E-PiCo
Electric Vehicle Propulsion and Control

Erasmus Mundus Joint Master Degrees
Agreement number 2019-1452/001-001

With the support of the Erasmus+ Programme of the European Union

SYLLABUS

Erasmus Mundus Joint Master Degrees

Electric Vehicle Propulsion and Control: E-PiCo

ECOLE CENTRALE DE NANTES

KIEL UNIVERSITY

UNIVERSITY POLITEHNICA OF BUCHAREST

UNIVERSITY OF L'AQUILA

SEMESTER 1

SEMESTER 1 - ECN

CONTROL SYSTEMS		
Credits	4 ECTS	**Semester 1** **ECN**
Lectures	18 h	
Tutorials	4 h	
Labs	8 h	
Exam	2 h	
Total	32 h	
Instructor		Guy LEBRET - guy.lebret@ec-nantes.fr Franck PLESTAN – franck.plestan@ec-nantes.fr
Objectives		At the end of the course (30 hours + personal work) the students will be able to have basic skills on the analysis and the control of linear and non-linear systems with the state approach.
Content		Part 1: Linear systems • Systems analysis (commandability, observability) • Controllers synthetizes (state feedback, observers, output feedback) • Lab1: Inverse pendulum stabilization with linear controller Part 2: Nonlinear systems • Systems analysis (accessibility, observability) • Controllers synthetizes (input-output linearization, robust control) • Lab2: Inverse pendulum stabilization with nonlinear controller

RESEARCH METHODOLOGY		
Credits	4 ECTS	**Semester 1** **ECN**
Lectures	12 h	
Tutorials	4 h	
Labs	14 h	
Exam	2 h	
Total	32 h	
Instructor		Mohamed Assaad HAMIDA – mohamed.hamida@ec-nantes.fr
Objectives		• Understand research terminology. • Know the researcher qualities. • Describe quantitative, qualitative and mixed methods approaches to research. • Prepare bibliographic research.
Content		Digital ID of researchers Qualitatives research methods Literature review: • Systematic literature review • Content analysis • Citation bibliography management Scientific writing • Foundation of scientific writing • Structured scientific writing • Writing a research proposal • Writing a journal paper

<table>
<tr><th colspan="3">EMBEDDED COMPUTING</th></tr>
<tr><td>Credits</td><td>4 ECTS</td><td rowspan="6">Semester 1
ECN</td></tr>
<tr><td>Lectures</td><td>12 h</td></tr>
<tr><td>Tutorials</td><td>4 h</td></tr>
<tr><td>Labs</td><td>16 h</td></tr>
<tr><td>Exam</td><td>2 h</td></tr>
<tr><td>Total</td><td>34 h</td></tr>
<tr><td colspan="2">Instructor</td><td>Mikaël BRIDAY - mikael.briday@ec-nantes.fr</td></tr>
<tr><td colspan="2">Objectives</td><td>At the end of the course the students will be able to:
• understand the architecture of a microcontroller;
• design a low-level driver to access to a peripheral of a microcontroller and deal with microcontroller interrupts ;
design a bare metal application</td></tr>
<tr><td colspan="2">Content</td><td>The first part deals with the software environment for deeply embedded systems:
• cross compiler: bit operations, memory model, common C design rules, low level C and assembly specific attributes
• link script to declare the memory model to the application
• debugging with a JTAG probe (breakpoints, memory watch, …)
The second part introduces hardware peripherals of a microcontroller to interact with the environment:
• standard GPIO
• timers
• serial communication peripherals
• interrupts

The third part of the module focuses on the design of a bare metal application, including concurrent execution of both software and hardware parts.</td></tr>
</table>

<table>
<tr><th colspan="3">STATISTICAL SIGNAL PROCESSING AND ESTIMATION THEORY</th></tr>
<tr><td>Credits</td><td>4 ECTS</td><td rowspan="6">Semester 1
ECN</td></tr>
<tr><td>Lectures</td><td>12 h</td></tr>
<tr><td>Tutorials</td><td>10 h</td></tr>
<tr><td>Labs</td><td>8 h</td></tr>
<tr><td>Exam</td><td>2 h</td></tr>
<tr><td>Total</td><td>32 h</td></tr>
<tr><td colspan="2">Instructor</td><td>Eric LE CARPENTIER - eric.le-carpentier@ec-nantes.fr</td></tr>
<tr><td colspan="2">Objectives</td><td>This course addresses the characterization and the processing of random signals by means of statistical tools. It provides the theoretical foundations used in practical problems to estimate a quantity of interest and to retrieve sought information.

At the end of the course the students will be able to:
Provide a statistical description of a random process
Solve a statistical estimation problem in a practical situation
Derive a numerical algorithm to calculate and to characterize the solution
Introduction to Kalman filter</td></tr>
<tr><td colspan="2">Content</td><td>Probability theory: random vectors, density, mean, variance.
Time analysis, frequency analysis: random signals, autocorrelation, power spectral density.
Classical estimation Theory, Bayesian estimation: maximum likelihood (ML) estimation, minimum mean square error (MMSE) estimator, maximum a posteriori (MAP) estimator, linear minimum mean square error (LMMSE).
Markov chains, Markov processes
Statistical filtering: from Bayes filter to Kalman filter</td></tr>
</table>

FUNDAMENTAL OF ELECTRIC VEHICLE SYSTEMS		
Credits	4 ECTS	**Semester 1** **ECN**
Lectures	18 h	
Tutorials	4 h	
Practical	8 h	
Exam	2 h	
Total	32 h	
Instructor		Malek GHANES - malek.ghanes@ec-nantes.fr
Objectives		At the end of the course the students will be able to: • Policy ambitions and policy instruments for electric mobility • Role of electric vehicles (EV) and hybrid electric vehicles (HEV) in the energy transition • EV/HEV architectures topologies • Different components of EV system
Content		• Electrified vehicle systems : history, environmental and economic impacts • Architectures, Topologies of EV (and HEV) • Power Electronics: Components and Converters • Electrical Machines for EV and HEV • Energy Storage system for EV and HEV • Demonstration of electric vehicle propulsion chain

ELECTRICAL VEHICULE MODELLING AND SIMULATION		
Credits	4 ECTS	**Semester 1** **ECN**
Lectures	12 h	
Practical	18 h	
Exam	2 h	
Total	32 h	
Instructor		Malek GHANES - malek.ghanes@ec-nantes.fr
Objectives		At the end of the course the students will be able to: • Modeling and simulation of electric vehicle components • Models for electric vehicles • Design of electric vehicle model and simulator on Matlab-Simulink. • Design of electric vehicle model and simulator on industrial tool AMESIM
Content		Hybrid electric vehicles (HEV) will be studied and simulated using advanced powertrain component analysis and modeling. An in-depth analysis and study of power flows, losses, and energy usage are examined for isolated powertrain components and HEV configurations. Simulation tools will be developed and applied to specify powertrain and vehicle components and to develop control and calibration for a constrained optimization to vehicle technical specifications. • Brief recall on Different EV components • Introduction to the electric vehicle components modelling • View of energy flows • Computerized simulation of electric vehicle propulsion system using Matlab/Simulink • Introduction to industrial simulation tool AMESIM • Electric vehicle propulsion chain simulation using AMESIM

FRENCH LANGUAGE COURSES		
Credits	3 ECTS	**Semester 1** **ECN**
Lectures	30 h	
Total	32 h	
Instructor		Silvia ERTL - silvia.ertl@ec-nantes.fr
Objectives		The objective is to familiarize the learner with the French language and French culture through an entertaining task-based communicative language teaching, focused on speaking combined with: • Phonetics • Self-correcting exercises on our learning platform • Learning Lab activities • Project work • Tutoring
Content		Full range of practical communication language exercises: reading comprehension, listening comprehension, written expression, oral expression. Learners will be able to use the foreign language in a simple way for the following purposes: 1. Giving and obtaining factual information: • personal information (e.g. name, address, place of origin, date of birth, education, occupation) • non-personal information (e.g. about places and how to get there, time of day, various facilities and services, rules and regulations, opening hours, where and what to eat, etc.) 2. Establishing and maintaining social and professional contacts, particularly: • meeting people and making acquaintances • extending invitations and reacting to being invited proposing/arranging a course of action • exchanging information, views, feelings, wishes, concerning matters of common interest, particularly those relating to personal life and circumstances, living conditions and environment, educational/occupational activities and interests, leisure activities and social life 3. Carrying out certain transactions: • making arrangements (planning, tickets, reservations, etc.) for travel, accommodation, appointments, leisure activities • making purchases • ordering food and drink

SEMESTER 2

SEMESTER 2 - UPB

POWER ELECTRONIC CONVERTERS		
Credits	5 ECTS	**Semester 2** **UPB**
Lectures	28 h	
Labs	14 h	
Exam	2 h	
Total	44 h	
Instructor		Associate Professor Adriana FLORESCU
Objectives		To develop the knowledge and the abilities in the interdisciplinary domain of processing the electric power, with applications in communications, IT, industry, medicine etc.
Content		• Introduction in modern electric power conversion: circuit structure and application fields. • Electric power converters structure and functions: optimized structures. • Frequency and time analysis of switching topologies. • CA – CC, CA – CA, CC – CA and CC – CC converters used in electric vehicles. • Digital elements in power electronics. • Control in power electronic converters; microsystems implementation in electric vehicles

