SAPIENZA
UNIVERSITÀ DI ROMA

Didactic Offer

First year

First semester

Denomination	E.A.C.	SSD	CFU	Hours	Type Activity	Language
10596147 - Nonlinear Systems and Control			0	0		
Module I	B	ING-INF/04	6	60	AP	ENG
Module II	B	ING-INF/04	6	60		
10596148 - Filtering and Optimal Control			0	0		
Module I	B	ING-INF/04	6	60	AP	ENG
Module II	B	ING-INF/04	6	60		
Optional Group: Gruppo OPZIONALE:Lo studente deve scegliere 36 Cfu (l'acquisizione è da intendersi relativa a tutta la durata del corso di studi)	B					

Second semester

Denomination	E.A.C.	SSD	CFU	Hours	Type Activity	Language
10596147 - Nonlinear Systems and Control			0	0		
Module I	B	ING-INF/04	6	60	AP	ENG
Module II	B	ING-INF/04	6	60		
10596148 - Filtering and Optimal Control			0	0		
Module I	B	ING-INF/04	6	60	AP	ENG
Module II	B	ING-INF/04	6	60		
Optional Group: Gruppo OPZIONALE:Lo studente deve scegliere 36 Cfu (l'acquisizione è da intendersi relativa a tutta la durata del corso di studi)	B					
Optional Group: Gruppo OPZIONALE: Lo studente deve scegliere 18 cfu (l'acquisizione è da intendersi relativa a tutta la durata del corso di studi)	C					
- - A SCELTA DELLO STUDENTE	D		6	60	AP	ENG

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Optional Group: Gruppo OPZIONALE:Lo studente deve scegliere 36 Cfu (l'acquisizione è da intendersi relativa a tutta la durata del corso di studi)	B					
Optional Group: Gruppo OPZIONALE: Lo studente deve scegliere 18 cfu (l'acquisizione è da intendersi relativa a tutta la durata del corso di studi)	C					
- - A SCELTA DELLO STUDENTE	D		6	60	AP	ENG

Second semester

Denomination	E.A.C.	SSD	CFU	Hours	Type Activity	Language
Optional Group: Gruppo OPZIONALE:Lo studente deve scegliere 36 Cfu (l'acquisizione è da intendersi relativa a tutta la durata del corso di studi)	B					
Optional Group: Gruppo OPZIONALE: Lo studente deve scegliere 18 cfu (l'acquisizione è da intendersi relativa a tutta la durata del corso di studi)	C					
AAF1041 - Training	F		3	30	I	ENG
AAF1025 - Final exam	E		27	270	I	ENG

Detail of optional units

Denomination	E.A.C.	SSD	CFU	Hours	Type Activity	Language
Optional Group: Gruppo OPZIONALE:Lo studente deve scegliere 36 Cfu (l'acquisizione è da intendersi relativa a tutta la durata del corso di studi)						
1041422 - PROCESS AUTOMATION *(first semester)*	B	ING-INF/04	6	60	AP	ENG
1023235 - ROBOTICS I *(first semester)*	B	ING-INF/04	6	60	AP	ENG
1041453 - ROBUST CONTROL *(first semester)*	B	ING-INF/04	6	60	AP	ENG
1041426 - MULTIVARIABLE FEEDBACK CONTROL *(second semester)*	B	ING-INF/04	6	60	AP	ENG
1021883 - ROBOTICS II *(second semester)*	B	ING-INF/04	6	60	AP	ENG
1022775 - AUTONOMOUS AND MOBILE ROBOTICS *(first semester)*	B	ING-INF/04	6	60	AP	ENG
1041429 - CONTROL OF COMMUNICATION AND ENERGY NETWORKS *(first semester)*	B	ING-INF/04	6	60	AP	ENG
1041428 - DIGITAL CONTROL SYSTEMS *(first semester)*	B	ING-INF/04	6	60	AP	ENG
1041454 - DYNAMICS OF ELECTRICAL MACHINES AND DRIVES *(first semester)*	B	ING-IND/32	6	60	AP	ENG
1041431 - VEHICLE SYSTEM DYNAMICS *(second semester)*	B	ING-IND/13	6	60	AP	ENG
1041427 - Control of Autonomous Multi-Agent Systems *(second semester)*	B	ING-INF/04	6	60	AP	ENG
Optional Group: Gruppo OPZIONALE: Lo studente deve scegliere 18 cfu (l'acquisizione è da intendersi relativa a tutta la durata del corso di studi)						
10592834 - Neuroengineering *(second semester)*	C	ING-INF/06	6	60	AP	ENG
1021883 - ROBOTICS II *(second semester)*	C	ING-INF/04	6	60	AP	ENG
10592976 - Advanced methods in control *(second semester)*	C	ING-INF/04	6	60	AP	ENG

