



Study Plan

School: Institute for Research and Advanced Training
Degree: Doctorate
Course: Mechatronics Engineering and Energy (cód. 456)

Specialization Energy

1st Year - 1st Semester Specialization Energy

Component code	Name	Scientific Area Field	ECTS	Duration	Hours
MAT08996D	Computational Mathematics and Optimization	Mathematics	6	Semester	156
INF08997D	Advanced Programming	Informatics	6	Semester	156
FIS08995D	Electromechanics of Continuous Media	Physics	6	Semester	156

Group of Options

Component code	Name	Scientific Area Field	ECTS	Duration	Hours
FIS09007D	Complexflow Structures of Earth Fluids	Energy and Environment	3	Semester	78
FIS09008D	Fossil Fuels and Carbon Sequestration	Energy and Environment	6	Semester	156
FIS09009D	Atmospheric Modelling	Energy and Environment	3	Semester	78
FIS09010D	Resources, Energy and Environment	Energy and Environment	6	Semester	156
FIS09011D	Advanced Energy Conversion Systems	Energy and Environment	6	Semester	156
FIS09012D	Advanced Combustion Topics	Energy and Environment	6	Semester	156
FIS09013D	Advanced Computational Fluid Mechanics Topics	Energy and Environment	6	Semester	156
FIS09014D	Advanced Topics on Energy Transfer	Energy and Environment	6	Semester	156
FIS10557D	Advanced Optimization on Electric Energy Systems	Energy and Environment	6	Semester	156
FIS10558D	Optimization of Equipments and Thermal Systems	Energy and Environment	6	Semester	156
FIS10559D	Applied Optics to Solar Radiation Concentration: New Applications	Energy and Environment	6	Semester	156
FIS10560D	Thermal Conversion of Solar Radiation at Medium and High Temperatures: Technologies and Applications	Energy and Environment	6	Semester	156

*** TRANSLATE ME:Optativa livre ***

1st Year - 2nd Semester Specialization Energy

Component code	Name	Scientific Area Field	ECTS	Duration	Hours
	Thesis				



2nd Year - 3rd Semester

Specialization Energy

Component code	Name	Scientific Area Field	ECTS	Duration	Hours
Thesis					

2nd Year - 4th Semester

Specialization Energy

Component code	Name	Scientific Area Field	ECTS	Duration	Hours
Thesis					

3rd Year - 5th Semester

Specialization Energy

Component code	Name	Scientific Area Field	ECTS	Duration	Hours
Thesis					

3rd Year - 6th Semester

Specialization Energy

Component code	Name	Scientific Area Field	ECTS	Duration	Hours
Thesis					

4th Year - 7th Semester

Specialization Energy

Component code	Name	Scientific Area Field	ECTS	Duration	Hours
Thesis					

4th Year - 8th Semester

Specialization Energy

Component code	Name	Scientific Area Field	ECTS	Duration	Hours
Thesis					

Conditions for obtaining the Degree:

*** TRANSLATE ME: Para aprovação na componente curricular nesta especialização deste programa de doutoramento é necessário a aprovação (através de avaliação ou creditação) das seguintes unidades curriculares: {\ }newline
 {\ }newline
 1º Semestre: {\ }newline
 - 3 UC Obrigatórias num total de 18 ECTS {\ }newline
 - 2 UC Opativas num total de 12 ECTS do conjunto de optativas disponíveis no plano de estudos desta especialização. {\ }newline
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 Para obtenção do grau, é necessário a aprovação na tese num total de 210 ECTS do 1º ao 4º ano ***

Specialization Mechatronic

1st Year - 1st Semester

Specialization Mechatronic

Component code	Name	Scientific Area Field	ECTS	Duration	Hours
MAT08996D	Computational Mathematics and Optimization	Mathematics	6	Semester	156
INF08997D	Advanced Programming	Informatics	6	Semester	156
FIS08995D	Electromechanics of Continuous Media	Physics	6	Semester	156



