Course guide
240AR014 - 240AR014 - Optimization in Control & Robotics

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 AUTOMATIC CONTROL AND ROBOTICS (Syllabus 2012). (Compulsory subject).
MASTER'S DEGREE IN INDUSTRIAL ENGINEERING (Syllabus 2014). (Optional subject).

Academic year: 2023 **ECTS Credits:** 4.5 **Languages:** English

LECTURER

Coordinating lecturer: FRANCISCO JAVIER RUIZ VEGAS

Others: FRANCISCO JAVIER RUIZ VEGAS
VICENÇ PUIG CAYUELA

PRIOR SKILLS

It is assumed that the student has the basic concepts in calculus, algebra and theory/differential system of equations acquired in the bachelor that gives access to the Automatic Control and Robotics Master's Degree.

DEGREE COMPETENCES TO WHICH THE SUBJECT CONTRIBUTES

Specific:
1. The student will be able to know how to apply the methods of parameter estimation and control / optimal states and the search techniques and constraint satisfaction applications of robotics area.
2. The student will be able to recognize and represent problems in the area by automatic and robotic techniques optimization, and then apply analytical methods / numerical resolution.

Generical:
3. Ability to conduct research, development and innovation in the field of systems engineering, control and robotics, and as to direct the development of engineering solutions in new or unfamiliar environments, linking creativity, innovation and transfer of technology
4. Have adequate mathematical skills, analytical, scientific, instrumental, technological, and management information.

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. Moreover, the student will be trained to the use of specific optimization software for the solution of problems and lab exercises. More precisely, MATLAB and ILOG OPL optimization packages will be introduced during the course and will be used in the labs.

STUDY LOAD

Type	Hours	Percentage
Hours large group	31,5	28.00
Self study	72,0	64.00
Hours small group	9,0	8.00

Total learning time: 112.5 h

CONTENTS

1. Continuous 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

Full-or-part-time: 25h
Theory classes: 6h 30m
Laboratory classes: 1h 30m
Self study : 17h

2. Discrete optimization and constraint satisfaction

Description:
2.1 Typical problems of discrete optimization (knapsack problem, travelling salesman problem, ...)
2.2 Deterministic discrete optimization algorithms: Branch and Bound, backtracking, greedy search, dynamic programming.
2.3 Heuristic/stochastic discrete optimization algorithms: Methods of Montecarlo/Las Vegas, genetic / evolutionary algorithms.
2.4 Constraint satisfaction problems.

Specific objectives:
- Be able to apply some algorithms of discrete optimization to typical problems (knapsack problem, travelling salesman problem, ...)
- Understand and be able to apply searching methods to solve constraint satisfaction problems.
- Know to use some discrete optimization and constraint satisfaction packages.

Related activities:
Activity 2

Full-or-part-time: 22h 30m
Theory classes: 6h
Laboratory classes: 1h 30m
Self study : 15h

3. Optimal control

Description:
3.1 Formulation of the problem of optimal control
3.2 Performance indices
3.3 Solution by means of Langrage multipliers (maximum principle)
3.4 Solution by means of dynamic programming
3.5 Solution by means of numerical methods (mathematical programming)
3.6 LQR control
3.7 Introduction to predictive control

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:
Activity 3

Full-or-part-time: 22h 30m
Theory classes: 6h
Laboratory classes: 1h 30m
Self study : 15h

4. Optimal estimation and filtering

Description:
4.1 Introduction to estimation
4.2 Principle of least square estimation
4.3 State estimation: Kalman filter
4.4 Parameter estimation: Recursive estimation
4.5 Relation between the state and parameter estimation
4.6 Control LQG: separation principle
4.7 Introduction to the hybrid estimation
4.8 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 4

Full-or-part-time: 22h 30m
Theory classes: 6h
Laboratory classes: 1h 30m
Self study : 15h

ACTIVITIES

1. CONTINUOUS OPTIMIZATION

Description:
In this activity, students will use the MATLAB program and its toolbox optimization.

Specific objectives:
- Learn to solve problems formulating them as continuous optimization problems.
- Learn to solve continuous optimization problems by means of numerical algorithms.

Material:
By the end of the activity, students will deliver a report of results.

Delivery:
Individual practice report.

Full-or-part-time: 2h
Laboratory classes: 2h

2. DISCRETE OPTIMIZATION

Description:
In this activity, students will learn to formulate a discrete optimization and to solve it by means of optimization solvers.