Denomination	E.A.C.	SSD	CFU	Hours	Type Activity	Language
1022775 - AUTONOMOUS AND MOBILE ROBOTICS *(first semester)*	C	ING-INF/04	6	60	AP	ENG
1022792 - COMPUTER AND NETWORK SECURITY *(first semester)*	C	ING-INF/05	6	60	AP	ENG
1041429 - CONTROL OF COMMUNICATION AND ENERGY NETWORKS *(first semester)*	C	ING-INF/04	6	60	AP	ENG
1055496 - Control problems in robotics *(first semester)*	C	ING-INF/04	6	60	AP	ENG
1041428 - DIGITAL CONTROL SYSTEMS *(first semester)*	C	ING-INF/04	6	60	AP	ENG
1022858 - MACHINE LEARNING *(first semester)*	C	ING-INF/05	6	60	AP	ENG
1041427 - CONTROL OF AUTONOMOUS MULTI-AGENT SYSTEMS *(second semester)*	C	ING-INF/04	6	60	AP	ENG

Summary

Tip. Att. (Tipo di attestato): **AP** (Attestazione di profitto), **AF** (Attestazione di frequenza), **I** (Idoneità)

E.A.C. (Educational Activities classification): **A** BASIC TEACHING/LEARNING ACTIVITIES **B** SPECIFIC TEACHING/LEARNING ACTIVITIES **C** RELATED/SUPPLEMENTARY TEACHING/LEARNING ACTIVITIES **D** ELECTIVE TEACHING/LEARNING ACTIVITIES **E** FINAL EXAMINATION AND FOREIGN LANGUAGE SKILLS **F** OTHER ACTIVITIES **R S** TRAINING PERIODS AND INTERNSHIPS AT COMPANIES, PUBLIC AND PRIVATE BODIES, AND PROFESSIONAL ROLLS (ART.10, PAR. 5, POINT E)

Objectives of the course

Filtering and Optimal Control

General goals (Mod. I) The course illustrates the methodologies of optimal control. The student will be able to formulate, analyze, and search for solutions of optimization problems of different nature by an appropriate use of optimality conditions, with emphasis on optimal control problems. Specific outcomes - Knowledge and understanding The Students will lean the methods of optimal control theory and the main applications in different fields. - Capability to apply knowledge and understanding The Students will be able to propose the optimal control strategies depending on the specific problem at hand. - Critical and judgment skill The Students will be able to analyze control problems, proposing and implementing optimal control strategies. - Communication skills The course activities will allow the Students to increase their communication capabilities in scientific fields. - Learning skills One of the aim of the course is to increase the critical skills of the Students; they will be able to tackle a control problem, starting from the literature analysis, to the optimal control aspects, up to the implementation. General goals (Mod. II) The course illustrates the basic estimation and filtering methodologies. The student will be able to use the most important estimation techniques and to formulate and study optimization problem of different kinds. Specific objectives - Knowledge and understanding The student will learn the estimation and filtering methodologies for being applied to different frameworks. - Capability of applying knowledge and understanding The student must be able, from the available data, of designing estimation algorithm for characteristic parameters of a process. - Critical and judgement skills The student will be able to formulate an estimation problem and design the optimal estimate, by implementing it to evaluate the consequent results - Communication skills The course will allow the student to communicate and share the main problems in specific application fields, by focusing on the possible design procedures and evaluating their strength or weakness - Learning skills The course will empower the analytical skills of the student, from the problem analysis to the study of the available scientific literature and down to the design and implementation

