Course guide
240IAU21 - 240IAU21 - Non-Linear, Optimal and Predictive Control

Last modified: 16/05/2023

Unit in charge: Barcelona School of Industrial Engineering
Teaching unit: 707 - ESAII - Department of Automatic Control.

Degree: MASTER'S DEGREE IN INDUSTRIAL ENGINEERING (Syllabus 2014). (Optional subject).

Academic year: 2023 **ECTS Credits:** 4.5 **Languages:** Catalan, Spanish

LECTURER

Coordinating lecturer: Vicenç Puig Cayuela

Others: Pau Marti Colom

PRIOR SKILLS

The ones acquired in the Process Control course of this master.

REQUIREMENTS

To have followed the Process Control course of this master.

TEACHING METHODOLOGY

The course will be given by means of theory/problems classes and by means of practical labs.

LEARNING OBJECTIVES OF THE SUBJECT

The objective of this subject is to provide to the students the concepts and basic tools of optimization (continuous and discrete) for their application to dynamic systems in the fields of the automatic control and robotics. To this aim, optimal control and estimation of system states/parameters will be studied. Application in the field of robotics as robot trajectory planning, process scheduling, etc. will also be considered.
Without avoiding the formality of the mathematical contents, special emphasis will be given to the engineering point of view, presenting different real applications to illustrate the interest and the need of the presented methods.

STUDY LOAD

Type	Hours	Percentage
Self study	72,0	64.00
Hours small group	13,5	12.00
Hours large group	27,0	24.00

Total learning time: 112.5 h

CONTENTS

1. Optimization

Description:
1.1 Introduction
1.2 Optimization problem classification
1.3 Convex optimization
1.4 Optimization problems without constraints
1.5 Optimization problems with equality constraints. Lagrange multipliers.
1.6 Optimization problems with inequality constraints. Karush Kuhn Tucker (KKT) conditions.
1.7 Duality
1.8 Numerical methods: gradient based, simplex QP, ...

Specific objectives:
- Acquire the fundamental concepts of continuous optimization problems, with and without constraints.
- Understand the role of convexity in the optimization problems and its relation with the local optimum problem.
- Use the Lagrange multipliers to determine the conditions to find the optimal functions of several variables subjected to constraints.
- Be able to apply the conditions of Karush-Kuhn-Tucker in the optimization problems with inequality constraints.
- Be able to apply numerical optimization methods using commercial program packages.

Related activities:
Activity 1 and 2

Full-or-part-time: 6h 30m
Practical classes: 4h 30m
Laboratory classes: 2h

2. Optimal/Predictive Control

Description:
2.1 Formulation of the problem of optimal control
2.2 Performance indices
2.3 Solution by means of Langrage multipliers (maximum principle)
2.4 Solution by means of dynamic programming
2.5 Solution by means of numerical methods (mathematical programming)
2.6 LQR control
2.7 Introduction to predictive control
2.8 Real applications

Specific objectives:
- Understand the formulation of the optimal control as an optimization problem with constraints.
- Be able to solve problems of optimal control by means of the method of Lagrange multipliers and dynamic programming.
- Be able to solve problems of optimal control by means of numerical methods (mathematical programming).
- Know to solve the LQR control problem.
- Understand the predictive control principles.

Related activities:
Activitity 1

Full-or-part-time: 6h
Practical classes: 4h
Laboratory classes: 2h

3. Optimal State/Parameter Estimation

Description:
3.1 Introduction to estimation
3.2 Principle of least square estimation
3.3 State estimation: Kalman filter
3.4 Parameter estimation: Recursive estimation
3.5 Relation between the state and parameter estimation
3.6 Control LQG: separation principle
3.8 Real applications

Specific objectives:
- Apply the principle of least squares to the estimation of system states/parameters
- Apply the Kalman filter to the state estimation of dynamic systems.
- Apply the Kalman filter to the parameter estimation of dynamic systems.
- Apply in an integrated way optimal control and estimation

Related activities:
Activity 3

Full-or-part-time: 6h
Practical classes: 4h
Laboratory classes: 2h

4. Non-linear Systems

Description:
4.1 Non-linear system modelling and simulation
4.2 Phase plane analysis
4.3 Stability of non-linear systems

Specific objectives:
- Learn how to model and simulate non-linear systems
- To study the behavior of non-linear systems using the phase plane analysis
- To be able to study the stability of non-linear systems

Related activities:
Activity 4

Full-or-part-time: 6h
Practical classes: 4h
Laboratory classes: 2h

5. Non-linear Control

Description:
5.1 Control based on Linearization
5.2 Control based on Lyapunov theory
5.3 Control based on Exact Linearisation
5.4 Sliding Mode Control
5.5 Control based on Energy
5.6 Adaptive Control

Specific objectives:
To learn to design controllers for non-linear systems using:
- Control based on Linearization
- Control based on Lyapunov theory
- Control based on Exact Linearisation
- Sliding Mode Control
- Control based on Energy
- Adaptive Control

Related activities:
Activity 5

Full-or-part-time: 16h
Practical classes: 12h
Laboratory classes: 4h

GRADING SYSTEM

The evaluation will be carried out by means of a partial exam, a final exam and evaluation of the laboratory activities. The weight of these two exams is 40% and 40%, respectively. The weight of the laboratory activities is 20%. To evaluate the laboratory activities, reports of each lab activity will be taken into account and, in addition, a writting test will be carried out the same partial and final exam days. Extraordinary evaluation will follow the School rules and it will substitute the mid-term and final exams.

EXAMINATION RULES.

The exam will be carried out individually with the authorised support material and on the established dates in the academic calendar of the master.

BIBLIOGRAPHY

Basic:
- Slotine, Jean-Jacques E; Li, Weiping. Applied nonlinear control. Englewood Cliffs, NJ: Prentice-Hall, cop. 1991. ISBN 9780130408907.
- Goodwin, Graham C ; Seron, M ; De Doná, José A. Constrained control and estimation [Recurs electrònic] : an optimization approach [on line]. London [etc.]: Springer Science & Business Media, cop. 2005 [Consultation: 30/03/2023]. Available on: https://link-springer-com.recursos.biblioteca.upc.edu/book/10.1007/b138145. ISBN 9781846280634.
- Maciejowski, Jan Marian. Predictive control : with constraints. New York: Prentice Hall, 2001. ISBN 0201398230.

Complementary:
- Khalil, Hassan K. Nonlinear systems. 3rd ed. Upper Saddle River, NJ: Prentice Hall, 2002. ISBN 9780130673893.
- Goodwin, Graham C ; Graebe, Stefan F ; Salgado, Mario E. Control system design. Upper Saddle River, N.J.: Prentice-Hall, 2001. ISBN 9780139586538.