURSES

| Course code | Title | ECTS Credits |
|---|---|---|
| THESIS | Master Thesis or Internship | 30 |

# Conferences [CONF]

*LEAD PROFESSOR(S): Malek GHANES*

## Objectives

This course is set aside for general conferences that may be given during the year.

## Course contents

## Course material

## Assessment

Individual assessment: EVI 1 (coefficient 1.0)

| LANGUAGE OF INSTRUCTION | ECTS CREDITS | LECTURES | TUTORIALS | LAB | PROJECT | EXAM |
|---|---|---|---|---|---|---|
| English | - | 24 hrs | 0 hrs | 0 hrs | 0 hrs | 0 hrs |

Master Programme - Control and Robotics - Control Systems

YEAR 2 - Autumn Semester

# Mathematical Modeling [MAMO]

*LEAD PROFESSOR(S): Elkhatib IBRAHIM / Vinu THOMAS*

## Objectives

The aim of this course is to present the different types of mathematic models of dynamic systems used for analysis and control. The difference between a model and the system which is represented is demonstrated along with the classes of equivalent models of a given system. Methods to build models and estimate their parameters are given. Particular approaches to quantify uncertainties are discussed.

## Course contents

Purposes and classifications of models
- Control/simulation, Linear/nonlinear, Continuous/discrete/hybrid, Time invariant/time-varying
- Deterministic/stochastic, Parametric/non-parametric, Finite/infinite dimension
- State/frequency/transfer/Rosenbrock/Differential-Algebraic Equations (DAE), etc

Classes of equivalence of DAE models
- Intrinsic definition of a system
- linear case: dynamic systems as modules over polynomial rings
- nonlinear case: Lie-Bäcklund transformations, Orbital equivalence, Flatness

Parameterized models and identification
- ARMA, ARMAX, etc
- Parameters' identification

Fuzzy/neuro and bond graphs models
- Uncertainty quantification
- Energy/causality/multi-physics

## Course material

- L. Ljung, "Modelling of Dynamic Systems", Prentice Hall, 1994.
- T. Södertström, P. Stoica, "System identification", Prentice Hall, 1989.
- H. Bourlès and B. Marinescu (2010) Linear Time-Varying Systems: Algebraic-Analytic Approach, (2011) Springer-Verlag, New York.

## Assessment

Individual assessment: EVI 1 (coefficient 1.0)

| LANGUAGE OF INSTRUCTION | ECTS CREDITS | LECTURES | TUTORIALS | LAB | PROJECT | EXAM |
|---|---|---|---|---|---|---|
| English | 4 | 16 hrs | 6 hrs | 8 hrs | 0 hrs | 2 hrs |

Master Programme - Control and Robotics - Control Systems

YEAR 2 - Autumn Semester

# Project [MEREC]

*LEAD PROFESSOR(S): Ina TARALOVA*

## Objectives

The purpose of this project is for the student to apply the theories and techniques studied during the courses, according to his/her career plan. It is, therefore, either a technical project for an industrial application, or an introduction to research to consider a research profession.

## Course contents

This project can be either a technical project or an initiation to research: latest developments, proposals, experiments, analysis and prospects etc.
It is an extended individual project (including scientific support, bibliography, scientific study)

## Course material

## Assessment

Individual assessment: EVI 1 (coefficient 1.0)

| LANGUAGE OF INSTRUCTION | ECTS CREDITS | LECTURES | TUTORIALS | LAB | PROJECT | EXAM |
|---|---|---|---|---|---|---|
| English | 2 | 0 hrs | 0 hrs | 0 hrs | 24 hrs | 0 hrs |

Master Programme - Control and Robotics - Control Systems

YEAR 2 - Autumn Semester

# Observation and Diagnostic [OBSEDIA]

*LEAD PROFESSOR(S): Malek GHANES*

## Objectives

Measuring the state of a given system with physical sensors is sometimes impossible and sometimes possible, but too costly. That is why estimating the state of a system by means of software sensors (observers) is an important issue. The first part of this course investigates several methods of observer design for non-linear systems.

Moreover, faults in sensors, actuators or process components may deteriorate overall system performance and could cause serious damage.
From this point of view, the second part of this course will provide some basic definitions and different existing methods of diagnosis. Then, the diagnostic problem will be mainly investigated by using observers (studied in the first part) with fault estimation (simultaneous state and parameter estimation). Finally, fault tolerant control problem is briefly studied.

Examples and labs will illustrate the validity of these two parts in the framework of academic and real applications.