1st Year - 1st Semester
Specialization Mechatronic

Component code	Name	Scientific Area Field	ECTS	Duration	Hours
Group of Options					
Component code	Name	Scientific Area Field	ECTS	Duration	Hours
FIS08998D	MEMS Analysis and Modelling	*** TRANSLATE ME: Electrónica e Instrumentação/Projecto e Automação Industrial ***	6	Semester	156
FIS09006D	Reconfigurable Computing	*** TRANSLATE ME: Electrónica e Instrumentação ***	6	Semester	156
FIS08999D	Smart Structures and Materials	*** TRANSLATE ME: Projecto e Automação Industrial ***	6	Semester	156
FIS09000D	Computational Mechanics	*** TRANSLATE ME: Projecto e Automação Industrial ***	6	Semester	156
FIS09001D	Optimization of Structures and Mechanical Systems	*** TRANSLATE ME: Projecto e Automação Industrial ***	6	Semester	156
FIS09005D	Electronic Design Automation	*** TRANSLATE ME: Electrónica e Instrumentação ***	6	Semester	156
FIS09002D	Automatic Measurement Systems	*** TRANSLATE ME: Electrónica e Instrumentação ***	6	Semester	156
FIS09003D	Advanced Systems of Control and Supervision	*** TRANSLATE ME: Electrónica e Instrumentação/Projecto e Automação Industrial ***	6	Semester	156
FIS09004D	Advanced Systems Robotic	*** TRANSLATE ME: Electrónica e Instrumentação/Projecto e Automação Industrial ***	6	Semester	156
FIS10561D	Advanced Topics on Electronics and Energy	*** TRANSLATE ME: Electrónica e Instrumentação ***	6	Semester	156
*** TRANSLATE ME: Optativa livre ***					



**1st Year - 2nd Semester
Specialization Mechatronic**

Component code	Name	Scientific Area Field	ECTS	Duration	Hours
Thesis					

**2nd Year - 3rd Semester
Specialization Mechatronic**

Component code	Name	Scientific Area Field	ECTS	Duration	Hours
Thesis					

**2nd Year - 4th Semester
Specialization Mechatronic**

Component code	Name	Scientific Area Field	ECTS	Duration	Hours
Thesis					

**3rd Year - 5th Semester
Specialization Mechatronic**

Component code	Name	Scientific Area Field	ECTS	Duration	Hours
Thesis					

**3rd Year - 6th Semester
Specialization Mechatronic**

Component code	Name	Scientific Area Field	ECTS	Duration	Hours
Thesis					

**4th Year - 7th Semester
Specialization Mechatronic**

Component code	Name	Scientific Area Field	ECTS	Duration	Hours
Thesis					

**4th Year - 8th Semester
Specialization Mechatronic**

Component code	Name	Scientific Area Field	ECTS	Duration	Hours
Thesis					

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Para obtenção do grau, é necessário a aprovação na tese num total de 210 ECTS do 1º ao 4º ano ***



Conditions for obtaining the Degree:

*** TRANSLATE ME: Área de Especialização em Energia: {\ }newline
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Para aprovação na componente curricular nesta especialização deste programa de doutoramento é necessário a aprovação (através de avaliação ou creditação) das seguintes unidades curriculares: {\ }newline
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1º Semestre: {\ }newline
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Para obtenção do grau, é necessário a aprovação na tese num total de 210 ECTS do 1º ao 4 ano {\ }newline
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Área de Especialização em Mecatrónica: {\ }newline
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Para aprovação na componente curricular nesta especialização deste programa de doutoramento é necessário a aprovação (através de avaliação ou creditação) das seguintes unidades curriculares: {\ }newline
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Program Contents

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Computational Mathematics and Optimization (MAT08996D)

Representation of numbers in computing machines. Absolute and relative errors. Good and evil conditioned problems. Differentiation, integration and interpolation. Calculation derived from any order. Quadrature formulas, adaptive methods. Associated numerical errors. Interpolation of Lagrange, Hermite and continuity C_k Splines and NURBS. Interpolation curves, surfaces and volumes. Interpolation errors. Resolution of linear and non-linear equations. Direct and iterative methods for linear systems. Methods for sparse matrices, floods and large scale systems. Newton's method, quasi-Newton for nonlinear systems. Differential equations. Approximation of functions. The finite difference method. Integration methods in time (Runge-Kutta, multistep, Newmark, ...) The finite element method. Optimization. Optimization without restrictions. Necessary conditions of extreme. Methods for functions of one variable. Methods for multiple variable functions: algorithms unused and derived from use. Optimization with constraints. Optimality conditions and Lagrange multipliers. The interior point method. Multi-objective optimization. Global optimization. Genetic algorithms. Problems of Optimal Control.

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Advanced Programming (INF08997D)



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Electromechanics of Continuous Media (FIS08995D)

Algebra and tensor analysis{\}

Revision of base concepts of Mechanics: space, time, point, force, moment, mass and motion, and the corresponding mathematical description using tensors. Vector spaces of finite dimension, differentiation, reference systems and coordinate transformations.

