DOCTORAL PROGRAMME IN ELECTRICAL AND COMPUTER ENGINEERING

PROGRAMME GUIDELINES

Scientific Committee

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Contents

1 INTRODUCTION

This document defines the general guidelines of the Doctoral Programme in Electrical and Computer Engineering. Additional annual information is given in the Annual Annex to the Programme Guidelines, which contains information to a specific academic year.

The Department of Electrical and Computer Engineering (DEEC) of the Faculty of Engineering, University of Porto (FEUP) offers a Doctoral Programme in Electrical and Computer Engineering (PDEEC), covering the major areas of Electrical and Computer Engineering. A set of advanced mandatory and elective courses are offered during the first year, organized in two semesters. Typically the programme requires 8 courses of 7.5 ECTS(1), and advanced research work to be submitted and defended as a PhD thesis.

The research environment is composed of DEEC and the following research institutes associated with FEUP: INESC-Porto (Institute for Systems and Computer Engineering of Porto), ISR - Porto (Institute for Systems and Robotics - Porto), INEB (Biomedical Engineering Institute) and IT (Telecommunications Institute). Cister - Research Centre in Real-Time Computing Systems from ISEP (Instituto Superior de Engenharia do Porto) is a host research centre associated with PDEEC.

FEUP and DEEC have on-going cooperation programmes with MIT, Carnegie-Mellon University and University of Texas at Austin.

(1) ECTS – European Credit Transfer System

1.1 Important Dates

The deadlines for application to PDEEC are the following:

- Fall semester: Not later than a date to be established in July.
- Spring semester: Not later than a date to be established in December.

The candidates will be informed of the admission to the programme within one month after the deadlines. The accepted candidates should start the studies the semester immediately after being notified.

1.2 Calendar

Fall semester:

- A date to be established in the period from September to February

Spring semester:

- A date to be established in the period from February to July

2 PROGRAMME ORGANISATION

PDEEC courses are organized in two semesters (see table below). The students typically select two main streams plus two other electives. Seminars and Individual Topics are additional courses designed to help the students starting the research work, and to prepare the thesis research plan under the supervision of a supervisor. The plan needs to be discussed and approved by a Supervisory Committee.

1st Semester	2nd Semester
Seminars	Individual Topics
Main Stream 1 (two courses)	
Main Stream 2 (two courses)	
Elective 1	Elective 2

The courses offered by PDEEC are organized into the following streams, each one having two semester courses:

- **ENMAR** - Energy Markets
- **PSDCO** - Power System Dynamics and Control
- **DICOM** - Digital Communications
- **COTEC** - Communication Technology
- **SYCON** - Systems and Control
- **DEHSY** - Discrete Event and Hybrid Systems
- **COMPS** - Computer Science
- **SIPRO** - Signal Processing
- **IMRML** - Image Recognition and Machine Learning
- **MICRO** - Microelectronics and Microsystems Operations
- **TTDTE** - Test Technology and Design for Testability
- **OPRES** - Operations Research
- **ROBOT –** Robotics
- **ERTS –** Embedded Real-Time Systems

3 Course Description

PDEEC courses are shown in the following table. The list of courses for each student needs a previous approval of the PDEEC Scientific Committee.

The streams and the corresponding courses are listed in the table below.

Stream	1st Semester	2nd Semester
ENMAR - Energy Markets	Markets and Regulation	Market Simulation
PSDCO - Power system dynamics and control	Signals, Dynamics and Control	Systems with Renewables
DICOM - Digital Communications	Special Topics in Digital Communications	Communication Networks and Multimedia
COTEC - Communication Technology	Mobile Communications Systems	Advanced Optical Communications Systems
SYCON - Systems and Control	Vector Space Methods	Measure Theory and Stochastic Processes
DEHSY - Discrete Event and Hybrid Systems	Discrete Event Systems	Hybrid Systems
COMPS - Computer Science	Model Driven/Aspect oriented Software	Grid computing
SIPRO - Signal Processing	Signal Analysis, Classification and Processing	Digital Signal Processing Systems Architectures
IMRML - Image Recognition and Machine Learning	Machine Learning	Image Analysis and Recognition
MICRO - Microelectronics and Microsystems	Microelectronic and Microelectromechanical Technologies	Advanced Microelectronic Systems Design
TTDTE - Test Technology and Design for Testability	Test and Design for Testability	Instrumentation and Systems Testing
OPRES - Operations Research	Decision Support	Optimization Techniques
ROBOT - Robotics	Robotic Manipulators	Mobile Robotics
ERTS – Embedded Real-Time Systems	Real-Time Embedded Systems	Distributed Embedded Systems
SECINF – Security and Information	Security of Systems and Networks	Information Theory
POWELE – Power Electronics	Power Conversion	Power Electronic Systems

3.1 Streams

Energy Markets

Year	Semester	ECTS	Course name	Stream
1st	1st	7.5	**Markets and Regulation**	**ENMAR**

Introduction to electricity markets, new structures, agents and relations. The pool market (symmetric and asymmetric, voluntary and mandatory) and bilateral contracts (physical and financial). Simple bids and complexity conditions (concepts and mathematical optimization models). Network services and cost allocation methods (average, incremental and marginal approaches). Models to compute nodal short term active power marginal prices. Interpretation of nodal prices and computation of the congestion rent. Analysis and discussion of application examples. Regulatory approaches in use by regulatory agencies (Cost-of Service/Rate of Return, Price Caps, Revenue Caps and Comparison). Discussion on the advantages and disadvantages of these strategies and analysis of application

examples. The Portuguese tariff code – structure, tariff variables, access tariffs and integral regulated tariffs.

Markets and equilibrium. Generalized equilibrium and equilibrium models. Markets of futures and interaction with spot markets. Investment Analysis.

Year	Semester	ECTS	Course name	Stream
1st	2nd	7.5	**Market Simulation**	**ENMAR**

Simulation of market processes and player interaction through mathematical programming is accomplished by traditional optimization using Linear Programming. Simulation through modern control theory as differential equation models and as discrete event system simulations (DESS) is accomplished with the inclusion of strategy for risk management. Simulation by intelligent agents is introduced as an extension of the previous models. Short term simulation and long term validation is made by comparing the use of repeated auctions into the future or the use of forecasting models to replace future markets. Industry segment models and decomposition provide the framework to isolate a single market simulation for a complete micro-economic model.