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VEHICLE SYSTEM DYNAMICS

General objectives The course aims to provide the student with a unified theory for the study of vehicles in general, with particular reference to terrestrial and marine vehicles. On one hand the vehicle is decomposed into sub-systems: (i) propulsion (ii) transmission (iii) thrust and directional components (iv) suspension systems (v) brake systems (vi) guidance and control. On the other hand, a general model of the vehicle integrating the considered sub-systems is developed able to predict the different manoeuvring ability of the vehicle. The theoretical foundation to approach vehicle dynamics is provided. Specific objectives Knowledge and understanding: The student will learn the basic methods for vehicle modelling, analysis and control. In the first part of the course the notions of vehicle dynamics are conveyed to the students, while in the second part, particular attention is paid to the mechanical, sensor and hardware subsystems in use. Apply knowledge and understanding: The student will be able to analyse and design different architectures of terrestrial and marine vehicles. Moreover, the student is required to mature a sufficient knowledge to integrate the mechanical design together with control algorithms for autonomous driving vehicles. Critical and judgment skills: The student will be able to choose both the modelling methodology most suited to the specific problem, and will be able to examine an innovative device in the field of vehicle dynamics, understanding the operating principles and carrying out a feasibility analysis, examining, when needed, the related patents. Communication skills: The course activities allow the student to be able to communicate / share the main content related to the innovation of new devices/vehicles, through the team's work when preparing the team's project. Moreover, the final examination of the team is inherent to market needs, modelling of vehicles, simulations and theoretical analysis of components of vehicles, that are part of a professional presentation prepared by the entire project team. Learning ability: The student will be able to tackle a project synthesis problem thanks to the planned examination method. The student, appropriately guided, puts into practice the "problem solving" techniques, i.e. the set of processes aimed at analysing, facing and solving a specific problem based on the examination of patents and/or recent publications.

MACHINE LEARNING

General Objectives: The objectives of this course are to present a wide spectrum of Machine Learning methods and algorithms, discuss their properties, convergence criteria and applicability. The course will also present examples of successful application of Machine Learning algorithms in different application scenarios. The main outcome of the course is the capability of the students of solving learning problems, by a proper formulation of the problem, a proper choice of the algorithm suitable to solve the problem and the execution of experimental analysis to evaluate the results obtained. Specific Objectives: Knowledge and understanding: Providing a wide overview of the main machine learning methods and algorithms for the classification, regression, unsupervised learning and reinforcement learning problems. All the problems are formally defined and theoretical basis as well as technical and implementation details are provided in order to understand the proposed solutions. Applying knowledge and understanding: Solving specific machine learning problems starting from training data, through a proper application of the studied methods and algorithms. The development of two homeworks (small projects to be developed at home) allows the students to apply the acquired knowledge. Making judgements: Ability of evaluating performance of a machine learning system using proper metrics and evaluation methodologies. Communication skills: Ability of writing a technical report describing the results of the

homeworks, thus showing abilities in communicating results obtained from the application of the acquired knowledge in solving a specific problem. Being exposed to examples of communication of results obtained in practical cases given by experts within seminars offered during the course. Learning skills: Self-study of specific application domains, problems and solutions during the homeworks, with possible application of teamwork for the solution of specific problems.

COMPUTER AND NETWORK SECURITY

General objectives To provide the concepts necessary to: (a) understand the meaning of information security and security of infrastructures and networks; (b) enable the student to make analysis of the fundamental security features of networks and infrastructures; (c) provide the fundamental tools for the design and the assessment of the solutions implemented in the network for the information security requirements. Methodologies and notions include cryptography, access control, security protocols and architectures, firewalls. Specific objectives Capacity to - recognize the requirements of confidentiality, integrity, authenticity, authentication and non-repudiation during the analysis/design phase, identifying suitable standards to guarantee them; - support the process of analysis and definition of security policies at the organization level; - critically evaluate infrastructures and applications with respect to security requirements; - assess the presence of significant vulnerabilities in infrastructures and applications; - study and understand security standards. Knowledge and understanding Knowledge of the fundamentals of cryptography. Understanding of certification mechanisms and digital signature. Understanding of cyber threats arising from interaction with the web and the internet in general Apply knowledge and understanding To select and use effective and secure encryption standards. To select and use effective and secure document fingerprinting standards. To use digital signatures. To choose secure authentication mechanisms. Critical and judgment skills Being able to assess the adequacy of IT security measures employed by a small/medium enterprise. Communication skills Being able to easily and effectively interact with industrial and ICT domain specialists for all issues related to information security. Knowing how to motivate results of analyses and requirements. Learning ability: Ability to read and understand documents with technical standards and/or for the disclosure of new IT threats.

