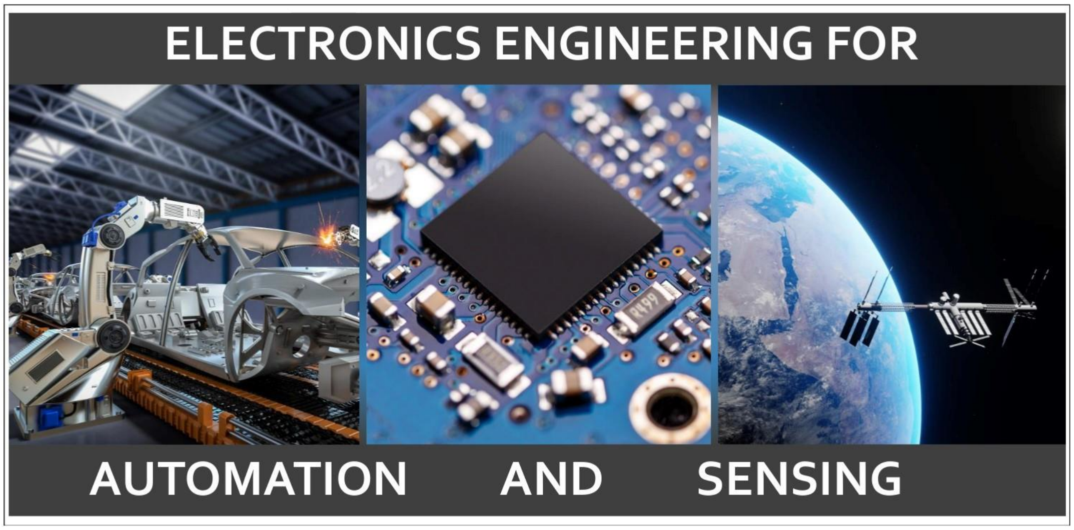
UNIVERSITÀ DEGLI STUDI DEL SANNIO Benevento

MASTER DEGREE IN

ELECTRONICS ENGINEERING FOR AUTOMATION AND SENSING



Welcome to the Master Degree Course in *Electronic Engineering for Automation and Sensing*. This is a short guide aimed to provide the following general information

- Course Description
- General Information
- Requirements for Admission
- Taxes

Feel free to contact prof Andrea Cusano (a.cusano@unisannio.it) or prof Carmen Del Vecchio (c.delvecchio@unisannio.it) for specific requests or information.

Course Description

The Master's Degree in *Electronics Engineering for Automation and Sensing* belongs to University of Sannio International Course Program and it is therefore delivered entirely in English. The course is designed as a natural evolution of a Bachelor's degree program in Electronics and Informatic Engineering.

The Course has been designed to provide a well-balanced combination of methodological and practical training.

Two curricula are on offer:

- Automation
- Sensing Technologies

These curricula are organized around three closely integrated areas of learning, namely electronics, telecommunications, and automation. The first year of the program emphasizes methodological aspects, while the second year is focused on practical applications.

The program's goal is to produce professionals who possess a broad range of interdisciplinary knowledge, along with specialized skills beyond electronic engineering, to enable them to compete effectively in the global job market.

The curricula cover a variety of topics related to automation systems, sensors, and monitoring systems, including IoT (Internet of Things), IoE (Internet of Everything), and the current and future industrial revolutions.

General Information (with reference to Academic Year 2023/2024)

Course duration: two years.

University Credits: 120 CFU (inside the standard ECTS)

Course Type: Master Degree (IT “*Laurea Magistrale*)

Language: English

Location: Dipartimento di Ingnegneria, Università del Sannio, I-82100 Benevento.
https://www.ding.unisannio.it/

Requirements for Admission

The Master's Degree program in Electronic Engineering for Automation and Sensing is open to students who hold a Bachelor's degree in related fields of information engineering, such as (not limited to) Electronic Engineering and Computer Engineering. Students holding a Bachelor's degree obtained from a foreign university are required to provide a list of their completed courses, along with their respective credits, in English. A dedicated committee will assess whether the total credits are sufficient to meet the basic admission requirements or if a supplementary interview is required.

To verify the admission requirements, students need to complete the application form and submit it via email to the Administrative Office of the Department of Engineering at didattica.ding@unisannio.it.

Before completing and submitting the application form candidates are invited to contact Prof Andrea Cusano (Chair of the Master Degree program) a.cusano@unisannio.it or Prof. Carmen Del Vecchio (Chair of the Orientation Commission of the Master Degree Course) c.delvecchio@unisannio.it.