Power system dynamics and control

Year	Semester	ECTS	Course name	Stream
1st	1st	7.5	**Signals, Dynamics and Control**	**PSDCO**

Detailed modelling of loads, excitation systems, prime movers (hydraulic turbines, thermal units) and frequency regulation systems. Description of emergency control actions. Study of advanced stability enhancement techniques. Modelling AGC system and performance analysis in systems with several control areas. Control via fuzzy controllers, neural networks and computational intelligence algorithms. Fuzzy controller design using Mamdani models. Training Takagi-Sugeno and neural network controllers to optimize parameters.

Analysis of power system oscillations due to the lack of damping torque at the generators rotors. Review of the concepts of eigenvalue analysis of linear systems, addressing the linearization of the state equations, the construction of the linear model in the canonical state space form and the physical meaning of eigenvalues, eigenvectors, participation factors, residues and controllability and observability factors. Design and tuning of power system damping controllers tackling with the configuration of power system stabilizers.

Year	Semester	ECTS	Course name	Stream
1st	2nd	7.5	**Systems with Renewables**	**PSDCO**

Detailed modelling of different types of renewable energy conversion systems Impacts of renewable energy conversion systems in power system operation. Impacts of wind power on grid voltage stability and on system dynamic behaviour - Ride through fault. Use of wind generators to damp electromechanical oscillations. Photovoltaic electric principles and determination of operation point of PV cells. Sizing PV systems, including solar resource evaluation, optimal sizing of PV system components.

Grid code requirements and new hierarchical managing control structures.

Economic Issues: Remuneration of renewable energy systems and participation in electricity markets.

Combined wind generation / storage operation (optimizing wind – hydro pumping operation).

Microgeneration and microgrids: overview of microsources technological aspects and MicroGrids concepts, power electronic interfaces: modelling and control, MicroGrid control for islanded operation, requirements to use MicroGrids in service restoration, MicroGrid safety and electrical protection requirements, Multi-microgrids: management operation and control and vehicle to grid.Digital Communications.

Digital Communications

Year	Semester	ECTS	Course name	Stream
1st	1st	7.5	**Special Topics in Digital Communications**	**DICOM**

Modern Error Correcting Codes. Review of classical coding theory. Classical (block, convolutional) and modern (turbo, LDPC) codes. Information theory limits to coding gain. Principles of iterative decoding. MAP estimation with Soft In Soft Out (SISO) modules. Turbo decoding. Codes on Graphs, factor graphs. Message passing algorithms (belief propagation, sum product algorithm). Design of turbo and LDPC codes. Interleavers. EXIT charts and Density Evolution. Applications of the turbo principle. Turbo Equalization. Turbo Multiuser Detection. Turbo MIMO systems.

Advanced Digital Communication. Review of single carrier modulation schemes and communication channels. Signal space geometrical interpretation. Channel impairments and channel estimation. The RAKE receiver. Multicarrier modulation. OFDM for broadband wireless communications. DMT over the twisted pair channel. Multiple Input Multi Output (MIMO) systems and techniques. Multiple access techniques. Spatial Diversity, MIMO capacity and MIMO channel models. Space Time Codes.

Year	Semester	ECTS	Course name	Stream
1st	2nd	7.5	**Communication Networks and Multimedia**	**DICOM**

Preliminary program: Introduction: review of basic network concepts, architectural models and switching principles. Enabling network technologies for broadband and multimedia communications in LANs, MANs and WANs (Gigabit Ethernet, Wireless LANs, ATM, MPLS, etc); layer 2 and layer 3 network services (tunnels, VPNs, etc.). Quality of Service models - ATM and IP (IntServ and DiffServ) - and signaling control (RSVP, NSIS). Traffic Control and Resource Management - admission control, policing, shaping, congestion control, scheduling. Multimedia communications in IP networks - architecture and high-level protocols.

Communication technology

Year	Semester	ECTS	Course name	Stream
1st	1st	7.5	**Mobile Communications Systems**	**COTEC**

Preliminary program: Mobile communications systems: introduction, history, current systems, future. Wireless transmission: wireless channel, signal propagation, digital modulation, coding. Medium access: radio link, access techniques, random access control. Mobility management. Circuit communications systems: GSM, TETRA, DECT. Packet communications sytems: GPRS, UMTS, 802.16, 802.11, 802.15. Satellite and broadcast systems. Mobile Networking. Security. Multicast.

Year	Semester	ECTS	Course name	Stream
1st	2nd	7.5	**Advanced Optical Communications Systems**	**COTEC**

Preliminary program: EDFAs, Raman amplifiers and semicondutor amplifiers. System applications: preamplified receiver performance. Amplified optical systems: power levels and noise accumulation. Nonlinear effects in fibre: Raman, Brillouin and Kerr (SPM, XPM, FWM). WDM multiplexing components: filters, gratings. WDM systems crosstalk. Multichannel systems: time, subcarrier code and polarization division. Solitons and dispersion managed systems. Coherent detection techniques. Spectral efficiency limits.

Systems and control

Year	Semester	ECTS	Course name	Stream
1st	1st	7.5	**Vector Space Methods**	**SYCON**

Linear Spaces. Basic definitions, Normed linear spaces, Banach spaces, Complete subsets, Quotient spaces, Denseness and Separability.

Linear Dynamic Systems. Solution methods for (control and state) affine ODEs, Controllability and observability, Kalman decomposition, Systems compensation.

Hilbert spaces, Projection theorem, Orthogonal complements, Approximation series, Application to Least Squares Estimation - Least-Squares, Gauss-Markov, Minimum Variance.

Linear Operators. Basic definitions, Inverse operators (Banach inverse theorem), Singular value decomposition, Adjoints, Pseudoinverse.

Dual Spaces. Basic concepts, Hahn-Banach theorem, Geometric interpretation, Minimum norm problems, Dual problems.

Optimization of Functionals. Local theory – concepts of derivatives, Euler-Lagrange equations, constrained problems, Lagrange multiplier theorems, Pontryaguin maximum principle; Global Theory – convex-concave functionals, conjugate functionals, dual optimization problems, mini-max theorem of GameTheory, Lagrange multipliers, sensitivity, duality.