Specific objectives:
- Learn to solve problems formulating them as discrete optimization problems.
- Learn to solve discrete optimization problems by means of specific algorithms.

Material:
In order to develop the activity students will be use the MATLAB program and a discrete optimization solver.

Delivery:
Individual practice report.

Full-or-part-time: 2h
Laboratory classes: 2h

3. OPTIMAL CONTROL

Description:
In this activity, students will learn to formulate an optimal control problem as an optimization problem and to solve it by means of optimization solvers.

Specific objectives:
- Learn to solve control problems formulating them as optimization problems.
- Learn to solve optimal control problems by means of numerical algorithms of optimization.

Material:
In order to develop the activity, the students will be use the MATLAB program and its optimization toolbox.

Delivery:
By the end of the activity, students will deliver a report of results.

Full-or-part-time: 2h
Laboratory classes: 2h

4. PARAMETER ESTIMATION

Description:
In this activity, students will learn to formulate a system state/parameter estimation problems as an optimization problem and to solve them by means of optimization solvers.

Specific objectives:
- Learn to solve parameter estimation problems formulating them as optimization problems.
- Learn to solve parameter estimation problems using numerical optimization problems.

Material:
In order to develop the activity, the students will use the MATLAB program and its optimization toolbox.

Delivery:
By the end of the activity, students will deliver a report of results.

Full-or-part-time: 2h
Laboratory classes: 2h

5. STATE ESTIMATION

Description:
In this activity, students will learn to formulate a system state estimation problems as an optimization problem and to solve them by means of optimization solvers.

Specific objectives:
- Learn to solve state estimation problems formulating them as optimization problems.
- Learn to solve state estimation problems using numerical optimization problems.

Material:
Per desenvolupar l'activitat s'utilitzarà el programa MATLAB i la seva toolbox d'optimització.

Delivery:
Al final de l'activitat de lliurarà una memòria de resultats.

Full-or-part-time: 2h
Laboratory classes: 2h

GRADING SYSTEM

The evaluation will be carried out by means of a midterm exam (Units 1 and 2), a final exam (Units 1,2, 3 and 4) and evaluation of the laboratory activities. The weight of these two exams is 30% and 50%, 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 be done in the period established by the School and it will substitute the mark of the midterm 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:
- Boyd, Stephen P; Vandenberghe, Lieven. Convex optimization. Cambridge: Cambridge University Press, 2004. ISBN 9780521833783.
- Nemhauser, George L; Wolsey, Laurence A. Integer and combinatorial optimization. New York, NY: John Wiley and Sons, cop. 1988. ISBN 047182819X.
- Ogata, Katsuhiko. Discrete-time control systems. 2nd ed. Englewood Cliffs, NJ: Prentice-Hall, cop. 1995. ISBN 0130342815.

Complementary:
- Phillips, Charles L; Nagle, H. Troy. Digital control system analysis and design. 3rd ed. Englewood Cliffs, N.J: Prentice-Hall International, cop. 1995. ISBN 013309832X.
- Bhatti, M. Asghar. Practical optimization methods : with Mathematica applications. New York: Springer, cop. 2000. ISBN 0387986316.
- Winston, Wayne L. Operations research : applications and algorithms. 4th ed. Belmont: Brooks/Cole - Thomson Learning, cop. 2004. ISBN 0534423620.
- Marriott, Kim; Stuckey, Peter J. Programming with constraints : an introduction. Cambridge: MIT Press, cop. 1998. ISBN 0262133415.
- Grewal, M. S.; Andrews, A. P. Kalman filtering : theory and practice using MATLAB [on line]. 2rd ed. Hoboken, N.J.: Wiley, 2008 [Consultation: 20/09/2022]. Available on: https://onlinelibrary-wiley-com.recursos.biblioteca.upc.edu/doi/book/10.1002/9780470377819. ISBN 9780470377819.
- Lewis, Frank L. [et al.]. Optimal control. 3rd ed. New York: Wiley & Sons, 2012. ISBN 9780470633496.
- Lewis, Frank L. Applied optimal control & estimation : digital design & implementation. Englewood Cliffs: Prentice Hall : Texas Instruments, 1992. ISBN 013040361X.

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- Ollero Baturone, Aníbal. Control por computador : descripción interna y diseño óptimo. Barcelona: Marcombo Boixareu, DL. 1991. ISBN 8426708137.