## Course contents

I. Observation

1. Introduction to Observation
2. Observation of linear systems
3. Observation for nonlinear systems

II. Diagnosis

1. Introduction to Diagnosis (FDI)
2. Diagnosis with UIO (Unknown Input Observer)
3. Diagnosis with Parity Space

- 2 practice labs
- 2-hour exam

## Course material

Observation:

- R. Hermann and A.J. Krener, Nonlinear controllability and observability, IEEE Trans. Automatic Control, 22:728-740, 1977.
- R.E. Kalman and R.S. Bucy. New results in linear filtering and prediction, theory. J. Basic Eng., 83:95-108, 1961.
- G. Besançon (Ed.). Nonlinear Observers and Applications. LNCIS, Vol. 363. Berlin, Springer-Verlag, 2007.
- Zaltni, D., & Ghanes, M. (2013). Observability Analysis and Improved ZeroSpeed Position Observer Design of Synchronous Motor with Experimental Results. Asian Journal of Control, 15(4), 957-970.
- M. Ghanes, JP. Barbot, L. Fridman and A. Levant, A novel differentiator: A compromise between super twisting and linear algorithms, IEEE CDC, 2017.

Diagnosis:

- R. Isermann, Fault-diagnosis applications: model-based condition monitoring: actuators, drives, machinery, plants, sensors, and fault-tolerant systems. Springer Science & Business Media, 2011.

## Assessment

Individual assessment: EVI 1 (coefficient 1.0)

| LANGUAGE OF INSTRUCTION | ECTS CREDITS | LECTURES | TUTORIALS | LAB | PROJECT | EXAM |
|---|---|---|---|---|---|---|
| English | 5 | 18 hrs | 4 hrs | 8 hrs | 0 hrs | 2 hrs |

Master Programme - Control and Robotics - Control Systems

YEAR 2 - Autumn Semester

# Optimization [OPTIMI]

*LEAD PROFESSOR(S): Ina TARALOVA*

## Objectives

Optimization is transversal to all engineering fields, and far beyond; it is about finding the best (i.e. optimal) solution, according to given /predefined/ criteria. In the field of control, it refers to identification and estimation problems, trajectory planning, control policies and controller design, denoising etc.

The aim of the course is to get acquainted with iterative optimization methods in one dimensional and multidimensional cases, linear or nonlinear, with or without constraints. Students will be given further analytical tools for the formulation and solution of functional optimization, with applications to benchmark problems in control theory.

## Course contents

- Introduction, definitions, examples of optimization problems
- Linear case, simplex method
- Monovariable optimization: Newton's method, golden section, Fibonacci's method, quadratic approximation, "economic" methods, minimax problems
- Multivariable optimization: Heuristical methods, Gradient method, Conjugate gradients, Quasi-Newton
- Constrained optimization: Primal and dual methods, Lagrangian function
- Functional optimization: Euler-Lagrange equations, Brachistochrone problem (optimal trajectory)
- Isoparametric optimization:  Dido's problem
- Pontryagin's Maximum Principle
- Applications:
  - o Minimum time problem: car-parking problem, linearized pendulum stabilization
  - o Minimum fuel control problem: moon lander

## Course material

- D.Bertsekas, Nonlinear Programming, Athena Scientific.
- P. Borne, Commande et optimisation des processus, Ed. Technip.

## Assessment

Individual assessment: EVI 1 (coefficient 1.0)

| LANGUAGE OF INSTRUCTION | ECTS CREDITS | LECTURES | TUTORIALS | LAB | PROJECT | EXAM |
|---|---|---|---|---|---|---|
| English | 4 | 20 hrs | 6 hrs | 4 hrs | 0 hrs | 2 hrs |

# Robust and Optimal Control [ROBOC]

*LEAD PROFESSOR(S): Bogdan MARINESCU*

## Objectives

At the end of the course the students will be able to:

- Analyse and control complex systems with multi-inputs / multi-outputs and state variables
- Apply techniques to ensure optimal performance and the robustness required in industrial specifications:
  - o robust stability, robust reference tracking, robust disturbance rejection,
  - o oscillation damping, compensation of the effect of data transmission delays

## Course contents

- Optimal control
  - o Linear quadratic (LQ and LQG) control
  - o Optimal state estimation and separation principle
  - o H2, H∞ control - robustness
  - o Lyapunov and Riccati equations / Linear Matrix Inequalities (LMI)
- Predictive control
- Control methodology for optimal and robust MIMO linear control:
  - o solution of the regulator problem with internal stability,
  - o specification to ensure robust asymptotic tracking and disturbance rejection,
  - o proposition of weight matrices of ARE to obtain robust stability

## Course material

Optimal control:
- F.L. Lewis, V.L. Syrmos, Optimal Control, 2nd edition 1995 Wiley.
- J.M. Dion, D. Popescu, Commande optimale - conceptions optimisées des systèmes, Diderot 1996
- S. Boyd, L. El Ghaoui, E. Feron, V. Balakrishnan (1994): Linear Matrix Inequalities in Systems and Control Theory. SIAM.