Year	Semester	ECTS	Course name	Stream
1st	2nd	7.5	**Measure Theory and Stochastic Processes**	**SYCON**

Introduction to Measure Theory: Theory of sets, Point set topology, Set functions, Construction and properties of measures, Measurability, Space of measurable functions, Definition and properties of the integral.

Introduction to Probability and Random Variables. Definitions and properties of probabilities, Algebra of events, Conditional probabilities, Random variables as measurable functions, Distributions, Characteristic functions, Moments, Independent random variables, Convergence of random variables, Joint distributions, The central limit theorem, Stochastic processes.

Stochastic models. General output sequence, ARMA models, Stochastic dynamic models, Innovations representations, Predictor models.

Filtering Theory. The geometry of linear estimation, Recursive estimation, The Kalman filter, Innovations representation of state space models.

System Identification. Point estimation theory, Models, Parameter estimation for static and dynamic systems, Off-line and on-line parameter estimation, Three stage least squares and order determination for scalar ARMAX models.

Discrete Event and Hybrid Systems

Year	Semester	ECTS	Course name	Stream
1st	1st	7.5	**Discrete Event Systems**	**DEHSY**

Introduction - Discrete-Event Systems, System Classifications.

Untimed Models of Discrete-Event Systems - Languages and Automata Theory, Petri Nets, Analysis of Untimed Models.

Time Models of Discrete-Event Systems - Timed State Automata, Timed Petri Nets, Algebra max-plus.

Stochastic Timed Models for Discrete-Event Systems - Introduction to Stochastic Processes, StochasticTimed State Automata, Generalized Semi-Markov Process, Poisson Process, Extensions of Generalized Semi-Markov Process

Markov Chains - Discrete-Time Markov Chains, Continuous-time Markov (Models, Transition Probability Matrix, Transient Analysis, Steady State Analysis), Controlled Markov Chains (Markov Decision Processes, Solving Markov Decision Problems).

Queueing Theory - Queueing Models, Performance and Dynamics of a Queuing System, Analysis of Markovian Queueing Systems, Markovian Queueing Networks, Control of Queueing Systems, Non-Markovian Queueing Systems.

Discrete-Event Stimulation - The Event Scheduling Simulation Scheme, The Process-Oriented Simulation Scheme, Discrete-Event Simulation Languages, Output Analysis.

Sensitivity Analysis - Sample Functions and Their Derivatives, Perturbation Analysis, Perturbation Analysis of GI/G/1 Queueing Systems, Infinitesimal Perturbation Analysis, IPA for Stochastic Time Automata, The Sensitivity Estimation Problem, Extensions of IPA, Smoothed Perturbation Analysis (SPA), Perturbation Analysis for Finite Parameter Changes, Sample Path Constructability Techniques.

Year	Semester	ECTS	Course name	Stream
1st	2nd	7.5	**Hybrid Systems**	**DEHSY**

This course addresses four main topics as follows: structure and interpretation of hybrid systems, modelling and simulation, analysis and design and applications. The first one includes motivation (convergence of computation, control and communications), fundamental concepts in dynamic systems: models; reachability; invariance; optimality and models of computation. In the second topic they are addressed formal models for hybrid systems (Finite automata; Differential equations; Hybrid automata; Open hybrid automata; Dynamic networks of hybrid automata), executions of hybrid

systems. and simulation tools and methods (Numerical methods; Simulink, Stateflow, Ptolemy and Shift), The third topic addresses properties of hybrid systems (sequence, safety, stability, liveness and ensemble), formal verification and decidability, reach set computations, Lyapunov stability of hybrid systems and controller design and optimal control of hybrid systems namely numerical methods (Fast Marching and Ordered Upwind Methods). Finally, the Applications include verified control architectures for multi-vehicle systems, coordination and control of dynamic systems, control over networks, embedded control and control and sensing languages.

Computer Science

Year	Semester	ECTS	Course name	Stream
1st	1st	7.5	**Model Driven/Aspect Oriented Software**	**COMPS**

Preliminary program: Model-driven Software Engineering: construction of formal, visual and executable models. Models verification and validation. Code generation from models. model based testing (implementation conformity).

Aspect Oriented Software Development: concepts associated to the aspect oriented programming paradigm. Aspect oriented programming languages. Aspect oriented requirements engineering and architecture design. Relationship and complementarily with other paradigms. Supporting tools and applications.

Year	Semester	ECTS	Course name	Stream
1st	2nd	7.5	**Grid Computing**	**COMPS**

Parallel Computing: Introduction to parallel computing, computer architectures, processors, memory organization and interconnection networks. Parallel Programming Fundamentals: task/channel paradigm, communication patters, synchronization, task granularity and scheduling. Cluster programming with MPI and OpenMP. Parallel computing characterization: execution models, programming models, computation models, performance and efficiency measures, scalability analysis.

Distributed Computing: a) peer-to-peer computing, pure and hybrid p2p networks, taxonomy of p2p systems and objectives of p2p networks. Applications: communications and collaborations, distributed computing, internet service support, data base applications and content distribution. P2P Algorithms for content distribution: centralized directory model, flooded request model and document routing model. b) Grid Computing Fundamentals and Standards Grid computing models: generic grid, utility grid and desktop grid; Evolution of grid middleware: metacomputing (Condor, LSF), resource-oriented (Globus 1, 2 and 3; LCG) and service-oriented (Globus 4, EGEE); Grid security: authentication, data integrity and encryption, authorization; Scheduling and Resource Management; Data Management; Grid Computing Portals; Hands-on Grid technology.

Signal Processing

Year	Semester	ECTS	Course name	Stream
1st	1st	7.5	**Signal Analysis, Classification and Processing**	**SIPRO**

Preliminary program: Advanced mathematical foundations for signal processing and stochastic systems: Signals models and distributions; Signal transforms, multiresolution processing and filterbanks; Feature extraction; Entropy-based signal analysis; Optimization and estimation techniques; Wiener and Kalman filtering; Dynamics of non-linear systems;. Signal classifiers: Trainable systems: Neural networks and Hidden-Markov chains; Statistical classifiers: vector quantization and clustering techniques

Year	Semester	ECTS	Course name	Stream
1st	2nd	7.5	**Digital Signal Processing Systems Architectures**	**SIPRO**

Preliminary program: Module1: Dedicated architectures for digital signal processing: Unified design of computing architectures and algorithms. Hardware/software partitioning. Dedicated and reconfigurable systems. Rapid prototyping of DSP systems. Numerical precision and speed/area trade-offs. FPGA and ASIP design flows.