<table>
<tr><td colspan="3">ELECTRICAL MACHINES</td></tr>
<tr><td>Credits</td><td>5 ECTS</td><td rowspan="6">Semester 2
UPB</td></tr>
<tr><td>Lectures</td><td>14 h</td></tr>
<tr><td>Tutorials</td><td>6 h</td></tr>
<tr><td>Labs</td><td>8 h</td></tr>
<tr><td>Exam</td><td>2 h</td></tr>
<tr><td>Total</td><td>30 h</td></tr>
<tr><td colspan="2">Instructor</td><td>Prof. dr. Ing. Tiberiu TUDORACHE</td></tr>
<tr><td colspan="2">Objectives</td><td>To understand and to learn electrical machines and transformers notions and their use in electrical vehicle propulsion: principles of operation, symbols, mathematical equations, characteristic variables</td></tr>
<tr><td colspan="2">Content</td><td>
Electrical transformer. Transformer construction. Rated data and symbols. Theory and equations of single-phase transformer. Electric diagrams and phasor diagrams. Transformer power balance and efficiency. Operation characteristics of electrical transformers. Three-phase transformers.
DC machine. Construction of DC machine. Rated data and symbols. Magnetic fields in a DC machine. Theory and equations of DC generators and motors. Electromagnetic torque and power. Power balance and efficiency of DC machines. Operation characteristics of DC machines. Starting, braking and speed control methods of DC motors. Special DC motors.
Induction machine. Construction of induction machine. Rated data and symbols. Rotating magnetic fields and synchronous speed. Theory and equations of induction motor. Electric diagram and phasors diagram. Mechanical torque and power. Electromagnetic torque. Power balance of induction motor. Operation characteristics of induction motors. Kloss formula. Starting, braking and speed control methods of induction motors.
Synchronous machine. Construction of synchronous machine. Rated data and symbols. Theory of synchronous machine. Equations, electric diagrams and phasors diagrams of synchronous machine. Operation characteristics of synchronous machines. Special synchronous machines.
</td></tr>
</table>

<table>
<tr><th colspan="3">RENEWABLE ENERGY AND STORAGE SYSTEMS</th></tr>
<tr><td>Credits</td><td>5 ECTS</td><td rowspan="5">Semester 2
UPB</td></tr>
<tr><td>Lectures</td><td>14 h</td></tr>
<tr><td>Labs</td><td>12 h</td></tr>
<tr><td>Exam</td><td>2 h</td></tr>
<tr><td>Total</td><td>28 h</td></tr>
<tr><td colspan="2">Instructor</td><td>Prof. dr. Eng. Adriana FLORESCU</td></tr>
<tr><td colspan="2">Objectives</td><td>The initiation in the interesting, useful and dynamic reality of unconventional energy sources. Presentation of the main types of power electronic converters used in solar, eolian and fuel cells systems. Accustoming students with the performance parameters specific to the power electronic converters used in some of the unconvention power conversion systems.</td></tr>
<tr><td colspan="2">Content</td><td>1. Introduction in renewable energy sources
• Types of renewable energy sources and their dynamics
• Basic structers and functioning principles of renewable energy sources
• The components of solar, eolian and fuel cells systems
2. Converter topologies used in photovoltaic systems
• Single-phase converter topologies for photovoltaic systems
• Three-phase converter topologies for photovoltaic systems
3. Converter topologies for eolian systems
• Single level converter topologies for eolian systems
• Multi-level converter topologies for eolian systems
4. Converter topologies used in hydrogen fuel cells
• Voltage source inverters
• Current source inverters
• Z inverter
• Multilevel converter for hydrogen fuel cells systems
• Modular DC-DC converters for modular fuel cells
• Converter systems for medium power fuel cells systems
5. Grid synchronization of single-phase and three-phase converters
6. Dedicated systems used in the command and control of the converters
7. International reglemantation regarding renewable energy sources electronics</td></tr>
</table>

<table>
<tr><th colspan="3">NON LINEAR CONTROL SYSTEMS</th></tr>
<tr><td>Credits</td><td>5 ECTS</td><td rowspan="5">Semester 2
UPB</td></tr>
<tr><td>Lectures</td><td></td></tr>
<tr><td>Practical</td><td></td></tr>
<tr><td>Exam</td><td></td></tr>
<tr><td>Total</td><td></td></tr>
<tr><td colspan="2">Instructor</td><td>Prof. dr. Ing. Ciprian LUPU</td></tr>
<tr><td colspan="2">Objectives</td><td>Comprehensive analysis and synthesis of linear analogical control systems.
Control systems and their constituent parts analysis by means of transfer functions and state variables.
Knowledge of control system performance in time and frequency. Familiarizing students with simple control system design.
Description of basic control system constituents: transducers, signal conditioners, controllers</td></tr>
<tr><td colspan="2">Content</td><td>• Introduction: Classical control structures.
• Processes and phenomena nonlinearities analysis: nonlinearities in continuous processes, nonlinearities in mechanic and electrical processes, nonlinearities determined by hardware and software implementations.
• Real time hardware and software architectures for for electric mobile systems.
• Multimodel systems: multimodel structures; Optimum number of models/algorithms determination; selecting the best model/algorithm; multimodel system stability.
• Internal model systems: internal model structures; internal model structures specific problems;internal model construction;control algoritm design.
• Adaptive systems: adaptive structures; adaptive structures specific problems. Control design; stability.
• Multivariable process driving: control loop coupling and decoupling; implementing solutions.</td></tr>
</table>

MACHINE LEARNING FOR AUTONOMOUS SYSTEMS		
Credits	5 ECTS	**Semester 2** **UPB**
Lectures	28 h	
Labs	14 h	
Exam	4 h	
Total	46 h	
Instructor		Prof. dr. Ing. Anamaria RADOI - anamaria.radoi@upb.ro
Objectives		The main objective is to understand the fundamental concepts related to machine learning, to learn and to use the main methods of classification, clusterization and neural networks. This course combines fundamental aspects from the Machine Learning domain with practical aspects that can be encountered in autonomous systems. The activities performed during the semester familiarize the students with the basic theoretical and applicative aspects that allow solving problems that require knowledge in the field of artificial intelligence
Content		1. Introduction to Machine Learning 2. Probability theory and information theory: • Probability densities • Expectations and covariances • Gaussian distribution • Binary random variables • Multimodal random variables • Entropy • Mutual information 3. Decision theory: • Bayes rule • Cost functions • Minimizing the expected loss • Decision • Inference • Regression 4. Estimation • Maximum aposteriori estimation • Maximum likelihood estimation 5. Clustering • K-means • Gaussian Mixture Models • Hierarchical clustering 6. Unsupervised classification • K-Nearest Neighbors 7. Support Vector Machines 8. Artificial Neural Networks • Feed-forward neural network • Gradient descent optimization • Error backpropagation 9. Convolutional Neural Networks

<table>
<tr><th colspan="3">ROMANIAN CULTURE, CIVILIZATION AND LANGUAGE</th></tr>
<tr><td>Credits</td><td>5 ECTS</td><td rowspan="5">Semester 2
UPB</td></tr>
<tr><td>Lectures</td><td>6 h</td></tr>
<tr><td>Labs</td><td>6 h</td></tr>
<tr><td>Exam</td><td>2 h</td></tr>
<tr><td>Total</td><td>14 h</td></tr>
<tr><td colspan="2">Instructor</td><td>Yolanda-Mirela CATELLY – yolandamirelacatelly@yahoo.com</td></tr>
<tr><td colspan="2">Objectives</td><td>To ensure trainees' access to comprehensive yet general information on the Romanian culture and civilization. To enable them to reach level A2 – CEFR in terms of Romanian language competences. To develop students' further autonomous learning strategies and skills in the field of Romanian culture, civilization and language.</td></tr>
<tr><td colspan="2">Content</td><td>• A brief introduction into the Romanian culture, civilization and language - General aspects: geography, history, economy, tourism, arts, main Romanian personalities; first language 'pill': essential information on the Romanian alphabet, pronunciation of letters, vocabulary for survival.
• Cultural Stereotypes - What is your own nationality stereotype? To what extent do you think there are nationality types? Critical incidents; aspects connected with the topic of multiculturalism; additional language pill – survival kit. Applications: tasks to discuss and compare approaches to multicultural groups; understanding and developing tolerance and an open-mindedness towards diversity and variety; presenting critical incidents from the trainees' own experience
• The Seven Arts In Romania – A Discussion Of Culture And Civilization - architecture, sculpture, painting, music, poetry, dance, theater/cinema. Applications: students are asked to react to music and paintings, to solve quizzes about main Romanian cultural personalities, language linked to the cultural topics
• Economy of Romania - General; History; Free market transition; Natural resources; Energy; Physical infrastructure; Agriculture; Industry; Services; Foreign trade. Miscellaneous data on: Telecommunications; Social welfare; Science and technology; Education; Healthcare; Media; Sports. Some rankings of Romania. Applications: end-of-course comparative discussion with students about the situation in their own countries, as well as in the countries they also studied in within the project; language activities – for each subsection of the course input, essential words are given and practice is organized based on them
• An invitation to visit Romania – main touristic sights - general information about touristic Romania – links, other sources; advisable itineraries around Romania; maps and other information; suggested itineraries and sights; tourism language in pills on: hotel, money, transport by car/air/train etc.; important signs and notes; Language - days of the week; months of the year. Applications: students are invited to share from their own experience in Romania; express their preferences and interests so that to receive more information about them; 10-question final quiz to check attention and capacity of retention of information from course 5
• The Significance of the National Day of Romania: history, echoes etc. National Anthem – presentation of 1918 events; revision of Romanian language. Applications: revision of language knowledge
• End-of-course test - four sections: Romanian language knowledge; Romanian language in use; Romanian culture and civilization; Romanian memories. End-of- Course Evaluation Sheet</td></tr>
</table>