Control of Autonomous Multi-Agent Systems

General objectives This course deals with modeling, analysis and control of multi-agent systems, with emphasis on communication/distribution networks and multi-robot systems. Specific objectives Knowledge and understanding: Students will learn basic methods for the modeling, analysis and control of multi-agent systems, with particular attention to distributed control strategies. In the first part of the course, applications will be presented to communication, energy distribution, transport networks, as well as to critical infrastructures and e-health platforms; in the second part, multi-robot systems will be studied, both terrestrial and aerial. Apply knowledge and understanding: Students will be able to analyze and design architectures and algorithms for the control of multi-agent systems in various application fields. Critical and judgment skills: Students will be able to choose the most suitable control methodology for a specific problem and to evaluate the complexity of the proposed solution. Communication skills: The course activities allow the student to be able to communicate/share the main problems concerning networks and systems presented in the course, as well as the possible design choices for the control of such networks/systems. Learning ability: The course development aim at giving the student a mindset oriented to the control of complex systems/networks by appropriately combining methodologies coming from the control theory as well as from other engineering disciplines.

CONTROL OF COMMUNICATION AND ENERGY NETWORKS

General objectives The course ... Specific objectives Knowledge and understanding: The course aims to apply control methods to networks/systems, with the adoption of a technology-independent approach that addresses the problem of controlling the network or systems regardless of specific technologies. These methodologies will be applied to communication, energy distribution and transport networks, as well as to critical infrastructures and e-health platforms. Apply knowledge and understanding: Students will be aware of the main problems and able to design control actions for communication, energy distribution, transport networks, as well as for critical infrastructures and e-health platforms. Critical and judgment skills: Students will be able to choose the most suitable control methodologies for specific problems and to evaluate the complexity of the proposed solutions. Communication skills: The course activities allow the student to be able to communicate/share (i) the main problems related to communication, energy distribution, transport networks, as well as critical infrastructures and e-health platforms, (ii) possible design choices for the control of such networks/systems. Learning ability: The course development methods aim to create a mindset of the student oriented to the control of complex systems/networks, by appropriately combining methodologies coming from the automation field and from various other engineering areas.

DIGITAL CONTROL SYSTEMS

General ojectives The course provides methodologies for the analysis of linear and nonlinear discrete time and sampled dynamics, the design of digital controllers with a major focus on linear systems, and implementation on embedded microcontrollers. The student will be able to compute digital models of given discrete time systems as well as digital discrete time equivalent models of continuous dynamics, to design digital control laws both for discrete and for continuous systems and to use standard microcontrollers for their implementation. Specific objectives Analysis and design techniques for discrete time and digital systems. Knowledge and understanding: The course provides methodologies for the analysis of linear and nonlinear discrete time and sampled dynamics, and for the design of digital controllers with a major focus on linear systems. Apply knowledge and understanding: The student will be able to compute digital models of given discrete time systems as well as digital discrete time equivalent models of continuous dynamics, to design digital control laws both for discrete and for continuous systems. Critical and judgment skills: The student will be able to choose between different methodologies, in order to solve the given problem in the best way. Communication skills: At the end of the course the student will be able to motivate his/her own design choices. Learning ability: The student will learn to develop independent studies by him/herself.

ROBUST CONTROL

General objectives The course presents advanced synthesis methods for the robust stabilization of linear multivariable and nonlinear systems in the presence of model uncertainties. Specific objectives Knowledge and understanding: Students will learn control design methods that handle the presence of structured or unstructured uncertainties on the model of the controlled system. The presented robust stabilization techniques will be based on the use of linear matrix inequalities (LMI) or on exact linearization via feedback and its extension to the case of non-measurable state. Apply knowledge and understanding: Students will be able to analyze robust stabilization problems for linear and nonlinear dynamical systems and to use advanced design techniques in the synthesis of control laws for their resolution. Critical and judgment skills: Students will be able to characterize structured and/or

unstructured uncertainties of the considered system, and to analyze the complexity of control law implementations, of their performance and critical issues. Communication skills: The course enables students to present some advanced and robust methods of solution for the classical problem of stabilization through feedback of dynamic systems. Learning ability: The course aims to create autonomous learning attitudes for the analysis and solution of control problems for linear multi-variable and nonlinear systems.