Module2: Design of DSP-based systems. Technologies and methods for audio and speech processing systems and for artificial vision systems.

Image Recognition and Machine Learning

Year	Semester	ECTS	Course name	Stream
1st	1st	7.5	**Machine Learning**	**IMRML**

Introduction to Bayes Decision Theory: Likelihood function and a priori probability, optimal Bayes decision, predictive problems, Inference versus decision. Linear Models for Regression: criteria, the bias/variance decomposition and Gauss-Markov theorem, Ridge and Lasso regression, Bayesian regression. Linear Models for Classification: linear discriminant analysis and fisher discriminants, logistic regression, the perceptron algorithm, support vector machines, large margin methods. Non-Linear Regression and Classification: basis expansions (splines, polynomials, RBF, wavelets), neural networks, kernels and RKHS, classification and regression trees, prototype and nearest-neighbour methods, additive models and boosting. Unsupervised Learning: clustering algorithms, finite and infinite mixtures, SOM, other problems (density estimation, PCA, ICA). Learning Theory and Model Selection: expected and empirical risks, cross-validation, empirical/structural risk minimization, generalization bounds, capacity measures (VC, cover numbers, Rademacher). Graphical Methods: Bayesian networks, conditional independence, Markov random fields, inference in graphical models. Sequential Data: Markov Models, Hidden Markov Models.

Year	Semester	ECTS	Course name	Stream
1st	2nd	7.5	**Image Analysis and Recognition**	**IMRML**

From edges to textures: edge and corner detection, texture analysis, texture segmentation and texture matching. Segmentation by clustering: grouping and gestalt theory, image segmentation using basic clustering methods, embedding local constrains, segmentation by graph-theoretic clustering, graphs, affinity measures, eigenvectors and segmentation, graph cuts and normalized cuts. Model-based segmentation: fitting lines and curves, robustness, M-estimators and RANSAC. Cooperative Methods in Image Segmentation: sequential and parallel frameworks, hybrid Methods, other forms of co-operation (wrapper-based, iterative and interactive methods). Tracking: tracking using linear dynamical models. Kalman filtering. Tracking examples (tracking people, tracking vehicles), tracking with non-linear dynamical models, particle filtering, extended Kalman filters. Image Registration: similarity measures. invariant local features, strategies for image registration of rigid and non-rigid objects. Image Recognition: object and shape representation using invariant features, feature extraction and selection, principal component analysis, classifiers for object recognition, weak classifiers, combining classifiers, recognition examples (face detection and recognition, pedestrian finding).

Microelectronics and Microsystems

Year	Semester	ECTS	Course name	Stream
1st	1st	7.5	**Microelectronic and Microelectromechanical Technologies**	**MICRO**

The main goal of the Microelectronics and Microsystems course is to develop the background knowledge necessary to understand the state-of-the-art of semiconductor technology, as well as of Micro-Electro Mechanical Systems (MEMS), and the integration of mechanical elements and electronics. The course is divided in three modules: Module-I will cover the microelectronics fundamentals, such as: technology and modelling foundations of semiconductor devices (focus on MOS-FET) and low-voltage, low-power, high-speed and non-linear electronics. Module-II, MEMS sensors and actuators, focuses on Micro-Electro Mechanical Systems (MEMS) and the integration of mechanical elements and electronics. Module-III, deals with the interface between MEM-analogue and digital worlds, both at the circuit level and design methodologies, to bring understanding of the fundamental aspects associated with full integrated systems.

Year	Semester	ECTS	Course name	Stream
1st	2nd	7.5	**Advanced Microelectronic Systems Design**	**MICRO**

The course provides students with the background needed for the design and implementation of complex integrated electronic systems, starting from high-level abstract requirements and proceeding through successive refinement stages to a complete physical implementation in a modern, highly integrated, IC technology. The course promotes an understanding of the fundamental aspects of the timing, power and testability involved in this task, and a solid knowledge of how these factors influence

design methodologies and design decisions for different target implementations (e.g., sub-micron CMOS or platform FPGA). The main topics are high-level digital system specification and modelling, system integration and physical synthesis, system timing and clock management, power-aware system design, and testable system design.

Test Technology and Design for Testability

Year	Semester	ECTS	Course name	Stream
1st	1st	7.5	**Test and Design for Testability**	**TTDTE**

This module addresses the area of test and design for test, with an emphasis on four main topics: i) basic concepts, involving the rationale and economics of testing, as well as various introductory technological subjects; ii) digital design for test, discussing scan design and the IEEE 1149.X digital scan test standards; iii) memory testing, as an example of an application area where non-scan design for test methods and a variety of fault models coexist; iv) analogue and mixed-signal design for test, where IEEE scan-test methods and built-in self-test approaches are discussed. Various practical assignments are envisaged for the three last topics, involving IEEE 1149.x applications and circuitry, and a visit to the test department of an electronics assembly plant in the vicinity of Porto.

Year	Semester	ECTS	Course name	Stream
1st	2nd	7.5	**Instrumentation and Systems Testing**	**TTDTE**

Instrumentation and Systems Testing aims at complementing the studies on testing methods started with the Test and Design for Testability course, addressing now an upper level in the electronic systems hardware hierarchy, i.e., that concerning with the interaction among different parts in a system. The course contents address both hardware and instrumentation issues. Regarding hardware this course point towards studying the embedded testing of embedded cores, multi-chip modules, boards, and micro-electromechanical systems. For instrumentation, the goal is to discuss the architecture and functional requirements of automatic test equipment and the implementation of test instruments based on virtual instrumentation.