SEMESTER 2 - CAU

<table>
<tr><th colspan="3">DESIGN OF POWER ELECTRONICS CONVERTERS</th></tr>
<tr><td>Credits</td><td>5 ECTS</td><td rowspan="6">Semester 2
CAU</td></tr>
<tr><td>Lectures</td><td>20 h</td></tr>
<tr><td>Tutorials</td><td>6 h</td></tr>
<tr><td>Labs</td><td>4 h</td></tr>
<tr><td>Exam</td><td>2 h</td></tr>
<tr><td>Total</td><td>32 h</td></tr>
<tr><td colspan="2">Instructor</td><td>Prof. Dr.-Ing. Marco Liserre</td></tr>
<tr><td colspan="2">Objectives</td><td>The students have an in-depth knowledge in the design process of power electronics converters characterized by high efficiency and high reliability. The students have developed a working understanding about how to handle the electrical energy conversions in applications ranging from power supplies to renewable energies and electric drives. The students focus on power converters based on Pulse Width Modulation, and are able to design the power converter starting from the components (mainly semiconductors, passive elements and cooling system) toward the choice of the proper topology and consequently the selection of the modulation strategy.</td></tr>
<tr><td colspan="2">Content</td><td>The course is a basic course for developing a career in power electronics. The current drivers in power electronics design are efficiency, reliability and cost. Reliability has become only recently one of the main topics in power electronics and it is expected to be a major player in future years, due to the growing use of power electronics and the consequent safety concerns. Furthermore reliability affects deeply the cost of the system because of the cost of maintenance. Both reliability and efficiency depend on the management of the temperature, hence thermal models are very important.
The topologies of PWM converters and the modulation have a deep impact on efficiency and reliability as well as on the power quality.

Topics overview:
• Design of a Power Electronics Converter (Semiconductors and Drivers, Soft and hard switching, Busbar design, EMC problems and remedies, Thermal model)
• Topologies of PWM power converters (dc/dc, dc/ac, ac/ac): single-cell and multi-cell converters, matrix converters etc.
• PWM modulation (single-phase, three-phase, space-vector, multilevel, interleaving, continuous/dis- continuous, optimized)</td></tr>
</table>

ELECTRIC DRIVES		
Credits	5 ECTS	**Semester 2** **CAU**
Lectures	20 h	
Tutorials	6 h	
Labs	4 h	
Exam	2 h	
Total	32 h	
Instructor		Prof. dr. Ing. Marco LISERRE
Objectives		The students have in-depth understanding on the control of electric drives. The students can formulate the dynamical model of the most adopted electrical machines in electric drives, and consequently choice the design of their controllers. The students have developed experience in the control design of electrical machines through simulation software, like Matlab, and have validated the control strategies in Simulink environment.
Content		Electric drives are a key technology for reducing energy consumption of industrial processes, for modern wind energy power generation and for enabling green-transportation (electric and hybrid vehicles, electric trains, more electric ships and airplanes). Moreover electric drives are starting to be widespread making easier everyday life with automation and robotics. The course starts from a deep modeling phase of ac electrical machines, nowadays the most used. Then the field oriented control of the asynchronous and synchro- nous (Permanent Magnet) machines are treated in details due to their wide use and importance in modern electric drives. Exercises are carried out with CAE-tools (Matlab/Simulink). Topics overview: • Space vector representation of electrical machines • Dynamic model of the synchronous machine • Dynamic model of the asynchronous machine • Overview of PWM modulation • Overview of Current Control techniques • Vector control of the permanent magnet synchronous machine: Current control loop and Speed control loop • Vector control of the asynchronous machine: Flux observer

RENEWABLE ENERGY SYSTEMS		
Credits	5 ECTS	**Semester 2** **CAU**
Lectures	20 h	
Tutorial	6 h	
Labs	4 h	
Exam	2 h	
Total	32 h	
Instructor		Prof. dr. Ing. Marci LISERRE
Objectives		The students have a general knowledge about how renewable energy systems (especially Wind and Photo- voltaic) work, how they are structured and how they are organized in parks. The students understand the issues related to the interaction with the electric grid, and they are able to analyze national grid codes and international standards compliance, mostly regarding faults and islanding conditions regulations. The students can generally discuss on advanced topics related to ancillary services, use of storage, micro-grid operation, Combined Heat and Power plants, Bio-gas and special connection using High Voltage DC Transmission.
Content		• Introduction to the dynamic analysis of nonlinear systems • Lyapunov theory and Lyapunov-based design methods • Differential geometric basics and methods • Exact input-output linearization and exact input-state linearization • Differential flatness Computer-algebra-systems in control design

NON LINEAR CONTROL SYSTEMS		
Credits	5 ECTS	**Semester 2** **CAU**
Lectures	20 h	
Tutorials	6 h	
Labs	4 h	
Exam	2 h	
Total	32 h	
Instructor		Prof. dr. Ing. Habil. Thomas MEURER
Objectives		The students have an in-depth understanding of nonlinear control systems. They understand the underlying differential geometric concepts and are able to apply these to new problems. The students are able to analyze control theoretic properties. They have a comprehensive understanding of the nonlinear control design methods and are able to independently apply these methods to nonlinear control problems.
Content		• Introduction to the dynamic analysis of nonlinear systems • Lyapunov theory and Lyapunov-based design methods • Differential geometric basics and methods • Exact input-output linearization and exact input-state linearization • Differential flatness • Computer-algebra-systems in control design

ADVANCED METHODS IN NONLINEAR CONTROL (Option)		
Credits	5 ECTS	**Semester 2** **CAU**
Lectures	20 h	
Tutorials	6 h	
Labs	4 h	
Exam	2 h	
Total	32 h	
Instructor		Prof. dr. Ing. Habil. Thomas MEURER
Objectives		The students are able to explain the first and second method of Lyapunov and apply them for the stability analysis of nonlinear systems. They are able to decide for an appropriate control design method on the basis of the structural properties of a given system. The students can design controllers for nonlinear systems using different approaches and perform closed-loop stability analysis. They are able to implement basic numerical solvers for performing simulations of nonlinear control systems and discuss the performance of the closed-loop system.
Content		• Lyapunovs first and second method • Passivity-based control • Backstepping control • Extremun-seeking control • Sliding-mode control

APPLIED NONLINEAR DYNAMICS (Option)		
Credits	5 ECTS	**Semester 2** **CAU**
Lectures	20 h	
Tutorials	6 h	
Labs	4 h	
Exam	2 h	
Total	32 h	
Instructor		Prof. dr. Ing. Habil. Thomas MEURER
Objectives		The students are able to explain fundamental system properties using terminology from linear and nonlinear system analysis. They can analyze the stability properties and existence conditions for stationary and periodic solutions of dynamical systems using local and non-local approaches. The students know the differences between the basic types of bifurcations in one and two-dimensional continuous and discrete-time systems. They are able to implement basic numerical solvers for performing simulations of dynamical systems.
Content		• Linear and nonlinear dynamical systems • Qualitative behavior of vector fields • Local and non-local bifurcations • Discrete-time nonlinear systems • Introduction to deterministic chaos

CONTROL OF PDE SYSTEMS (Option)		
Credits	5 ECTS	**Semester 2** **CAU**
Lectures	20 h	
Tutorials	6 h	
Labs	4 h	
Exam	2 h	
Total	32 h	
Instructor		Prof. dr. Ing. Habil. Thomas MEURER
Objectives		The students have an in-depth understanding of control design methods for distributed parameter systems governed by partial differential equations. They understand the underlying mathematical concepts and are able to apply these to new problems. The students are able to analyze control theoretic properties for distributed parameter systems. They have a comprehensive understanding of the control design methods and are able to independently apply these methods to control problems involving partial differential equations.
Content		• Introduction to the distributed parameter systems: Mathematical modeling, classification, solution techniques for partial differential equations • Analysis and control design in frequency domain: input-output stability, output feedback control • Analysis and control design in time domain: controllability and observability, stability theory, state feedback control, backstepping • Flatness-based methods for trajectory planning and tracking control

EMBEDDED REAL TIME SYSTEMS (Option)		
Credits	5 ECTS	**Semester 2** **CAU**
Lectures	20 h	
Tutorials	6 h	
Labs	4 h	
Exam	2 h	
Total	32 h	
Instructor		Prof. dr. Rheinhard VON HANXLEDEN
Objectives		A cell phone that transmits voice signals correctly, but with too much delay, is unsatisfactory. An airbag controller, that ignites the correct airbags, but does so too late, is life threatening. These are two examples of embedded real-time applications, for which the reaction time is as critical as the reaction result. This lecture provides an introduction into different aspects of embedded real-time systems. After successfully completing this module, the students will understand the fundamentals of embedded/real-time systems. Students will be able to select suitable platforms and programming languages for such systems, and they will be able to conduct design projects in this area. They will be aware of dependability concerns, and should be familiar with concurrency issues.
Content		• Model-based design • Concurrency and scheduling • Embedded hardware • Distributed real-time systems • Worst-case execution time analysis