Nonlinear Systems and Control

General objectives The course presents the basic methodologies for studying the properties of processes decribed by a nonlinear model and design the necessary controller. The considered model are those described by a system of diffferential equations affine in the control; these models are successfully used to describe a variety of processes of interest in the engineering domain. Specific objectives Knowledge and understanding: Students will learn (1) the basic methodologies for studying the main properties from a control point of view and (2) the fundamental methodologies of nonlinear control and implemented architectures. Apply knowledge and understanding: Students will be able to apply the different methodologies for the analysis and control of nonlinear systems learnt in the course, to systems describing processes in different applicative fields. Critical and judgment skills: Students will be able to choose the most suitable control tools, between those studied in the course, to solve a specific control problem. they will be able to choose between different control strategies. Communication skills: The course activities will allow students to be able to communicate/share the main problems concerning nonlinear systems, as well as the possible design choices for the control of such systems. Learning ability: The course development aim at giving the student a mindset oriented to the comprehension of different metodologies, the capacity of setting up new ones in the solution of problems for the analysis and control of nonlinear systems

PROCESS AUTOMATION

General objectives The course aims at providing basic concepts and methodologies related to the most used control methodologies in the framework of process automation and at applying them to suitably modelled industrial process examples. Specific objectives Knowledge and understanding: The students will learn methodologies for the robust control of linear time-delay systems, Internal Model Control and Model Predictive Control with specific reference to process control problems. Apply knowledge and understanding: Students will be able to design robust controllers for process automation equipment, e.g., to achieve robust tuning of PID controllers, and to apply industrial Model Predictive Control algorithms. Critical and judgment skills: The student will be able to choose the most suitable control methodology for a specific process control problem starting from its state-space model or from its transfer-function model. Communication skills: The course activities allow the student to be able to communicate and discuss the main problems concerning process control and the possible design choices for their solutions in terms of control laws. Learning ability: The aim of the course is to make the students aware on how to deal with control problems in the context of process automation.

ROBOTICS II

General objectives The course provides tools for the dynamic modeling of robot manipulators, the use of kinematic redundancy, the design of feedback control laws for free motion and interaction tasks, including visual servoing. Specific objectives Knowledge and understanding: Students will learn the methods for the dynamic modelling of manipulators, for the use of kinematic redundancy, as well as how control laws can be designed to execute robotic tasks in free motion or involving interaction with the environment. Apply knowledge and understanding: Students will be able to analyze the robot dynamics and to design algorithms and modules for controlling robot trajectories and contact forces with the environment. Critical and judgment skills: Students will be able to characterize the dynamic functionality of a robotic system with reference to a given task, analyzing the complexity of the solution, its performance, and the possible weaknesses. Communication skills: The course will allow students to be able to present the advanced problems and related technical solutions when using robots in dynamic conditions. Learning ability: The course aims at developing autonomous learning abilities in the students, oriented to the analysis and solution of advanced problems in the use of robots.

Neuroengineering

* General objectives The course aims to introduce the principles, methodologies, and applications of the main engineering techniques used to study and interact with neural systems. * Specific objectives - Knowledge and understanding Students will learn the basics of the human brain functioning and organization at different scales, and to the main applications of engineering and information technologies to neuroscience - Applying knowledge and understanding Students will familiarize with basic tools to utilize to acquire, process and decode neurophysiological and muscular signals and to interface them with artificial devices - Critical and judgment skills Students will learn how to choose the most suitable control methodology for a specific problem and to evaluate the complexity of the proposed solution. - Communication skills Students will learn to communicate in a multidisciplinary context the main issues of interfacing neurophysiological signals with artificial systems, and to convey possible design choices for this purpose. - Learning ability Students will develop a mindset oriented to independent learning of advanced concepts not covered in the course.

ROBOTICS I

General objectives The course provides the basic tools for the kinematic analysis, trajectory planning, and programming of motion tasks for robot manipulators in industrial and service environments. Specific objectives Knowledge and understanding: Students will learn how actuation units and sensing components of robots operate, the basic methods for the kinematic modeling, analysis and control of robot manipulators, as well as the main algorithms for trajectory planning. Apply knowledge and understanding: Students will be able to analyze the kinematic structures of industrial robots and to design algorithms and modules for planning and controlling robot trajectories. Critical and judgment skills: Students will be able to characterize the functionality of a robotic system with reference to a given industrial or service task, analyzing the complexity of the solution, its performance, and the possible weaknesses. Communication skills: The course will allow students to be able to present the main problems and the technical solutions related to the use and application of robotic systems. Learning ability: The course aims at developing autonomous learning abilities in the students, oriented to the analysis and solution of problems in the use of robots.