Operations Research

Year	Semester	ECTS	Course name	Stream
1st	1st	7.5	**Decision Support**	**OPRES**

The program of this course includes six main topics as follows: Operations research basics, Decision theory, Multicriteria decision-making, Simulation, Non-populational metaheuristics and Populational metaheuristics. Regarding Operations research basics, it addresses linear programming (the art and science of modelling – case studies and practice, linear programming and integer programming algorithm basic concepts and solving linear programming problems using open source tools) and heuristics and local search (heuristic approaches versus optimization algorithms, general combinatorial optimization models and constructive and improvement heuristics). Decision theory addresses topics as alternatives and states of nature, utility theory and decision trees. Multicriteria decision-making includes methods for multi attribute and multi objective problems and analytical hierarchy process. Simulation includes topics as simulation basics, statistical simulation and event based discrete simulation models. In non-populational metaheuristics they are studied techniques as Simulated Annealing, Tabu Search, Greedy Randomized Adaptive Search Procedure and Variable neighborhood search approaches while in Populational metaheuristics they are addressed Genetic Algorithms, Ant Colonies and Particle Swarm Optimization.

Year	Semester	ECTS	Course name	Stream
1st	2nd	7.5	**Optimization Techniques**	**OPRES**

The program of this course includes five main topics as follows: Operations research basics, Tree search algorithms, Constraint programming, Complexity analysis and design and Dynamic programming. Regarding Operations research basics, it addresses linear programming (the art and science of modelling – case studies and practice, linear programming and integer programming

algorithm basic concepts and solving linear programming problems using open source tools) and heuristics and local search (heuristic approaches versus optimization algorithms, general combinatorial optimization models and constructive and improvement heuristics). Tree search algorithms include the following topics: Branch and Bound algorithms, Column generation, branch and price algorithms and valid inequalities and branch and cut algorithms. Within Constraint programming they are studied constraint-based modelling, constraint propagation and consistency, constraint models for combinatorial problems and constraint programming languages – ILOG CP. In Complexity analysis and design they addressed algorithm complexity analysis and algorithm design. Finally, Dynamic programming includes the Bellman's optimality principle, recursion functions and states and stages – discrete dynamic programming.

Robotics

Year	Semester	ECTS	Course name	Stream
1st	1st	7.5	**Robotic Manipulators**	**ROBOT**

Rigid motions and homogeneous transformations: rotational transformations, homogeneous transformations. Forward and inverse kinematics: the Denavit-Hartenberg convention, inverse kinematics. The Jacobian: skew symmetric matrices, derivation of the Jacobian, singularities, static force/torque relationships, inverse velocity and acceleration, manipulability. Path and trajectory planning: potential fields, probabilistic roadmap, trajectory planning. Joint control: actuator dynamics, joint model, set-point tracking, PD, PID, feed forward and state space design. Manipulator dynamics: equations of motion, properties of robot dynamic equations. Manipulator control: robust control, adaptive control, force control, nonlinear control. Advanced external sensors: force/torque sensors, vision based sensors. Rapid teaching and programming interfaces: programming by demonstration, programming using advanced input-output devices, using CAD files.

Year	Semester	ECTS	Course name	Stream
1st	2nd	7.5	**Mobile Robotics**	**ROBOT**

Sensors and perception: sensor models, correlation-based measurement, feature-based measurement. Robot modelling: kinematics, dynamics, velocity / odometry motion model. Localization: local versus global localization, passive an active approaches, dynamic environments, multiple robots. Navigation and trajectory generation: configuration space, potential fields, road maps, cell decompositions. Motion control: feedback control, non-linear control, hierarchical systems. Cooperation and multi-robot systems. Applications (soccer, indoors, outdoors, aerial, underwater,…).

Embedded Real-Time Systems

Year	Semester	ECTS	Course name	Stream
1st	1st	7.5	**Real-Time Embedded Systems**	**ERTS**

Specification and modelling: Definition of real-time and embedded system; Origin and type of real-time constraints; Specification languages; Modeling techniques and technologies. Real-time scheduling: The recurrent task model and constraints (revisit multi-tasking OSs and concurrency concepts, the WCET...); Periodic task scheduling; Aperiodic task scheduling; Accessing shared resources. Real-time operating systems: Existing RTOS and their architecture (RTOS vs GPOS); Programming models associated to RTOS; Building an RT kernel.

Year	Semester	ECTS	Course name	Stream
1st	2nd	7.5	**Parallel and Distributed Embedded Systems**	**ERTS**

Multiprocessors: architecture and scheduling: Multiprocessors and multicores; Interprocessor communication paradigms; Global and partitioned scheduling; Access to globally shared resources. Distributed architectures and communication protocols: Distributed systems versus multiprocessors, global architecture (include highly dispersed distributed architectures); Modeling paradigms for distributed embedded systems; Protocols for real-time communication, the protocol stack; Holistic and end-to-end scheduling. Programming distributed systems: Time and state in distributed systems, clock

synchronization; Concurrency issues in distributed systems; Program partitioning and allocation; Middleware paradigms.

Information and Security

Year	Semester	ECTS	Course name	Stream
1st	1st	7.5	**Security of Systems and Networks**	**INFSEC**

The program of this course is divided into two parts:

1) Security Mechanisms: Symmetric ciphers, public key cryptography, key distribution, authentication, hash functions;

2) Services and security protocols: authentication applications, E-mail, IP and Web security, intrusion detection, malicious software, firewall

Year	Semester	ECTS	Course name	Stream
1st	2nd	7.5	**Information Theory**	**INFSEC**

Measures of Information: introduction to several measures of information such as entropy, conditional entropy, mutual information and divergence, as well as their main implications. The Asymptotic Equipartition Property. Study of the AEP and its consequences. Source coding: study of the source coding theorem; study of several source coding codes, comprising Huffman codes, Fano and Shannon. Algorithms for coding /decoding. Channel coding: study of the channel coding theorem; study of several channel coding codes, such as block codes, convolutional codes. Algorithms for coding /decoding. Theory of Rate-Distortion. Quantization. Rate-distortion function and theorem. Multi-user information theory: introduction to the fundamental concepts of information theory with multiple users; study of multiple access channel, broadcast and relay channels.