MATHEMATICAL METHODS IN FIELD THEORY (Option)		
Credits	5 ECTS	**Semester 2** **CAU**
Lectures	20 h	
Tutorials	6 h	
Labs	4 h	
Exam	2 h	
Total	32 h	
Instructor		Prof. dr. Ing. Ludger KLINKENBUSCH
Objectives		The students are able to describe standard mathematical methods in field theory and to analytically calculate scalar und vector fields. They can judge general features of linear operator equations in field theory and neighboring disciplines, e.g. systems theory. Students have the ability to mathematically model corresponding problems in engineering.
Content		• Mathematical foundations: Dirac "δ-Function", δ-convergent series, ortho-normalized function systems, Sturm-Liouville-Theory (Solution of boundary value problems with ordinary 2nd order differential equations) • Green's functions: Definition, properties, representations, solution of boundary value problems by means of Green's functions, 1st and 2nd boundary value problems (Dirichlet and Neumann problems) • Helmholtz- and Laplace equation: Separation in plane-polar coordinates, separation in spherical coordinates, free-space solutions • Multipole analysis of electromagnetic fields: Maxwell's equations, spherical-multipole analysis, plane-wave expansion, Diffraction by a sphere (Mie theory)

SEMESTER 2 - UAQ

POWER ELECTRONICS CONVERTERS		
Credits	5 ECTS	**Semester 2 UAQ**
Lectures	30 h	
Tutorials	20 h	
Exam	2 h	
Total	52 h	
Instructor		Concettina BUCCELLA - concettina.buccella@univaq.it
Objectives		The course will introduce some fundamental concepts related to power electronics converters, in particular, those suitable for transportation electrification: electric power trains and recharging infrastructures.
Content		• Power devices for transportation electrification: diode, MOSFET, IGBT; silicon and wide band gap devices • DC/DC Converters for electric vehicles • AC converters for electric vehicles • Fundamental control techniques for power converters for transportation electrification • Modulation of power converters • Wired and wireless recharging systems Simulation of electric power trains and recharging systems.

ELECTRICAL MACHINES		
Credits	5 ECTS	**Semester 2 UAQ**
Lectures	30 h	
Tutorials	20 h	
Exam	2 h	
Total	52 h	
Instructor		Carlo CECATI - carlo.cecati@univaq.it
Objectives		The course will introduce some basic concepts related to modeling, analysis, simulation and control of electric machines and their operations in electric vehicles. The interaction between the electric machine and the power converter will also be highlighted.
Content		• Principles of electro-mechanical energy conversion • DC machines and their static and dynamic models • Rotating magnetic field and AC machines • Induction motors, permanent magnets synchronous motors • Static and dynamic models of AC machines • Scalar and vector control of AC machines • Sensorless control of AC machines • Power converters for electric power trains and their interaction with the electrical machine.

RENEWABLE POWER ENERGY AND STORAGE SYSTEMS		
Credits	5 ECTS	**Semester 2** **UAQ**
Lectures	30 h	
Tutorials	20 h	
Exam	2 h	
Total	52 h	
Instructor		Carlo CECATI - carlo.cecati@univaq.it
Objectives		The course will introduce some basic concepts related to generation of electric energy from sun, wind and hydro and their conversion in forms suitable for utilization in electric vehicles and in storage systems. The interaction between the electric powertrain and the battery energy storage system will also be highlighted.
Content		• Principles of photovoltaic energy systems and their operations • Principles of wind and hydro energy systems and their operations • Principles of Fuel Cells and their operations • Maximum Power Point Tracking and optimization of energy conversion • Principles of electrochemical conversion and control • Power converters for Renewable Energy Systems and for Battery Management Systems • Integration of energy storage systems with the grid.

NONLINEAR CONTROL SYSTEMS		
Credits	5 ECTS	**Semester 2** **UAQ**
Lectures	40 h	
Tutorials	20 h	
Exam	2 h	
Total	62 h	
Instructor		Stefano DI GENNARO - stefano.digennaro@univaq.it
Objectives		The aim of the course is to provide the student with knowledge of the fundamental properties of nonlinear systems and on some design techniques of controllers, and with skills in designing such controllers some relevant classes of such systems. On successful completion of this module, the student will be able to design controllers for the stabilization of nonlinear systems and for the tracking of desired trajectories.
Content		Introduction to nonlinear systems and examples. Fundamental properties: Existence and uniqueness, continuous dependence on initial conditions and parameters. Differentiability of solutions and sensitivity equations. Comparison principle. Lyapunov stability of autonomous and nonautonomous systems. The invariance principle. Linear systems and linearization. Center manifold theorem. Converse theorems. Perturbed systems and ultimate boundedness. Input–to–state stability. Some design techniques: regulation theory (introduction), stabilization via linearization, backstepping, sliding mode control.

<table>
<tr><th colspan="3">HYBRID SYSTEMS CONTROL AND SIMULATION</th></tr>
<tr><td>Credits</td><td>5 ECTS</td><td rowspan="5">Semester 2
UAQ</td></tr>
<tr><td>Lectures</td><td>40 h</td></tr>
<tr><td>Tutorials</td><td>20 h</td></tr>
<tr><td>Exam</td><td>2 h</td></tr>
<tr><td>Total</td><td>62 h</td></tr>
<tr><td colspan="2">Instructor</td><td>Maria Domenica DI BENEDETTO -mariadomenica.dibenedetto@univaq.it</td></tr>
<tr><td colspan="2">Objectives</td><td>The course is intended to provide students with fundamental knowledge about modeling, control and simulation of complex systems. In the first part of the course, networked multi-agent systems are introduced and analyzed. In the second part, hybrid systems are considered, and their specific properties investigated. At the end of the course, the student will be able to model complex systems and master the tools for control design based on consensus techniques, and controller synthesis with stability requirements and logic specifications.</td></tr>
<tr><td colspan="2">Content</td><td>Hybrid systems models and their use in the design of control systems, with particular emphasis on cyber-physical distributed systems.
• Modeling: Finite state automata, transition systems, timed automata, hybrid automata, switching systems, hybrid systems. Safety properties, liveness, deadlocks.
• Stability of switching systems.
• Analysis and Control: Reachability and safety problems. Simulations and bisimulations.
• Abstractions and verification by abstraction.
• Observability of hybrid systems and hybrid observers.
• Security problems and resilience properties with respect to malicious attacks.
• Symbolic models and formal methods for control and verification.
• Simulations tools for hybrid systems.
• Applications: autonomous driving, control of electric vehicles, micro-grids.</td></tr>
</table>

SEMESTER 3

SEMESTER 3 - ECN - SPECIALIZATION A

<table>
<tr><th colspan="3">OPTIMIZATION, APPLICATION TO ENERGY MANAGEMENT OF ELECTRIC VEHICLE CHARGING</th></tr>
<tr><td>Credits</td><td>5 ECTS</td><td rowspan="6">Semester 3
ECN</td></tr>
<tr><td>Lectures</td><td>12 h</td></tr>
<tr><td>Tutorials</td><td>10 h</td></tr>
<tr><td>Labs</td><td>8 h</td></tr>
<tr><td>Exam</td><td>2 h</td></tr>
<tr><td>Total</td><td>32 h</td></tr>
<tr><td colspan="2">Instructor</td><td>Fouad BENNIS – fouad.bennis@ec-nantes.fr</td></tr>
<tr><td colspan="2">Objectives</td><td>The lecture presents different theoretical and computational aspects of a wide range of optimization methods for solving a variety of problems in electrical vehicles. The main objective of this courses is to give the students the ability to formalise, select the appropriate method, implement the optimisation problem and then analyse the results in order to take the best decision regarding the objectives, variables and the constraints.</td></tr>
<tr><td colspan="2">Content</td><td>Basic concepts of optimization
Gradient based methods
Evolutionary algorithms
Multi objective optimization methods
Robust optimization methods
Multidisciplinary optimization problems
Programming aspects
Practical Work: exercises and project on the design optimisation of energy management and vehicle charging.
The students will be able to: Understand different theoretical and computational aspects of a wide range of optimization methods, use of optimization toolbox, and apply these methods in electric vehicle system.</td></tr>
</table>

CONTROL OF POWER CONVERTERS FOR ELECTRIC PROPULSION SYSTEM		
Credits	5 ECTS	**Semester 3** **ECN**
Lectures	14 h	
Tutorials	8 h	
lABS	8 h	
Exam	2 h	
Total	32 h	
Instructor		Malek GHANES - malek.ghanes@ec-nantes.fr
Objectives		Objectives of this course are: • Analysis of power converters used in electric vehicle • Power converters design • Power converters modelling and control

Content		This course considers the design and control of power converters in electric drive vehicles. The course includes an overview of system architectures and covers system-level dynamic modeling and control using MATLAB/Simulink at levels appropriate to determine requirements and validate the performance of switched-mode power converters in the vehicle system. Analysis, modeling and design of switched-mode power converters in electric-drive vehicle systems are then covered, including battery DC-DC converters, battery management electronics, motor drive inverters and battery chargers.
		• Power converters for motor drives (DC-AC)
		  - Bi-directional DC-AC converter
		  - Sensing and digital control
		• Power converters for energy storage (DC-DC converters)
		  - Energy storage cells, battery management system electronics
		  - Bi-directional DC-DC converter
		  - Sensing and digital control
		• Power converters for battery chargers (AC-DC)
		  - Charger requirements
		  - Bi-directional AC-DC
		• Control and coordination with BMS