Mechanics of continuous media{\}

The continuum hypothesis and the constitution of matter. Solids and fluids materials. Configurations, deformation and motion, Eulerian and Lagrangian descriptions. Deformation measures and deformation rates. Deformation of lines, areas and volumes and its material derivatives. Distributed forces and couples. Measures of stress in different configurations. Balance laws for the mass, momentum and energy in the integral and local form. The constitutive laws for the case of elastic solids and inviscid and Newtonian fluids. Objectivity. The first and second laws of Thermodynamics, entropy balance, reversible and irreversible processes.

Electrodynamics{\}

The Lorentz force and the notion of electric charge. Electric field, electric current and magnetic field, conductors, semiconductors, dielectrics and magnetic materials. The free space Maxwell equations in the integral and differential form. The electroquasistatic (EQS) and magnetoquasistatic (MQS) approximations. The polarization and conduction phenomena and the EQS equations in the presence of matter. The magnetization phenomena and the MQS equations in the presence of matter. The Maxwell equations in the presence of matter.

Equations of the electromagnetic continuum{\}

The influence of motion and the Maxwell equation in material form in the non relativistic approach. Electromagnetic forces exerted over matter. The Maxwell tensor. The influence of relativity.

Constitutive models{\}

The basic postulates of material modeling. The importance of experimentation. Examples for the thermal, elastic, plastic, viscoelastic, fluid, piezoelectric, piezomagnetic, electrostrictive, magnetostrictive, pyroelectric and pyromagnetic behaviour.

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Complexflow Structures of Earth Fluids (FIS09007D)

-Flows between volume (surface) to point and point to volume (surface). Competing regimes. Fluid trees.

- Constructal theory. Flow optimization under local constraints. Structure of fluid trees.

-Scaling laws. Hierarchy of scales Fractal description. Fractals and dynamics.

Application: River basins; flow through porous media (sub-soil); convective boundary layer; convection at planetary scale.

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Fossil Fuels and Carbon Sequestration (FIS09008D)

Geological genesis and deposits of hydrocarbons and coals. Resource base and reserve categories. Conventional and non-conventional hydrocarbon reserves. Types of deposits and extraction technologies. Enhanced oil and gas recovery.

Production and consumption statistics of fossil fuels. Categories and timelines. Energy efficiency of primary energy extraction. Assessment of ultimate reserves. Depletion rates and the Hubbert curve.

Petrochemical technologies. Conversion of solid and of gaseous fuels into synthetic fuels and feed-stocks. CTL and GTL trends. Syncrude.

Carbon biogeochemical cycle basics. Fossil fuels' combustion emissions. CO₂ capture methods in power stations. CO₂ sequestration; geological and oceanic sequestration solutions and opportunities.

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Atmospheric Modelling (FIS09009D)

Scales of motions and types of atmospheric models: LES, mesoscale, weather forecast and general circulation models.

The governing equations. Coordinate systems and projections.

Numerical methods and computational concepts. Discretization of the dynamic equations and parameterization of subgrid-scale physical processes.

Atmosphere-surface interactions and Boundary Layer representations. turbulence

Radiative transfer schemes. Clouds and precipitation. Shallow and deep convection. Atmospheric chemistry and aerosols parameterizations.

Data assimilation and model initialization.

Performing numerical simulations with atmospheric models: case studies



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Resources, Energy and Environment (FIS09010D)

- The climate system and environmental fluxes. Solar energy and planetary mechanical energy (wind, wave and hydropower energies). Photosynthesis and biomass. Potentialities and limitations for renewable energy and matter flows use.
- Mineral resources in the crust and the ocean. Amounts and types of mineral sources. Prospecting and discovery; quantification and time evolution of resources availability. Mineral extraction and processing; environmental impacts. Nature as source and sink of all fluxes; fluxes of energy and matter in the geosphere. Life-cycle analysis of economic activities.

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Advanced Energy Conversion Systems (FIS09011D)

1. Thermodynamics and chemical kinetics in homogeneous and heterogeneous media.
2. Kinetics and transport phenomena in energy systems.
3. Direct and indirect energy conversion.
4. Energy conversion using renewable energy systems.
5. Optimal integration of heterogeneous energetic systems for hybrid utilization.
6. Energy vectors production (hydrogen, syngas, etc.)
6. Theoretical chemistry fundamentals associated to energy conversion on the micro and macroscopic level.
7. Examples of energetic systems, referring, fuel cells, PV, supercritical cycle, combined cycle and advances gas turbine cycles.
8. Examples of power plants from industrial scale to microgeneration.