Power Electronics

Year	Semester	ECTS	Course name	Stream
1st	1st	7.5	**Power Conversion**	**POWELE**

Single and three-phase Pulse-Width Modulation (PWM) rectifiers. Modelling with instantaneous and average models. Model linearization. Design criteria for the AC inductance, the DC capacitor and the switching frequency. Main control requirements for active and reactive power control. Methods for grid synchronization: comparative analysis and design. Scalar control. Vector control. Sliding mode control. Direct power control. Sensorless control methods. Fuzzy, neural network and computational intelligence based control methods. Multilevel converters. Analysis of the neutral-point clamped, nested-cell topologies, and cascaded H-bridges. Control methods for multilevel converters: sinusoidal PWM and space-vector methods. Closed-loop control. Comparative analysis between multilevel converters and conventional converters. Application of multilevel converters in railway traction and high power drives. Active power filters: voltage and current source structures. Single and three phase topologies. Four wire active power filtering. Control strategies for active power filters: voltage control, reactive power compensation and harmonics cancellation. Control methods for active power filters: scalar and vector control methods, pq theory. Circuit layout guidelines for power converters. EMI generated by power electronics converters: mitigation methods. Thermal modelling of semiconductors and converters. High performance and dynamics analysis by simulation of power electronics converters based systems using MatLab, Saber^{TM} and PSIM software packages.

Year	Semester	ECTS	Course name	Stream
1st	2nd	7.5	**Power Electronic Systems**	**POWELE**

Fundamentals of renewable energy sources: wind energy, solar/photovoltaic energy, fuel cell and biomass. Modelling of renewable energy sources for power electronics conditioning. First stage conversion: form primary energy source to electrical energy. Fundamentals of electrical traction: electrical vehicles and trains. Modelling of mechanical loads for electrical circuits. Energy recovery. First stage conversion: form primary energy load to electrical energy. Power electronics conditioning

for the both domains: voltage and current sources. Analysis of requirements for converter design. Control methods considering the energy source/load characteristics: algorithms for maximum power flow. Analysis of converter control methods satisfying system requirements. Dynamical and permanent faults. Operation under abnormal conditions. Safe operation of global system. Standardization. High performance and dynamics analysis by simulation of power electronics converters based systems using MatLab, Saber™ and PSIM software packages.

3.2 Pre-requisites for the courses in the streams

The two courses included in one stream are offered in a sequence. Depending on the stream, the courses in the spring semester may have pre-requisites on the material studied in the corresponding course in the fall semester. Although there are no formal pre-requisites, the students before registering for the first time in the Spring semester should contact the PDEEC Scientific Committee to validate her/his registration.

3.3 Seminars and Individual Topics

Seminars and Individual Topics are two courses that prepare students to initiate their research work. During Seminars, students attend a set of technical and non-technical seminars (see section 5.2 for the past activities) together with a special topic under the supervision of a faculty member. Early in the semester, students must engage in conversations with the faculty and choose the thesis supervisor, who must be appointed by the Scientific Committee.

During Individual Topics with the help of the selected supervisor, students must define the scope and topic of the research. This typically consists in identifying the state-of-the-art material, and developing a research plan that must be submitted as a Thesis Research Plan (TRP).

3.4 Special Topics

Special Topics (7,5 ECTS) is an elective course offered in both semesters but the students may only do it once. The course assumes two different forms:

1. As a planned individual study on a topic not covered in the programme, but considered relevant for the topic of the thesis. In this case, the requirements are defined by the professor supervising the study.
2. As a teaching assignment, involving the students in teaching activities, as a Teaching Assistant (TA) in DEEC/FEUP. The goals are the following:
    1. To give PDEEC students the opportunity to be involved in teaching activities in Master Degree Courses offered in the Department of Electrical and Computer Engineering;
    2. To create opportunities for TAs to use their expertise and skill to co-operate in the development of course curriculum;
    3. To give TAs the opportunity to co-operate in course planning;
    4. To expose TAs to teaching activities at lab level to a limited number of students and at a lecture hall to the entire class.

The requirements in this second form, are:

- Preparation of lab work: set-up the experiments, prepare the theoretical background and elaborate the experimental guide (at least 4 lab works);
- Teaching activity in lab classes: to assist lab classes, accompanying students and evaluation activities of lab work;
- Teaching activity in theoretical classes: to teach two different topics in theoretical classes.

How to apply:

- Enrol in the course Special Topics;
- Interact with PDEEC Scientific Committee to define the supervisor or the course/professor of the Master Degree course offered by DEEC/FEUP.

The course will be evaluated by the study supervisor or by the professor of the master degree course, taking into consideration the requirements mentioned above.

3.5 Electives

Electives are optional courses. The students may select as an elective any course included in other streams or other courses offered by doctoral programmes in FEUP. Electives need to be approved by PDEEC Scientific Committee. If the student has already a supervisor, the electives should be approved by the supervisor and communicated to the Scientific Committee.

4 RESEARCH OVERVIEW

The PDEEC is organized in the Department of Electrical and Computer Engineering (DEEC) encompassing the major areas in Electrical, Electronics and Computer Engineering.

The DEEC research activity is mostly organized in R&D units recognized by the Portuguese Research Council (FCT). You may find relevant information regarding the research activities in the websites of these Institutes:

- INESC-Porto - Instituto de Engenharia de Sistemas e Computadores do Porto (www.inescporto.pt);
- INEB – Instituto de Engenharia Biomédica (http://www.ineb.up.pt – follow the Signal & Image division link);
- ISR–Porto – Instituto de Sistemas e Robótica (http://paginas.fe.up.pt/isrp/);
- IT – Instituto de Telecomunicações (http://www.it.pt/).

As a host research centre associated with PDEEC Cister - Research Centre in Real-Time Computing Systems http://www.cister.isep.ipp.pt/) (from ISEP (Instituto Superior de Engenharia do Porto) also cooperates in this doctoral program.

5 PROGRAMME ACTIVITIES

5.1 Seminars

As part of the course Seminars, the PDEEC invites a number of researchers to present overviews on advanced research topics in electrical and computer engineering as well as broader topics of general interest for science and engineering. Participating in these Lectures is mandatory for the PDEEC students as part of the development of their scientific background and general knowledge.

PDEEC also organizes a number of seminars in which Ph.D. students are invited to present their research. These seminars are intended to let the community know the research activities that are being conducted in the department. On the other hand, they are also an excellent way to help students develop their presentation skills. Every PDEEC Ph.D. student must present at least one seminar during their Ph.D. programme.