OBSERVATION AND DIAGNOSIS, APPLICATION FOR ELECTRICAL SYSTEMS		
Credits	5 ECTS	**Semester 3** **ECN**
Lectures	12 h	
Tutorials	10 h	
Labs	8 h	
Exam	2 h	
Total	32 h	
Instructor		Malek GHANES - malek.ghanes@ec-nantes.fr
Objectives		Measuring the state by a physical sensors of a given system may fail because sometimes the measurements are impossible and sometimes, possible, but too expensive. That is why estimating the state of the system by means of software sensors (observers) is an important issue. The first part of this lecture investigates several methods of observer design for nonlinear systems. Moreover, faults in sensors, actuators or process components may lead to the degradation of the overall system performance and could cause serious damage. From this point of view, the second part of this lecture will give some basic definitions and different existing methods of diagnosis. Then, the diagnosis problem will be mainly investigated by using observers (studied in the first part) in case of fault estimation (simultaneous state and parameters estimation). Finally fault tolerant control problem is briefly studied. Examples and labs will illustrate the well founded of these two parts in the framework of academic and real applications (mainly electric vehicles).
Content		• Introduction to Observation and Diagnosis Problems • Observation: - Observability study - Estimation of the internal states of the system (observer-based or software sensors) - Parameter identification/estimation (observer-based or left invertibilty) - Simultaneous State and Parameter estimation, i.e. Adaptive Observation, - Estimation of unmeasured perturbations • Diagnosis: - Fault Detection and Isolation Problems - Fault Tolerant Control • Applications for electric vehicles (power converters, DC and AC machines, energy storage, …)

ADVANCED CONTROL OF ELECTRIC PROPULSION SYSTEMS		
Credits	5 ECTS	**Semester 3** **ECN**
Lectures	14 h	
Tutorials	8 h	
Labs	8 h	
Exam	2 h	
Total	32 h	
Instructor		Jean-Pierre BARBOT – barbot@ensea.fr
Objectives		After having followed the course, the candidate shall have obtained thorough insight in and understanding of: • Analysis of electric machine used in electric vehicle • Electric machine design • Electric machine modeling and control
Content		This course introduces the concept of control of electric motors for electric vehicle application. Initially, the dynamic models of the ac motors are developed that will be useful in understanding the dynamic control. Advanced control techniques are applied to optimize the performance of ac motor drives. • Application-Specific Selection of Machine-and-Drive Systems • High-Speed Electric Machines • Control principles for electrical motor drives • Performances improvement of AC machines control • Sensorless control of AC machines

CASE STUDY APPLICATION DEDICATED ELECTRIC VEHICLE TOPOLOGY		
Credits	5 ECTS	**Semester 3** **ECN**
Lectures	12 h	
Tutorials	6 h	
Project	12 h	
Exam	2 h	
Total	32 h	
Instructor		Industrial intervener
Objectives		Objectives of this course are to study the following three case studies: • Electric fault tolerant control and safety of electric propulsion • Sensorless control to render electric vehicles more affordable • Battery management system and interaction between the battery charger and the renewable energy sources
Content		• The application of a simple design of fault tolerant control (FTC) methodology to the propulsion of electric vehicle will be study. The existing approaches to fault detection and isolation and fault tolerant control in a general framework of an active fault tolerant control will be presented. Failure mode and effects analysis will be carried out. • This study will focus on the design of a battery energy storage system to reduce the charging time and to maximize battery life. The interaction between the electric vehicle and the power grid will be deeply study especially with the renewable energy sources.

SEMESTER 3 - UPB - SPECIALIZATION B

<table>
<tr><th colspan="3">BATTERY CHARGERS (FOR ELECTRIC VEHICLE)</th></tr>
<tr><td>Credits</td><td>6 ECTS</td><td rowspan="6">Semester 3
UPB</td></tr>
<tr><td>Lectures</td><td>28 h</td></tr>
<tr><td>Tutorials</td><td>6 h</td></tr>
<tr><td>Labs</td><td>14 h</td></tr>
<tr><td>Exam</td><td>2 h</td></tr>
<tr><td>Total</td><td>50 h</td></tr>
<tr><td colspan="2">Instructor</td><td>Assist. Prof. Dr. Ing. Stefan George ROSU</td></tr>
<tr><td colspan="2">Objectives</td><td>Students attending this lecture should be able to design, implement and demonstrate the operation of a power electronic converter solution for a battery charging system in the field of electric vehicles. Knowledge about the advantages and disadvantages of different power electronics circuits including the operational characteristics should be acquired. Differences between analog and digital control along with specific practical implementations versus computer simulations should be learnt.</td></tr>
<tr><td colspan="2">Content</td><td>Automotive electronics for battery chargers
• automotive charger structures, classifications, grid interface.
Single-phase AC-DC converters with power factor correction
• operation, specific parameters, control methods
Three-phase AC-DC converters with power factor correction
• two-, multi-level or modular topologies for level 3 chargers
DC-DC converters with unidirectional and bidirectional power flow
• non-isolated conversion topologies - buck, boost
• high frequency transformer isolated conversion topologies - LLC, DAB
Wireless power transfer (WPT) battery chargers
• static and dynamic WPT battery chargers
• transmitter and receiver coils and converters
• command and control methods
Practical realization of battery chargers
• control circuits with real time microcontrollers
• interface and protection circuits
• use of new generation semiconductor devices - GaN, SiC</td></tr>
</table>

ENERGY STORAGE REQUIREMENTS (FOR EV)		
Credits	6 ECTS	**Semester 3** **UPB**
Lectures	20 h	
Tutorials	6 h	
Labs	4 h	
Exam	2 h	
Total	32 h	
Instructor		Prof. Dr. Ing. Daniel OANCEA – dianel.oancea@upb.ro
Objectives		Knowledge of different energy storage methods, of its specific requirements, ensures the best technical solution in the field of electric traction. The current state, as well as the subsequent developments in the field, determines the decision of the final choice of the energy storage solution.
Content		• The need for energy storage. Energy storage methods • Mechanical energy storage • Electrochemical storage of energy • Electrical and electromagnetic storage of energy • Chemical energy storage • Requirements for sizing energy storage elements • Perspectives on energy storage elements • Final verification

<table>
<tr><th colspan="3">BATTERY MANAGEMENT SYSTEMS AND BATTERY LIFE CYCLE</th></tr>
<tr><td>Credits</td><td>6 ECTS</td><td rowspan="6">Semester 3
UPB</td></tr>
<tr><td>Lectures</td><td>26 h</td></tr>
<tr><td>Tutorials</td><td>12 h</td></tr>
<tr><td>Labs</td><td>14 h</td></tr>
<tr><td>Exam</td><td>4 h</td></tr>
<tr><td>Total</td><td>56 h</td></tr>
<tr><td colspan="2">Instructor</td><td>As. Prof. Dr. Ing. Alexandru VASILE – alexandru.vasile@cetti.ro</td></tr>
<tr><td colspan="2">Objectives</td><td>This course presents the state-of-the-art in research and development of battery technologies and Battery Management Systems (BMS) used in Electric Vehicles (EV) or Energy Storage Systems (ESS). It summarizes their features in terms of performance, cost, service life, management, charging facilities, and safety.</td></tr>
<tr><td colspan="2">Content</td><td>

Introduction to Energy Storage Systems. History and evolution of batteries. Actual applications: Electric Vehicles (EV), Photovoltaic (PV) systems.
Battery modelling and design. Battery chemistries. Electrochemical and electrochemical-thermal models. Performance parameters. Measuring techniques and estimation algorithms.
Battery charging methods. Constant Voltage, Constant Current and Hybrid methods.
Battery Monitoring Systems (BMS). Design and manufacturing requirements.
BMS architectures. Voltage and current measurement techniques. Passive balancing technique. Active balancing techniques. Communication protocols for data acquisition and remote control.
Case studies on different commercial BMS.
Thermal management for batteries and electronic units.
Battery recycling policies.

Abilities: After completing this course the students will be able to:

understand BMS architecture and balancing techniques;
design and development of BMSs for specific battery packs;
installation and configuration of after-market BMSs on large battery packs;
understand and apply safety rules in manufacturing and maintenance of battery packs..