H2, H∞, LQ, Model reduction:
- S. Skogestad, I. Postlethwaite, Multivariable Feedback Control - Analysis and Design, Wiley 2005.
- K. Zhou, J.C. Doyle, K. Glover, Robust and Optimal Control, Prentice-Hall 1996.
- K. Zhou, J.C. Doyle, Essential of Robust Control, Prentice Hall 1998.

Predictive control:
- P. Boucher, D. Dumur, La commande prédictive - avancées et perspectives, Hermes-Lavoisier 2006
- Bemporad, M. Morari (1999): Robust model predictive control: A survey. Robustness in Identification and Control, Springer London, 207-226.

Control Methodology for Linear Systems:
- W.M. Wonham, Linear Multivariable Control: A Geometric Approach Springer Verlag, 1985
- Ph. de Larminat, Contrôle d'état standard, Hermes 2000.

## Assessment

Individual assessment: EVI 1 (coefficient 1.0)

| LANGUAGE OF INSTRUCTION | ECTS CREDITS | LECTURES | TUTORIALS | LAB | PROJECT | EXAM |
|---|---|---|---|---|---|---|
| English | 4 | 18 hrs | 4 hrs | 8 hrs | 0 hrs | 2 hrs |

# Analysis and Control methodologies: Standard, Generalized and Time-Varying Systems [SGTVS]

*LEAD PROFESSOR(S): Bogdan MARINESCU / Swann MARX*

## Objectives

System coefficients may vary with time. This is often the case in industry and leads to difficulties in analysis and control of such systems, called time-varying or non-stationary systems.
Dynamic systems are often modelled by transfer matrices (in the linear case), state-space realizations, etc. These representations relay on an a priori definition/choice of the input and output variables (controls and measures) which are not appropriate in many cases.
The first part of the course provides analysis and control solutions for time-varying systems in an intrinsic approach which considers the system close to its analytic modeling. It is thus close to physics and unifies several engineering fields. Those methods rely on simple algebraic computations, being thus easy to implement in practice. Many of them have already been used to solve industrial problems and will be used as examples in the class.
The second part of the course is about the control and the regulation of partial differential equations (PDEs), in particular systems of transport equations. This kind of equations may appear in many practical situations: electronics (telegrapher equation) or fluids mechanics (Saint-Venant equation). Because of the complexity of such models, new theoretical tools are needed. The objective of the course is to present some of them. The methods that will be presented rely mainly on the Lyapunov method, which allows to apply more sophisticated methods, such as the backstepping or the forwarding.

After the course, the students will be able to:
- Compute poles of linear time-varying systems
- Synthesize and implement time-varying regulators
- design a PI controller for systems of transport equation.

## Course contents

Part I
- Time-varying systems; motivating examples
- Intrinsic structural analysis (poles, zeros, stability, controllability, observability)
- Pole placement for linear time-varying systems
- Extensions to the case of nonlinear systems
- Control by linearization around trajectories
- Industrial applications

Part II
- Motivating examples.
- Method of the characteristics.
- Lyapunov theory.
- Backstepping method
- PI controller and forwarding method.

## Course material

H. Bourlès and B. Marinescu (2010) Linear Time-Varying Systems: Algebraic-Analytic Approach, (2011) Springer-Verlag, New York.
Kailath, T. (1980) Linear systems, Prentice-Hall, Englewood Cliff, N.J.
G. Bastin and J.-M. Coron (2016) Stability and Boundary Stabilization of 1-D Hyperbolic Systems. Birkhaüser.
M. Tucsnak and G. Weiss (2008) Observation and Control for Operator Semigroups, Birkhaüser.

## Assessment

Individual assessment: EVI 1 (coefficient 1.0)

| LANGUAGE OF INSTRUCTION | ECTS CREDITS | LECTURES | TUTORIALS | LAB | PROJECT | EXAM |
|---|---|---|---|---|---|---|
| English | 5 | 14 hrs | 8 hrs | 8 hrs | 0 hrs | 2 hrs |

Master Programme - Control and Robotics - Control Systems

YEAR 2 - Autumn Semester

# Complex Systems [SYCOMP]

*LEAD PROFESSOR(S): Ina TARALOVA*

## Objectives

The aim of this course is to for students to become acquainted with complex system dynamics: delayed, hybrid and chaotic systems, from analysis to design: stability, controllability, identifiability, synchronization, and applications.