Control problems in robotics

General objectives The course is composed of two modules and presents a selection of advanced topics in Robotics and is intended as an introduction to research. Guided through case studies taken from the research activities of the teachers, the student will be able to fully develop a problem in Robotics, from its analysis to the proposal of solution methods and their implementation. Specific objectives Knowledge and understanding: Students will learn some advanced control techniques used in some robotic research areas where the lecturers are active. Apply knowledge and understanding: Students will be able to use and design complex control systems for advanced robotic problems. Critical and judgment skills: Students will be able to evaluate some methodologies used in the difference robotic applied illustrated areas. Communication skills: The course activities will allow students to be able to communicate and share the different solutions, adopted in a research framework, for the different illustrated robotic areas. Learning ability: The course development aims at giving the student the capacity to design complex control systems for advanced robotic systems.

AUTONOMOUS AND MOBILE ROBOTICS

General objectives The course presents the basic methods for achieving mobility and autonomy in robots. Specific objectives Knowledge and understanding: Students will learn (1) basic methods for the modeling, analysis and control of mobile robots, both wheeled and legged, and (2) fundamental algorithms for autonomous motion planning. Apply knowledge and understanding: Students will be able to analyze and design architectures, algorithms and modules for planning, control and localization of autonomous mobile robots. Critical and judgment skills: Students will be able to choose the most suitable functional control architecture for a specific robotic system and to analyze its complexity as well as possible weaknesses. Communication skills: The course activities will allow students to be able to communicate/share the main problems concerning autonomous mobile robots, as well as the possible design choices for the control of such systems. Learning ability: The course development aim at giving the student a mindset oriented to the development of modules for the autonomous mobility of robots.

Advanced methods in control

General objectives: The course presents advanced methods of control for delay systems with unknown parameters. Specific objectives: Knowledge and understanding: The student will learn advanced techniques of control for delay systems with unknown parameters. Apply knowledge and understanding: The student must learn, from the available data, to design advanced algorithms of control in the presence of delays and unknown paramterers. Critical and judgment skills: The student will be able to analyze an estimation/control problem, formulating it and propose and implement the best estimation/control strategy by evaluating the ensuing results. Communication skills: The course activities will allow the Students to increase their communication capabilities in scientific fields. Learning ability: One of the aim of the course is to increase the critical skills of the Students; he will be able to tackle a control problem, starting from the literature analysis, to the optimal control aspects, up to the implementation.

MULTIVARIABLE FEEDBACK CONTROL

General objectives Analyze the performance limitations of a control system. Learn the specificities of multivariable systems. Formulate control problem with closed loop specifications in order to achieve robust stability and performance. Specific objectives Knowledge and understanding: Students will learn (1) the tools for evaluating the performance limitations and (2) to formulate in the frequency domain robust control problems for multivariable systems. Apply knowledge and understanding: Students will be able to analyze and design multivariable control systems. Critical and judgment skills: Students will be able to evaluate the attainable performance of a control system. Communication skills: The course activities will allow students to be able to communicate/share the main problems concerning multivariable control systems. Learning ability: The course development aims at giving the student the capacity to design complex control systems in a linear setting.

DYNAMICS OF ELECTRICAL MACHINES AND DRIVES

The course aims to guide the student in the understanding of the principles of operation of electrical drives and their components. The course provides the tools for analyzing the behavior of an electrical drive at steady state and during transients. The course is completed by some design fundamentals. At the end of the course the student will be able to understand the principle of operation and analyze the behavior of an electrical drive both at steady state and during transients. The acquired knowledge will allow to addressing design and control issues of electrical drives.

Final exam

The student will present and discuss the results of a technical activity, producing a written thesis supervised by a professor and showing the ability to master Control Engineering methodologies and/or their application.

Training

The specific aim is to allow the student to use and expand the bulk of knowledge acquired during the course of study performing some activities in an industrial setting, a company, or a research laboratory.