5.2 Past activities

As examples of the Lectures and Seminars just referred, during 2007/2008 the PDEEC organized the following Lectures:

- "Brain Machine Interface - modeling strategies for signal processing", Prof José Carlos Princípe, University of Florida, USA, and Invited Professor of FEUP, Porto, Portugal;
- "The Energy Challenges of the 21st Century - the role of renewable sources and rational end-use of energy", by Prof. Hans Puttgen, École Polytechnique Federale de Lausanne, Switzerland;
- "The Resilient Analogue, by Prof. Dinis Magalhães Santos, University of Aveiro, Portugal;
- "The Invisible Omnipresence of the Technologic Mediations", by Prof Teresa Levy, from the Centre for the Philosophy of Sciences, University of Lisbon, Portugal;
- "Cognitive Robotics: a multidisciplinary effort for the synthesis of socially intelligent robots", by Prof Estela Guerreiro Silva Bicho Erlhagen, University of Minho, Portugal.

Regarding the student seminars, the sessions already organized included the following presentations:

- "Management of Dynamically Reconfigurable Resources in Combined CPU/FPGA Systems", by Miguel Lino Magalhães Silva;
- "Overlay Networks over Wireless Sensor Networks", by Bruno Filipe Lopes Garcia Marques;
- "Synthetic Aperture Sonar Assisted by Satellite", by Sérgio Rui Santos Barbosa Oliveira da Silva;
- "Hybrid System Modelling and Control: An Impulsive Approach", by Rui Manuel Ferreira Gomes;
- "Infrastructure for the Coordination and the Distributed Control of Autonomous Heterogeneous Vehicles with Man-System Interactions", by Paulo Alexandre de Sousa Dias;
- "Distribution of Informational Contents via Internet", by Helder Fernandes de Castro.

In the first semesters of 2009/2010, 2010/2011, and 2011/"012 a number of sessions devoted to different topics on ECE were organized. More detailed information on these activities can be obtained in http://sites.google.com/site/eceback2basics/.

6 Path in the programme

6.1 Enrolling in the Programme

Students graduated in Electrical and Computer Engineering (including Electronics and Telecommunications) can apply to the PDEEC. Other profiles are likely to be accepted, especially in Computer Science, Physics or Energy and Environment. The admission of any candidate is subject to analysis and approval by the Scientific Committee of the Doctoral Programme PDEEC.

6.2 Student supervision

The student must find in the first semester a scientific supervisor. The dialogue between the Ph.D. candidate and the supervisor should be planned, frequent, encompass a fruitful discussion of scientific topics, and it is deemed crucial for the successful completion of the degree. The supervisor helps the student select the elective courses, formulate the research proposal, assist the students during the research period, check for timeliness of the research plan, and is also the liaison between the Ph.D. student and the PDEEC. Once the student chooses the Ph.D. supervisor, the Scientific Committee officially appoints the Supervisor and a Supervising Committee to each student and defines each student's Study Plan

6.3 Supervisory Committee

The Supervisory Committee must include the Supervisor, a second member from FEUP and a third external member, and it is appointed by the Scientific Committee in the 1st semester of the 2nd year. The supervisory committee must submit a yearly progress report to the PDEEC Scientific Committee evaluating the progress of the research.

6.4 Getting a degree

The Doctor Degree in Electrical and Computer Engineering is granted to the student that successfully:

- Completes 8 courses in PDEEC, obtaining 60 ECTS credit units;
- Gets approval from his Supervisory Committee for a Thesis Research Plan, submitted in the first semester of the second year in the Programme;
- Submits and successfully defends an original Thesis, as a result of the Research Plan previously accepted.

6.5 Defending the Thesis Research Plan

The research work to be done by the student must be defined by his Supervisor as early as possible, up to the end of the 1st year. The work done in the course Individual Topics must contribute to the preparation of the Thesis Research Plan to be submitted to the Supervising Committee. This plan is a written document that the student shall defend in an oral exam, to take place within 30 days of the submission of the TRP. If the student fails the oral portion of the exam, s/he may retake it only once within two semesters of the original defense date. A doctoral student becomes definitively a doctoral candidate when the following requirements are satisfied:

- The student academic record in all the courses is satisfactory;
- The student has a dissertation topic approved by the programme Scientific Committee;
- The student has Thesis Research Plan approved in the oral exam.

6.6 Thesis Submission

The Thesis must be submitted in English or Portuguese, although the former is advised. For the submission of the PhD thesis it is recommended that at least one journal article is accepted in a Journal listed in ISI Web of Science. This requirement is mandatory and takes effect for the PhD students that started their programme on or after the academic year 2010/2011.

7 Admission Procedures

For an application to be considered the candidates should have a Master Degree Diploma in Electrical and Computer Engineering or in equivalent fields. There are two phases to apply to PDEEC (the exact dates will be defined each year):

- 1st phase: April to July. For the selected candidates, the academic period starts in a date to be defined each year in September.
- 2nd phase: October to December. For the selected candidates, the academic period starts in a date to be defined each year in January.

Acceptance Requirements

Successful candidates for acceptance in this doctoral program will be:

a) Holders a master's degree or legal equivalent;
b) Holders of a *licenciatura*/bachelor's degree with relevant academic or scientific curriculum recognized by the program's Scientific Committee as enabling to attend this cycle of studies;
c) Owners of an academic, scientific or professional curriculum recognized by the Scientific Committee as enabling them to attend this cycle of studies.

The program´s Scientific Committee will assess the relevance of the academic and professional curricula and verify whether the educational background is appropriate to attend a doctoral program in Engineering.

Selection Criteria:

For the evaluation of the applications, the PDEEC Scientific Committee will take into consideration the following items, being the first four mandatory:

1. Curriculum Vitae of the candidate.
2. Certified transcripts of grades obtained in all courses and of final marks in degrees held by the candidate.
3. Motivation statement.
4. At least two recommendation letters (these letters should be sent directly by electronic means by the persons who write them to pdeec@fe.up.pt).
5. GRE – Graduate Record Examinations (http://www.ets.org/gre/).
6. TOEFL – Test of English as a Foreign Language (http://www.ets.org/).