</td></tr>
</table>

<table>
<tr><th colspan="3">SENSORLESS CONTROL OF ELECTRIC MACHINES</th></tr>
<tr><td>Credits</td><td>6 ECTS</td><td rowspan="6">Semester 3
UPB</td></tr>
<tr><td>Lectures</td><td>28 h</td></tr>
<tr><td>Tutorials</td><td>14 h</td></tr>
<tr><td>Labs</td><td>14 h</td></tr>
<tr><td>Exam</td><td>2 h</td></tr>
<tr><td>Total</td><td>58 h</td></tr>
<tr><td colspan="2">Instructor</td><td>As. Prof. Dr. Ing. Bogdan Cristian FLOREA – bogdan.florea@upb.ro</td></tr>
<tr><td colspan="2">Objectives</td><td>Comprehensive analysis and synthesis of linear analogical control systems. Sensorless control techniques using mathematical models and state estimation applied for electrical machine. Control systems and their constituent parts analysis by means of transfer functions and state variables. Knowledge of control system performance in time and frequency. Familiarizing students with simple control system design. Description of basic control system constituents: transducers, signal conditioners, controllers. Transitioning from sensor-based to sensorless control</td></tr>
<tr><td colspan="2">Content</td><td>• Definitions
• Open control systems and feedback control systems
• Classification of control systems
• Electrical machines
• Classification of electrical machines
• Electrical machines modelling
• Electrical machines control techniques
• Sensors for electrical machines control
• Types of sensors
• Sensor based control
• State estimation
• Controlability and observability of a system
• State estimation using observers
• Integrating state observers in LCCS
• Sensorless control
• Open loop and closed loop sensorless drives
• Performance of sensorless control

Abilities: After completing this course the students will be able to:
• Analyse and model electrical machines
• Design and implement state observers and analyse the controllability of a system
Design open loop and closed loop sensorless control algorithms</td></tr>
</table>

MICROPROCESSOR APPLICATIONS FOR REAL-TIME SYSTEMS		
Credits	6 ECTS	**Semester 3** **UPB**
Lectures	28 h	
Tutorials	14 h	
Labs	28 h	
Exam	4 h	
Total	74 h	
Instructor		Prof. Dr. Ing. Corneliu BURILEANU
Objectives		Students attending this course should be able to implement applications, in typical situations, of basic methods of signal acquisition and processing and implement knowledges, concepts and basic methods that refer to the computer systems, microcontrollers, programming languages and techniques
Content		1. Microcomputer Structure. Definitions 1.1. Microcomputer Functional Blocks 1.2. CISC and RISC Microprocessors 1.3. Information in Digital Systems 1.4. Conventions 2. Overview of a CISC, General Purpose Microprocessor Core 2.1. First Step Approach: Data register and Address Register 2.2. Second Step Approach: General-Purpose Registers 2.3. Third Step Approach: Arithmetic Processing Unit 2.4. Forth Step Approach: Memory Addressing Control Unit 2.5. Fifth Step Approach: Microprocessor Control Unit 2.6. Functional Blocks of 16 or 32 bit Microprocessor 3. Fundamentals of a Typical CISC Architecture 3.1. Registers 3.2. Microcomputer Memory Architecture 3.3. Data Transfers 3.4. Addressing Techniques 3.5. Types of Instructions 4. Fundamentals of a Typical RISC Architecture 4.1. Registers 4.2. Instruction Set and Addressing Techniques 4.3. Microprocessor Control Unit 4.4. Software Layer for RISC Architecture 5. Input/Output Strategies 5.1. Input/Output Devices Map 5.2. Typical Input/Output Techniques 5.3. Interrupt System for General Purpose Microprocessor 5.4. . Interrupts for x86 Intel Microprocessor (IA-32) in Real Mode 6. Time-Dimension of a General Purpose Microprocessor Architecture 6.1. CISC Instruction Timing 6.2. Speed Increase for Advanced CISC Microprocessor 6.3. RISC Instruction Timing 7. An Overview of Intel x86 Architecture (IA-32) in Real Mode 7.1. Block Diagram 7.2. Registers 7.3. Memory Organization 7.4. Port Organization 7.5. Addressing Modes

SEMESTER 3 - CAU - SPECIALIZATION C

Specialization C1 – Control of Complex Dynamical Systems

OPTIMIZATION AND OPTIMAL CONTROL		
Credits	5 ECTS	**Semester 3** **CAU**
Lectures	20 h	
Tutorials	6 h	
Labs	4 h	
Exam	2 h	
Total	32 h	
Instructor		Prof. Dr. Ing. habil. Thomas MEURER
Objectives		The students have an in-depth understanding of static and dynamics optimization with constraints. They understand the underlying mathematical concepts and are able to apply these to new problems. They have a comprehensive understanding of optimization methods and are able to independently apply these methods to static and dynamic optimization problems. The students know different numerical solution approaches, comprehend their working principles and are able to implement them for optimization problems.
Content		• Fundamentals of static and dynamic optimization problems • Static optimization without and with constraints • Dynamic optimization without and with constraints • Introduction to numerical methods for optimization.

RIGID BODY DYNAMICS AND ROBOTICS		
Credits	5 ECTS	**Semester 3** **CAU**
Lectures	20 h	
Tutorials	6 h	
Labs	4 h	
Exam	2 h	
Total	32 h	
Instructor		Prof. Dr. Ing. habil. Thomas MEURER
Objectives		The students have an in-depth understanding of rigid body kinematics and dynamics. They understand the underlying mathematical concepts and are able to apply these to new problems. They have a comprehensive understanding of the principles of analytical mechanics. The students can apply this knowledge to mathematically describe and analyze the kinematic and the kinetics of multi-body and robot systems. They comprehend the basic principles for model-based control of robot systems and are able to apply these.
Content		• Fundamentals of static and dynamic optimization problems • Static optimization without and with constraints • Dynamic optimization without and with constraints • Introduction to numerical methods for optimization

SEMINAR ON SELECTED TOPICS IN SYSTEMS AND CONTROL		
Credits	5 ECTS	**Semester 3** **CAU**
Lectures	20 h	
Tutorials	6 h	
Labs	4 h	
Exam	2 h	
Total	32 h	
Instructor		Prof. Dr. Ing. habil. Thomas MEURER
Objectives		The students comprehend advanced control and observer design methods. They can independently review and organize existing literature. They can summarize and explain the content of the scientific publications. The students can compare the results, can design and evaluate controllers for nonlinear systems, and can assess them critically. They know presentation techniques and have developed presentation skills. The students can present the results, discuss them and recommend further research steps on the research topic.
Content		In the seminar current research topics in systems and control are considered.

M. Sc. LABORATORY ADVANCED CONTROL		
Credits	5 ECTS	**Semester 3** **CAU**
Lectures	20 h	
Tutorials	6 h	
Labs	4 h	
Exam	2 h	
Total	32 h	
Instructor		Prof. Dr. Ing. habil. Thomas MEURER
Objectives		The students have an in-depth understanding of computer-assisted modeling and control design methods for nonlinear systems. They understand the underlying mathematical and algorithmic concepts and are able to apply these to new practical problems. The students are able build and analyze simulation models. They have the ability to implement nonlinear controllers using symbolic and numerical computational tools taking into account real-time aspects.
Content		Experiments addressing the themes: • Mathematical modeling and control design using computer-algebra-systems • Computer-assisted nonlinear control design (primary focus of laboratory) • Implementation and experimental validation

ADVANCED DIGITAL SIGNAL PROCESSING (OPTION)		
Credits	5 ECTS	**Semester 3** **CAU**
Lectures	20 h	
Tutorials	6 h	
Labs	4 h	
Exam	2 h	
Total	32 h	
Instructor		Prof. Dr. Ing. habil. Thomas MEURER
Objectives		Students have an in-depth understanding of the differences of analog and digital processing. They apply robust and efficient versions of digital signal processing structures. They compare different filter approaches. Students deepen their knowledge on sampling and complexity reduction.
Content		• Digital processing of continuous-time signals - Sampling and sampling theorem - Quantization - AD- and DA-conversion • Efficient FIR structures - Block-based approaches • DFT and FFT - Leakage effect - Windowing - FFT structure Digital filters - FIR filters - Structures - Linear phase filters - Least-squares frequency domain design - IIR-filters - Structures - Finite word-length, effects Multirate, digital signal, processing - Decimation and interpolation - Filters in sampling rate alteration systems - Polyphase decomposition and efficient structures - Digital filter banks

MODELING AND CONTROL OF POWER ELECTRONICS CONVERTERS (OPTION)		
Credits	5 ECTS	**Semester 3** **CAU**
Lectures	20 h	
Tutorials	6 h	
Labs	4 h	
Exam	2 h	
Total	32 h	
Instructor		Prof. Dr. Ing. Marco LISERRE
Objectives		The students are able to derive the mathematical models of PWM dc/dc and dc/ac converters. The students are able to design their controllers using average model and small-signal linearization. The students know basic of digital control and learn how to apply to power converters. The students have understanding of power theories and their application to power quality conditioner.
Content		The course is focused on dc/dc and dc/ac PWM converters, their model and their control. Particularly, since most of the adopted dc/ac converters in electric drives and renewable energies are voltage source con- verters, the current control is the first and most important control stage and it is responsible of high dyna- mical behavior and low harmonic content. Finally the course focuses on how to select current references to achieve the desired active and reactive powers even in unbalance situations, using the instantaneous power theory, nowadays an indispensable tool for smart grid technologies. Topics overview: • dc/dc converter model • Average model, small-signal linearization, transfer functions • Design of the controller for dc/dc converters • dc/ac converter model: ac dynamics in different reference frames • Continuous and discrete current control (PI, resonant controller, deadbeat) • dc voltage control, active and reactive power controls

IMAGE-BASED 3D SCENE RECONSTRUCTION (OPTION)		
Credits	8 ECTS	**Semester 3** **CAU**
Lectures	20 h	
Tutorials	6 h	
Labs	4 h	
Exam	2 h	
Total	32 h	
Instructor		Prof. Dr. Ing. Rheinhard KOCH
Objectives		The students learn to handle entities of projective geometry and image-based geometric transformations and implement these in the context of image-based 3-D scene reconstruction. Programming exercises are solved with the help of MATLAB and simple C++ examples in a dedicated framework.
Content		• The following topics are discussed: • Image sequence correspondence analysis • Basics of projective geometry • Homographies and panoramic images from rotating cameras • Multi-view geometry from a moving camera • Epipolar geometry and depth estimation • Camera tracking and pose estimation • Application in the field of augmented reality and image-based modeling