Hybrid complex systems or those involving delays are used in many fields, for example in biology, economics, mechanical or electrical engineering. Basically, delays appear when different agents interact and exchange goods or information, and the delays are associated with their transport.

Classical examples of hybrid systems are encountered in sampled-data control systems that combine both continuous-time plants and discrete-time control algorithms, and in electronics, where components (diodes, transistors, on/off switches) induce sudden changes in the systems dynamics. The same systems for particular parameters could exhibit also more complex, chaotic behavior, encountered as well in other engineering fields implying particular non-linearities: robotics, control, chemical engineering, process modelling, optimisation, random number generators design, etc.

The above systems are all complex, but exhibit at the same time specific features, since the complexity could be attributed to different sources (combined continuous/discrete dynamics; delays; specific non-linearities), therefore specific methods will be used for the design and evaluation of the performance.

## Course contents

Delayed systems

- Examples of time-delay systems.
- Basic control design: Ziegler and Nichols, Smith's predictor, Tsypkin's theorem.
- Models and approaches: Convolution systems, transfers, systems over a ring, 2D systems, realization theory.
- Stability: Exponential, L1, L2, and BIBO-stability, zeros of quasi-polynomials, robust stability, D-partition.
- Stabilization: Static feedback, Robust stabilisation, Prediction and pole placement.
- Examples of control design: Crane control, Logistic system, Cyber-physical system.

Hybrid systems

- Switched and impulsive models – motivations and examples.
- Stability and stabilization of switched and impulsive systems
- LMI implementation of stability / stabilizability criteria
- Structural properties (observability, controllability, minimality) of switched systems with arbitrary switching

Chaotic systems

- Introduction to chaotic systems - definitions, examples
- Analysis of chaotic systems:
  - o Periodic and aperiodic orbits, chaotic attractors
  - o Bifurcations and basins of attraction, multi-stability
- Synchronization of chaotic systems using observers
- Applications: Chaotic maps for encryption, design of pseudo-random number generators

## Course material

- S.-I. Niculescu (2001): Delay effects on stability. A robust control approach, Springer: Heidelberg, Series:LNCIS, vol. 269.New York.
- D. Liberzon (2012). Switching in systems and control. Springer Science & Business Media.
- Z. Sun (2006). Switched linear systems: Control and design. Springer Science & Business Media.

- T.Kapitaniak (2012). Chaos for Engineers: Theory, Applications, and Control. Springer Science & Business Media.

## Assessment

Individual assessment: EVI 1 (coefficient 1.0)

| LANGUAGE OF INSTRUCTION | ECTS CREDITS | LECTURES | TUTORIALS | LAB | PROJECT | EXAM |
|---|---|---|---|---|---|---|
| English | 4 | 20 hrs | 2 hrs | 8 hrs | 0 hrs | 2 hrs |

Master Programme - Control and Robotics - Control Systems

YEAR 2 - Spring Semester

# Master Thesis or Internship [THESIS]

*LEAD PROFESSOR(S): Ina TARALOVA*

## Objectives

- Be exposed to and adapt to an industrial or research environment
- Apply the scientific and technical skills acquired in the previous semesters
- Strengthen interpersonal and communication skills
- Be part of or manage a project
- Organize tasks, analyze results and build deliverables

## Course contents

Students should be pro-active and career-oriented in the search for their thesis/internship. The topics are approved by the program supervisor to ensure an adequate Master level. The thesis/internship is evaluated through the submission of a written report and an oral defense.

## Course material

- Turabian Kate Larimore, Booth Wayne Clayton, Colomb Gregory G., Williams Joseph M., & University of Chicago press. (2013). A manual for writers of research papers, theses, and dissertations: Chicago style for students and researchers (8th edition.). Chicago (Ill.) London: University of Chicago Press.
- Bui Yvonne N. How to Write a Master's Thesis. 2nd ed. Thousand Oaks, Calif: Sage, 2014.
- Evans David G., Gruba Paul, Zobel Justin. How to Write a Better Thesis. 3rd edition. Carlton South, Vic: Melbourne University Press, 2011.

## Assessment

Individual assessment: EVI 1 (coefficient 1)

| LANGUAGE OF INSTRUCTION | ECTS CREDITS | LECTURES | TUTORIALS | LAB | PROJECT | EXAM |
|---|---|---|---|---|---|---|
| English | 30 | 0 hrs | 0 hrs | 0 hrs | 0 hrs | 0 hrs |