The PDEEC Scientific Committee may require an interview to the candidate.

The application (including the required documents) should be submitted electronically through the FEUP website http://www.fe.up.pt.

Address:
Faculdade de Engenharia da Universiade do Porto
Serviços Académicos – Divisão de Pós-graduação e Educação Contínua
Rua Dr. Roberto Frias - 4200-465 Porto, Portugal
Tel.:+351225082130 | 225081406; Fax: +351225081409
http://www.fe.up.pt or http://paginas.fe.up.pt/~candidat/en/ Email: sposgrad@fe.up.pt

8 Important Documents and Forms

- Application form and other instructions: http://www.fe.up.pt/pdeec (follow the link Documents. This form is need for the application to the programme).
- Programme bylaws: http://www.fe.up.pt/pdeec (follow the link Documents). This document is in Portuguese. It defines the framework of the programme.
- For important information for candidates to FEUP go to the website:
  http://paginas.fe.up.pt/~candidat/en/

9 PhD Checklist

✓	In the 1st semester, complete 4 courses in 2 streams (2 courses per stream), plus Seminars and an optional course (typically a course in a different stream. This list of courses needs approval from the Programme Scientific Committee.	First Year
	Appoint the supervisor and co-supervisor if exists. The supervisor (and co-supervisor) must be appointed during the first year, being the 2nd semester the recommended period for this appointment.	
	In the 2nd semester, complete 4 courses in 2 streams (2 courses per stream), plus Individual Topics and an optional course (typically a course in a different stream. This list of courses needs approval from the Programme Scientific Committee.	
	Arrange with the supervisor(s) the details of your written Thesis Research Plan that is to be defended in the oral exam.	Second Year
	The Scientific Committee nominates the Supervising Committee	
	Take the oral exam during the 1st semester of the 2nd year.	
	At least two weeks in advance of the oral exam, notify, in writing, the Student Services Office of plans to complete the qualifying exam.	
	Pass oral exam	
	Based on a positive evaluation of your academic record in the courses and in the oral exam, the Scientific Committee can issue the definitive registration as a Doctoral Candidate	
	Check with the Graduate Office to see if all graduation requirements, including appropriate course credits, will be satisfied.	Semester Before Graduation
	Give the supervisor(s) and Graduate Office 8 copies of the dissertation. The Dissertation will be evaluated by an Examination Committee who will decide if it can be defended as is or if it needs any change. In this last case it needs a second re-submission.	

10 Living in Porto

10.1 About Portugal

Portugal is located is the westernmost country of mainland Europe and is bordered by the Atlantic Ocean to the west and south and by Spain to the north and east. The Atlantic archipelagos of the Azores and Madeira are also part of Portugal. Lisboa is the capital and the largest city. The second largest city is Porto.

The climate in Portugal is warm, and the annual temperature averages in mainland Portugal are 13 °C in the north and 18 °C. Recent studies indicate Portugal to be the 7th most peaceful and the 13th most globalized country in the world, ranking 19th with respect to the highest quality of life.

Portugal has a relatively low cost of living, as compared to other EU Member States, although some products might be more expensive here than in other countries. For example, you may have a full meal between €5 to €11 per person in a snack bar, or between €13 and €20 in a restaurant. We can take a taxi from the airport to the city centre for about €20 or a Metro ticket from FEUP to the city centre can cost you around €1. As for culture an entrance ticket to a Museum, National Monument or exhibition may cost between €2 and €5. A cinema ticket costs around €5.00.

10.2 About Porto

For relevant information about "Studying at FEUP" or "Living in Porto" or similar issues go to the web page http://paginas.fe.up.pt/~candidat/en/. Here we just summarize some of them.

The City of Porto has one of the richest artistic, cultural and historical heritages in Portugal, with several monuments and museums all over the city. This was officially recognised by UNESCO, which considered Porto (its historical part) as "World Heritage". It is to be stressed as well that Porto was chosen "European Capital of Culture 2001" in cooperation with Rotterdam. But Porto is also a city where its history can be found in a small street or in a dialogue with its inhabitants, so we invite you to explore it and start a new adventure here. Porto Wine is also world-famous and has left its mark on Porto.

There are several student residences. Please look at the following links to get more information:

- Accommodations: University of Porto
  http://sigarra.up.pt/sasup_uk/WEB_BASE.GERA_PAGINA?P_pagina=2287
- Residential Structures: www.bonjoia.org

10.3 How to arrive to Porto

BY PLANE

Porto is just 15/20 minutes away from Francisco Sá Carneiro - Porto International Airport, that has frequent flights to the main cities in Europe and America. For transportation to the city you can take the Metro (see the instructions below).

BY TRAIN

Porto is served by the "Porto - Campanhã" and "Porto - São Bento" train stations. To get to the hotel and the conference venue you must take a taxi or a bus. For updated information on timetables, lines and services: http://www.cp.pt. If you aim to visit the capital city, the price of Porto/Lisbon one-way ticket in an Alfa Pendular Train costs about € 30.00.

BY METRO

After getting the ticket at the Aeroporto Station, take line E (Violet) and change to line B (Red) at Verdes station (see the lines of metro here) and take the Metro till Porto (direction South). For more information: http://www.metrodoporto.pt/.

10.4 Arriving at FEUP

FEUP is served by the line D of METRO. The closest Metro Stations is IPO in line D (yellow line). For more details follow the link http://www.metrodoporto.pt/.

10.5 Useful information

You may find additional useful information in the following documents:

- **EURAXESS** – Researchers in Motion:
  http://sigarra.up.pt/up_uk/web_base.gera_pagina?p_pagina=122322
  Within the scope of the Research Mobility Strategy of the European Research Area, the European Commission launched **EURAXESS**. EURAXESS aims to encourage and support international mobility of researchers, within and outside Europe. EURAXESS – Researchers in Motion is, therefore, a gateway to attractive research careers in Europe and to a pool of world-class research talents;
- INESCPorto Welcome Guide: http://www2.inescporto.pt/ip-en/work-with-us/welcome-guide;
- Carnegie-Mellon Portugal Student Guide:
  http://www.cmuportugal.org/uploadedFiles/resources/carnegie_mellon_portugal_program_student_guide(3).pdf.