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Advanced Combustion Topics (FIS09012D)

1. Revisions of the basic aspects of combustion. Conservation equations for reacting flows. Chemical kinetics.
2. Turbulent flames. Structure of turbulent premixed and non-premixed flames. Turbulent flame speed. Flame stabilization.
3. Burning of liquids. Droplet evaporation and burning. Atomization and sprays. Combustion of sprays.
4. Burning of solids. Phenomena involved in the burning of solids. Heterogeneous reactions. Burning of carbon. Pulverized particles combustion. Fixed bed combustion. Fluidized bed combustion.
5. Energetic valorisation of biomass. Biomass characterization. Pyrolysis. Gasification. Types of gasifiers.

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Advanced Computational Fluid Mechanics Topics (FIS09013D)

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Advanced Topics on Energy Transfer (FIS09014D)

1. Revision of the fundamentals of thermal radiation and radiation exchange.
2. Radiative transfer in participating media: radiation in vacuum; attenuation by absorption and scattering; augmentation by emission and scattering; the radiative transfer equation and solution methods
3. Radiative properties of gases: Emission and Absorption probabilities; atomic and molecular spectra; spectral models (narrow/wide bands); total emissivity and mean absorption coefficient.
4. Radiation on particulate media and Radiation on semitransparent media;
5. Solution methods for the RTE: exact solution for one-dimensional gray media; approximate solution methods for one-dimensional media; numerical methods: PN-Approximation, the method of discrete ordinates, the zonal method.
6. Radiation combined with conduction and convection: radiation and conduction; radiation and convection in boundary layers; radiation and free convection; radiation and combustion; interaction radiation/ turbulence.



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Advanced Optimization on Electric Energy Systems (FIS10557D)

1. Energy Planning (EP)

Scheduling of EP; Historical Perspective of PS; Structure of PS; Production System and Load Diagram; Supply-side and Demand-side Models

2. Optimization Methods (OM)

Dynamic Programming (DP); Lagrangian Relaxation (LR); Linear Programming; Nonlinear Programming; Mixed Integer Linear Programming (MILP)

3. Scheduling of Thermal Units

Problem formulation (PF); Restrictions on Thermal Units (TU) and Hydraulic Units; Suboptimization and Optimality Principle; DP and LR

4. Economic Dispatch (ED) of TU

Function of Cost (FC); Linearization Techniques of FC; Equality and Inequality constraints; PF of ED; Optimization: MILP; Losses

5. Optimal Power Flow (OPF)

Problem of ED in the PS; PF of OPF; Primal / Dual solution

6. Hydrothermal coordination (HTC)

PF; HTC Short Term; Reservoirs in Cascata; Lagrange function; Lagrange's dual problem; OM: LR

7. Price

El of the Lagrange Dual Function; Marginal Price (M); Marginal Cost (MC); Shadow prices; Price Policies

8. Simulation and optimization

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Optimization of Equipments and Thermal Systems (FIS10558D)

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MEMS Analysis and Modelling (FIS08998D)

Introduction to MEMS: Examples of developed succeeded applications, actuators, sensors and offered possibilities.

Materials used in the applications: Possibilities offered by different materials, manufacturing related constraints. Material testing at this scale. Active materials, sensors and actuators.

Manufacturing processes: Chemical based processes. Mechanical based processes.

Modelling: Scale factor and the relevance of the associated phenomena. The contribution of gravity, electromagnetic, thermal and friction forces for the system behaviour. Governing equations of the structural system. Microfluidics and fluid structure interaction. Multiscale methods and particulate dynamics.

Analysis and design: The finite element method as an analysis tool. Application to the development of miniaturized machines, mechanisms, sensors and actuators.

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Reconfigurable Computing (FIS09006D)

1. Introduction to reconfigurable computing.

2. Reconfigurable hardware architectures: CPLDs e FPGAs.

3. Fine-grain and coarse-grain granularity.

4. Hardware description languages.

5. FPGA synthesis and mapping.

6. Fixed and reconfigurable processors.

7. Reconfigurable systems.

8. Static, dynamic and partial reconfiguration.

9. Hardware/software combined project.

10. New reconfigurable technologies.

11. Applications.



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Smart Structures and Materials (FIS08999D)

Application tailored materials. Anisotropy benefits. Classes of composite materials. Used materials and main manufacture processes. Constitutive laws, failure modes and criteria. Delamination, fracture and fatigue problems.

Composite materials modelling. Laminated plate and shell theories. Finite element models. Multiscale analysis.

Introduction to the smart material systems concept. Sensors and actuators. Ferroelectricity, piezoelectric, piezomagnetic, electrostrictive and magnetostrictive metallic, polymeric and ceramic materials. Main production processes. Constitutive laws. Shape memory alloys. Electrorheological and magnetorheological fluids. Passive and active damping capacity. Actuation force. Vibration absorbers. Optical fibers.