EMBEDDED REAL-TIME SYSTEMS (OPTION)		
Credits	8 ECTS	**Semester 3** **CAU**
Lectures	20 h	
Tutorials	6 h	
Labs	4 h	
Exam	2 h	
Total	32 h	
Instructor		Prof. Dr. Reinhard von HANXLEDEN
Objectives		A cell phone that transmits voice signals correctly, but with too much delay, is unsatisfactory. An airbag controller, that ignites the correct airbags, but does so too late, is life threatening. These are two examples of embedded real-time applications, for which the reaction time is as critical as the reaction result. This lecture provides an introduction into different aspects of embedded real-time systems. After successfully completing this module, the students will understand the fundamentals of embedded/real-time systems. Students will be able to select suitable platforms and programming languages for such systems, and they will be able to conduct design projects in this area. They will be aware of dependability concerns, and should be familiar with concurrency issues.
Content		• Model-based design • Concurrency and scheduling • Embedded hardware • Distributed real-time systems • Worst-case execution time analysis

Specialization C2 – Power Electronics Drives Technology

MODELING AND CONTROL OF POWER ELECTRONICS CONVERTERS		
Credits	5 ECTS	**Semester 3** **CAU**
Lectures	20 h	
Tutorials	6 h	
Labs	4 h	
Exam	2 h	
Total	32 h	
Instructor		Prof. Dr. Ing. Marco LISERRE
Objectives		The students are able to derive the mathematical models of PWM dc/dc and dc/ac converters. The students are able to design their controllers using average model and small-signal linearization. The students know basic of digital control and learn how to apply to power converters. The students have understanding of power theories and their application to power quality conditioner.
Content		The course is focused on dc/dc and dc/ac PWM converters, their model and their control. Particularly, since most of the adopted dc/ac converters in electric drives and renewable energies are voltage source con- verters, the current control is the first and most important control stage and it is responsible of high dyna- mical behavior and low harmonic content. Finally the course focuses on how to select current references to achieve the desired active and reactive powers even in unbalance situations, using the instantaneous power theory, nowadays an indispensable tool for smart grid technologies. Topics overview: • dc/dc converter model • Average model, small-signal linearization, transfer functions • Design of the controller for dc/dc converters • dc/ac converter model: ac dynamics in different reference frames • Continuous and discrete current control (PI, resonant controller, deadbeat) • dc voltage control, active and reactive power controls

GRID CONVERTERS FOR RENEWABLE ENERGY SYSTEMS		
Credits	5 ECTS	**Semester 3** **CAU**
Lectures	20 h	
Tutorials	6 h	
Labs	4 h	
Exam	2 h	
Total	32 h	
Instructor		Prof. Dr. Ing. Marco LISERRE
Objectives		The students have in-depth knowledge in designing the power electronics interface for Renewable Energy Systems to the electric grid. The students can recognize the different topologies associated to PV and wind Energy Systems and understand their working mechanism. The students can recognize, analyze and solve issues for electric grid interactive applications of these energy systems, such as synchronization, low frequency harmonic rejection and design of grid filters for reducing PWM harmonics. The students have developed experience in the control design of grid converters through simulation software, like Matlab, and have validated the control strategies in Simulink environment.
Content		Grid-connected PWM converters are gaining increasing importance in view of a growing contribution of Distributed Power Generation Systems (DPGS) to the total power flow in the European electric grid. This is also owed to an increasing inflow from Renewable Energy Sources (RES). After a review of the power electronics solutions used for Photovoltaic (PV) and Wind Turbine (WT) systems and an overview about modulation and current/voltage control techniques, the course focuses on the specific issues related to the connection of a PWM converter to the grid. Exercises are carried out with CAE-tools (Matlab/Simulink). Topics overview: • PV converter topologies • WT converter topologies • Overview of PWM modulation • Overview of Current Control techniques • Single-phase synchronization with the electrical grid • Three-phase synchronization with the electrical grid • Harmonic rejection • Grid-filter design and resonance issues • Parallel connection of power electronics converters

SEMINAR POWER ELECTRONICS		
Credits	5 ECTS	**Semester 3** **CAU**
Lectures	20 h	
Tutorials	6 h	
Labs	4 h	
Exam	2 h	
Total	32 h	
Instructor		Prof. Dr. Ing. Marco LISERRE
Objectives		The students can formulate a research question for independent analysis in the area of power electronics. The students can perform a literature search and organize publications by relevance. They can summarize and explain the content of the scientific publications. The students can compare the results and assess them critically. The students can present the results, discuss them and recommend further research steps on the research topic.
Content		The students will investigate a scientific or technical problem by means of several publications and collect, reproduce and evaluate the material in a seminar paper. Possible fields of interest are: • Power semiconductors • Power electronic circuits • Electric drives • Control of electric drives • Renewable energy production

M. Sc. LABORATORY POWER ELECTRONICS - RENEWABLE ENERGY - DRIVE ENGINEERING		
Credits	5 ECTS	**Semester 3** **CAU**
Lectures	20 h	
Tutorials	6 h	
Labs	4 h	
Exam	2 h	
Total	32 h	
Instructor		Prof. Dr. Ing. Marco LISERRE
Objectives		The students learn abilities to measure electrical quantities in experimental evaluations and they are able to analyze these measurement results for essential power electronic, renewable energy, and drive technology systems. The students can formulate theories and apply solutions formulated by themselves to solve specific technical problems.
Content		Laboratory exercises for power electronics, renewable energies, and drive technologies

ADVANCED DIGITAL SIGNAL PROCESSING (OPTION)		
Credits	5 ECTS	**Semester 3** **CAU**
Lectures	20 h	
Tutorials	6 h	
Labs	4 h	
Exam	2 h	
Total	32 h	
Instructor		Prof. Dr. Ing. Gerhard SCHMIDT
Objectives		Students have an in-depth understanding of the differences of analog and digital processing. They apply robust and efficient versions of digital signal processing structures. They compare different filter approaches. Students deepen their knowledge on sampling and complexity reduction.
Content		• Digital processing of continuous-time signals - Sampling and sampling theorem - Quantization - AD- and DA-conversion • Efficient FIR structures - Block-based approaches • DFT and FFT - Leakage effect - Windowing - FFT structure • Digital filters - FIR filters - Structures - Linear phase filters - Least-squares frequency domain design - IIR-filters - Structures - Finite word-length effects • Multirate digital signal processing - Decimation and interpolation - Filters in sampling rate alteration systems - Polyphase decomposition and efficient structures - Digital filter banks

OPTIMIZATION AND OPTIMAL CONTROL (OPTION)		
Credits	5 ECTS	**Semester 3** **CAU**
Lectures	20 h	
Tutorials	6 h	
Labs	4 h	
Exam	2 h	
Total	32 h	
Instructor		Prof. Dr. Ing. habil. Thomas MEURER
Objectives		The students have an in-depth understanding of static and dynamics optimization with constraints. They understand the underlying mathematical concepts and are able to apply these to new problems. They have a comprehensive understanding of optimization methods and are able to independently apply these methods to static and dynamic optimization problems. The students know different numerical solution approaches, comprehend their working principles and are able to implement them for optimization problems.
Content		• Fundamentals of static and dynamic optimization problems • Static optimization without and with constraints • Dynamic optimization without and with constraints • Introduction to numerical methods for optimization.

WIDE-BANDGAP SEMICONDUCTORS (OPTION)		
Credits	5 ECTS	**Semester 3** **CAU**
Lectures	20 h	
Tutorials	6 h	
Labs	4 h	
Exam	2 h	
Total	32 h	
Instructor		Prof. Dr. Ing. Holger KAPELS
Objectives		Students can describe the most important wide band gap power semiconductor devices. They know the basic structures, the operating principles as well as the characteristics and the limits of the devices. They can calculate the most important device dimensions and parameters of wide-bandgap power semiconductor devices. They can solve typical scientific questions in the design of wide band gap power semiconductor devices. They can appropriately classify the devices according to their fields of application.
Content		• Semiconductor materials with wide band gap • Characteristic deviceparameters (breakdown voltage, area-specific on-resistance) • SiC Schottky diodes, pin diodes, MPS diodes • SiC field-effect transistors, cascode circuit, SiC-MOSFETs, SiC-IGBTs • GaN HEMTs and GaN MOSFETs • Manufacturing processes • Measurement method • Application examples (PFC, resonant converters)