Smart structural components. Structure-actuator interaction. Current control systems. Active and passive vibration control in beams and plates.

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Computational Mechanics (FIS09000D)

Review of the basic equations of continuous media and energy principles in structural mechanics. Numerical solutions by finite differences, FEM and boundary elements.

Introduction to the usage of commercial codes, ANSYS, ABAQUS and integrated systems. CAE, CAD/CAM and CIM systems.

The Finite Element Method. Discrete approach and the computational implementation. Continuous approach. Formulation of beam, plate, shell and solid elements. Dynamic analysis, linear buckling. Comparison with commercial codes.

Introduction to nonlinear analysis, plasticity and large deformation analysis.

Element formulation for the solution of coupled problems (electrical, magnetic, thermal, mechanical, etc.) including active materials (piezoelectrics, magnetostrictives, electrostrictives, etc.). Finite element formulations for fluid flow.

Introduction to multiple scales analysis. Micromechanics and homogenization. Theorems and bounds on change and equivalence of scales.

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Optimization of Structures and Mechanical Systems (FIS09001D)

Objective functions on structures. Optimization algorithms. Local and global optimum. Sensitivity Analysis: design variables. Sensibilities by finite difference. Analytical sensitivities. Automatic differentiation. Classic algorithms, evolutionary and genetic.

Use of Matlab and Ansys programs in analysis and optimization of structures, plates, shells and composites structures.

Global systems of equations to analyze kinematic mechanism and its numeric solution. The resolution using the Newton-Raphson iteration method, and the modularity of the construction of the jacobiana array. Analysis of models contained in commercial codes and its applicability.

Beam and plate finite elements. Formulation of flexible bodies. Methods of substructures. Linearization complex systems. Control of mechanical systems and structures as application examples. Biomechanics of movement as a test case. Contact/impact of mechanical systems

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Electronic Design Automation (FIS09005D)

1. Introduction. "EDA" Concept.

2. Design environments.

3. Symbolic project.

4. High-level project.

5. Modelling.

6. Testing.

7. Implementation.



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Automatic Measurement Systems (FIS09002D)

AMS: Automatic measure. Definition and purpose of a AMS.

Revisions of metrology: measurement, Accuracy, accuracy class, uncertainties, law of propagation of uncertainty, probabilistic distribution laws.

Methods of adjustment and approximations of functions: Criteria of least squares, Chebyshev criterion.

Revisions of digital instrumentation.

Communication interfaces: GPIB, RS232, USB 2.0.

IEEE 488.2: Communication protocol (handshaking) Physical characterization.

Project SAM.

Virtual instrumentation.

Laboratory applications: Draft a SAM to:

- Measurement of impedances.
- Determination of the transfer function of dynamic systems.
- Determination of frequency response of filters.
- Measurement of signal noise.
- Characterization of A/D converters by static and dynamic methods.
- Measurement and characterization in the frequency domain of audible noise.
- Measurement of mechanical deformations.
- Measurement of meteorological and environmental parameters.

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Advanced Systems of Control and Supervision (FIS09003D)

1) Review of Control Systems: State-Space formulation, Regulators and State Observers.

2) Optimal Control Systems: Performance indexes; optimization problems, Optimal control systems based on quadratic performance indexes; Time optimal control systems.

3) Model Reference Control Systems: Adaptive controllers and Predictive Controllers.

4) Analog/ Digital Controllers.

5) Review of sequential systems based on programmable automation - PLCs.

6) Local Control and Remote Control. The communication in distributed systems. Industrial communication networks (Ethernet and ProfiBus). Cooperation among GRAFCET multiple processes. The management of Master/Slave control chains.

7) SCADA Systems. Implementation examples with commercial applications: Axeda Supervisor and Siemens WinCC.

8) Design and implementation of a SCADA application using OPC protocol to communicate with other softwares: Matlab, LabView, etc.

9) Development of specific drivers using advanced control algorithms.

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Advanced Systems Robotic (FIS09004D)

1) Review of Robotic Systems: Mathematical models of the robotic typical components; kinematic chains (direct and inverse kinematics); robotic dynamics.

2) Robotic Controllers: Independent-joint controller, resolved motion controller (hand coordinates). Linearized feedback controller, robust controller and adaptive controller.

3) Trajectory planning and maximization of functionals.

4) Practical aspects on the implementation of robotic position-controllers (Laboratory application with step-motors, encoders and PLC controller).

5) The automatic vision and its application to Robotics. Artificial vision equipment. Mathematical operators for image filtering and signal processing.

6) Practical aspects on the implementation of vision systems for robotics (laboratory applications based on Siemens VisionSensor VS710 e VS725)