SEMESTER 3 - UAQ - SPECIALIZATION D

SYSTEM IDENTIFICATION AND DATA ANALYSIS		
Credits	6 ECTS	**Semester 3** **UAQ**
Lectures	60 h	
Tutorials	30 h	
Exam	2 h	
Total	92 h	
Instructor		Vittorio DE LULIIS - vittorio.deiuliis@univaq.it
Objectives		• The objective of this course is to initiate the students to the study of stochastic estimation theory, with focus on dynamical system identification and state estimation by filtering theory. After the completion of this course a student will be able to formulate and analyze problems of estimation and identification of dynamical models from noisy measurements, proposing various possible solutions and defining their statistical properties. The notions acquired in this course will increase the student's capability of modeling, simulation and control design. • At the end of this course the student: - will know methods and fundamental results of stochastic estimation theory; - will know the main methodologies of dynamical system estimation with noisy measurements; - will have deep knowledge of state estimation and filtering for linear and nonlinear systems, both in Gaussian and non-Gaussian framework; - will be able to write simulation programs to evaluate the accuracy of models estimated from noisy measurement of a dynamical system; - will be able to write simulation programs to evaluate the accuracy of dynamical system state estimation; - will be able to evaluate which estimation technique is more suitable for a given problem in the field of stochastic system estimation; - will be able to read and understand advanced scientific textbooks and articles on the topics of the course
Content		• Fundamentals of probability theory: events, sigma-algebras; random variables, integrals on probability spaces; expected value and higher order moments; measures induced by random variables and distribution functions; covariance matrices and their properties; standardizing random variables. Vector Gaussian distribution and its properties; conditional probability and conditioned random variables; properties of conditional expectation; independency of events and random variables. Computing the conditional expectation of Gaussian random variables; the Hilbert space of finite-variance random variables; conditional expectation and projection. Orthogonalization of sequences of random variables. • Estimation theory: minimum variance estimation; conditional expectation as a minimum variance estimator; optimal estimation and orthogonal projection; optimal estimation for Gaussian random

	variables; sub-optimal estimator and projections on subspaces of finite-dimensional functions; orthogonality conditions and optimal polynomial estimation; maximum likelihood estimation; likelihood ratio and likelihood function; parameter estimation; examples for Gaussian variables. Markov estimator. • Stochastic dynamical systems and Kalman Filter: separating noise and signal; signal-generating model and white noise model; linear discrete-time stochastic systems; definition and properties of state and output innovations; equivalence theorem; the Kalman Filter as the optimal estimator: recursive equations; recursive computation of the Kalman filter covariances and gain (Riccati equations). Optimal predictor and optimal smoothing with the extended state. Continuous-time stochastic systems with sampled observations: simplified model of white noise, discretization and Kalman filtering. Steady-state solution of Riccati equations and their unicity and convergence: detectability of (A,C) and stabilizability of (A,F). State estimation of nonlinear systems: extended Kalman filter. • Parameter estimation for stochastic systems: maximum-likelihood parameter estimation, heuristic solution of combined state-parameters estimation with Kalman Filter. • Fundamentals of subspace methods for linear system identification: singular value decomposition of a matrix and least squares methods; projection of vectors on subspaces; Ho-Kalman method for stochastic realization; MOESP/N4SID methods for linear subspace identification.

EMBEDDED SYSTEMS		
Credits	9 ECTS	**Semester 3** **UAQ**
Lectures	30 h	
Tutorials	30 h	
Labs	30 h	
Exam	2 h	
Total	92 h	
Instructor		Luigi POMANTE - luigi.pomante@univaq.it
Objectives		The goal of this module is to provide the fundamental set of concepts and techniques that relate to "HW/SW Dedicated Systems Engineering". In fact, it presents the main issues related to the design of dedicated (i.e. application-specific) HW/SW electronic devices that are also typically "embedded" (i.e. integrated into a more complex heterogeneous system) and/or with real-time constraints. In such a context, the course recalls the main HW/SW technologies and the related design methodologies and tools (both academic and commercial), providing also a unified (typically model-based) vision of all the involved concepts.
Content		Introduction: goals and structure of the course, general features of embedded systems, main design issues. Technologies: unified vision of basic HW technologies (ASIC, FPGA), HW components (processors, memories, timers, interfacing, communication) and HW/SW interaction. Architecture: system on-board, systems on-chip, networked/distributed embedded systems (in particular HW and SW technologies for Wireless Sensor Networks). Methodologies and tools: system-level design flow and tools, HW/SW design flow and tools, RTOS and advanced OS concepts. Case studies.

<table>
<tr><th colspan="3">ADVANCED CONTROL SYSTEMS</th></tr>
<tr><td>Credits</td><td>9 ECTS</td><td rowspan="5">Semester 3
UAQ</td></tr>
<tr><td>Lectures</td><td>60 h</td></tr>
<tr><td>Tutorials</td><td>30 h</td></tr>
<tr><td>Exam</td><td>2 h</td></tr>
<tr><td>Total</td><td>92 h</td></tr>
<tr><td colspan="2">Instructor</td><td>Pierdomenico PEPE - pierdomenico.pepe@univaq.it</td></tr>
<tr><td colspan="2">Objectives</td><td>Ability to design continuous-time and digital stabilizers, for nonlinear finite dimensional and nonlinear retarded systems.</td></tr>
<tr><td colspan="2">Content</td><td>Recalls on elementary theory of nonlinear feedback. Nonlinear Observer: the autonomous and the forced case. Nonlinear separation principle. Example of application to a continuous stirred tank reactor. Recalls on the Input-to-state stability. ISS redesign for attenuation of actuation disturbances effects. Artstein’s theory for controller design by Lyapunov functions. Sontag’s and Freeman’s universal stabilizers. Continuous and discontinuous state feedbacks yielding negative Dini directional derivative of the control Lyapunov function. Clarke’s theory of practical stabilization in the sample-and-hold sense. Sampled-data emulation of continuous-time, state feedback stabilizers. Sampled-data emulation of continuous-time, observer-based stabilizers. Global exponential stability preservation under sampling for globally Lipschitz systems. Example of application to an actuated inverted pendulum. Introduction to nonlinear retarded systems. Internal and external stability. Lyapunov-Krasovskii criteria. Methods based on Linear Matrix Inequalities. Elementary theory of nonlinear feedback for forward complete, retarded systems. Stabilization. Input-to-State Stabilization. State observers for retarded systems. Example of application to a glucose-insulin system. Basics of predictor design for linear systems with input/output delays.</td></tr>
</table>

OPTIMIZATION MODELS AND ALGORITHMS		
Credits	6 ECTS	**Semester 3** **UAQ**
Lectures	40 h	
Tutorials	20 h	
Exam	2 h	
Total	62 h	
Instructor		Claudio ARBIB - claudio.arbib@univaq.it
Objectives		Be able to: formulate integer linear programming problems, identify major combinatorial optimization problems, distinguish among them according to computational complexity, understand and reproduce main solution methods
Content		• Graphs. Finite graphs, vertex and edge set, degrees. Reflexive, non-reflexive, loopless, symmetric, transitive graphs. Regular graphs: examples. Graph isomorphism: examples. Cliques and stable sets. Complement of a graph. Walks, paths, circuits and cycles. Eulerian graphs and Hamiltonian graphs. Making a graph Eulerian. Node degrees and arc set. Odd degrees, Euler Theorem (enunciate). Hamiltonian paths. Connectivity. Trees and forests. Bipartite graphs and their characterization. More optimization problems on graphs: coloring. Applications. • Combinatorial optimization and 01 LP formulations. Transversal, stable set, dominating set, edge-cover, (perfect) matching in a graph. 01 linear programming formulations. Examples of applications and of formulation. The shortest path problem. Formulation as 01 LP, limits of the formulation. The spanning tree problem. Combinatorial optimization problems in general. Relation to linear programming. Other examples of 01 LP formulation (graph isomorphism problem, PLA folding, maximum cut problem etc.). • Computational complexity. Complexity of an algorithm, examples. Complexity of a problem, examples. Turing machine. The class P. Polynomial-time reduction. The class NP. The sarisfiability problem. Cook's Theorem (enunciate) and the class NP-complete. Examples of reduction: clique. • Totally unimodular matrices. The simplex method in a nutshell. LP in general and in standard form, reductions; basis, basic (feasible) solutions. Unimodular and totally unimodular matrices. A sufficient condition for the integrality of basic solutions. Necessary/sufficient conditions for total unimodularity. • Dynamic Programming. From partial to total order. Topological order of a graph, and DAGs. Bellman condition. Recursive computation of the best path in a DAG. Examples of application (covering a requirement at minimum cost, Levenshtein distance, Knapsack 01 etc.). • Fundamentals of Duality Theory in LP. Convex polyhedra: algebraic vs. geometric form. Projecting a polyhedron: Fourier-Veronese's Theorem (enunciate). Compatibility of systems of linear inequalities. Fourier-Motzkin elimination algorithm: numerical computation, particular cases. From Fourier-Veronese's Theorem to Duality in LP. Theorems of the Alternative: Gale's Theorem. • Matching theory. Matching and its relation to edge-cover, transversal and stable set. Gallai's Theorems. Primal-dual relations: Koenig's matching and edge-cover theorems. Bipartite

	matching and total unimodularity. Augmenting paths and a characterization of max matching. Bipartite matching: algorithms for the unweighted and weighted case. Non bipartite matching: Edmonds' formulation. Bi-stochastic matrices: introduction and definitions. Arithmetical magic squares and their construction. Semi-magic squares and bi-stochastic matrices: Sinkhorn algorithm. Characterization of (extremal) bi-stochastic matrices: perfect bipartite matchings and permutation matrices. • Matroids and the greedy algorithm. Introduction, motivation, examples. Maximal vs. maximum sets. Cheating the greedy algorithm. Sublclusion and the exchange property:matroids. Characterization of matroids: Rado's Theorem. Examples (uniform matroid, graphical matroid, vector matroid). Matroid representability: vector vs. graphic matroid. • Approximation algorithms. Introduction to deterministic approximation algorithms. Approximation ratio, polynomial-time approximation schemes. Example 1: TSP. Double tree algorithm. Christofides' (1/2)-approximation algorithm for the metric TSP. Example 2: Knapsack 01. A utility-based dynamic programming algorithm. Complexity. Scaling coefficients: a fully polinomial-time approximation scheme. Implicit enumeration algorithms. Search by split. Enumeration tree for COPs. Relations between ILP and LP. Bounds by LP and their use in a branch-and-bound method. First example of a branch-and-bound method: 01-knapsack. Computing the LP bound. Branching on fractional variables. Example: 01 Knapsack. Combinatorial bounds. Example: TSP.