Taxes

The annual comprehensive Course fee for foreign EU and non-EU students residing abroad is € 600.00 (in addition to the regional tax and 'stamp duty') to be paid according to deadlines and payment plan specified here. Foreign students falling in the specific cases reported in the "exemptions, reductions, and fee refunds" page are exempt from paying the annual comprehensive fee. On the basis of specific agreement with foreign Universities scholarships or extra tax reduction should be available; foreign students are encouraged to contact prof. Carmen Del Vecchio (c.delvecchio@unisannio.it) to check whether they are eligible for specific benefits.

CURRICULUM: AUTOMATION

LIST OF EXAMS

First year, first semester (CFU 27)

Measurements for Automation and industrial production (CFU 9)

Programmable Electronic Circuits (CFU 9)

Statistical Learning (CFU 9)

First year, Second semester (CFU 33)

Applied Thermodynamics and Mechanics (CFU 6)

Multiphysics modelling (CFU 9)

Electronics of Digital Integrated Systems (CFU 9)

Modern control (CFU 9)

Second year, first semester (CFU 33)

Dynamics and Control of Switched Electronic Systems (CFU 9)

Distributed measurement systems (CFU 9)

Advanced Control and Applications (CFU 6)

Freely chosen course (CFU 9, to be approved. The suggested course *Micro and Nano Fabrication Technologies*, is automatically approved.)

Second year, second semester (CFU 27)

Learning for dynamics and control (CFU 6)

Internship (CFU 9)

Final examination (CFU 12)

DETAILED COURSE DESCRIPTIONS

Measurements for Automation and industrial production (CFU 9)

Learning objectives

The measurement for automation and industrial production course provides the students with the knowledge to design and realize automatic measurement systems for the industrial environment. The development environment used during the course is LabVIEW.

Prerequisites

The student is required to know the contents of the base courses of Electronic Measurement, Analog Electronics and Digital Signal Processing.

Course contents

The course includes a theory section with classroom lessons and a practical section including experiments in laboratory and a final project to be carried out in laboratory.

Theory

Distributed measurement systems and sensor networks. Virtual instruments. Automatic test equipment. Data acquisition systems. Components of a measurement chain.

Definitions and metrological characterization of transducers. Piezoresistive effect. Photoconductive and photoelectric effects. Piezoelectric effect. Seebeck and Peltier effects. Hall effect.

Strain and force transducers. Resistive and capacitive position and displacement transducers. Inductive linear and angle position and displacement transducers. Photodetectors. Linear and angle optical transducers (encoders). Laser triangulation transducers and position sensitive detectors. Ultrasound transducers. Radar microwave transducers. Time of flight laser transducers. Laser scanners. Linear speed transducers. Level transducers. Rotary speed and flow transducers. Turbine flow meter. Acceleration and vibration transducers. Temperature transducers. Voltage and current transducers. Power transducers.

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Recall of basic notions about operational amplifiers and circuit configurations. Charge amplifiers. Transimpedance amplifier. Instrumentation amplifier. Wheatstone bridge design. Cabling. Shielding and grounding. Signal multiplexing.

Data acquisition boards: elements, main functions, metrological characteristics.

Instrumentation interface systems. Serial interfaces RS232, RS485. Parallel interface systems: IEEE 488 and IEEE 1155.

Basics of LabVIEW programming.

Laboratory activities

Laboratory sessions about transducer calibration. Design and realization of an automatic measurement station using LabVIEW.

Programmable Electronic Circuits (CFU 9)

Learning objectives

The aim of the course is to teach methods and techniques to implement electronic circuits using programmable components. At the end of the course, the student must be able to transform an idea of application into a working circuit, taking advantage of the most appropriate methodologies and project tools (through the use of commercial development environments, the description in HDL languages and the use of IP blocks) to implement a programmable circuit.

Prerequisites

Fundamentals of Digital Electronics

Course contents

Introduction to Programmable Electronic Circuits. Recalls of digital electronics: combinational circuits and sequential circuits. Programmable Logic Arrays (PLA). Programmable Array Logic (PAL) devices. Sequential Programmable Logic Devices (PLDs). Complex PLDs. Analysis of the main commercial PLD architectures. Field programmable gate arrays (FPGA). Analysis of the main commercial FPGA architectures. Project flow for FPGA. The Quartus Prime development system. The Verilog hardware description language for the synthesis and simulation of digital circuits.

Description and synthesis of combinational circuits in schematic and in Verilog language. Test bench for combinational circuits. Description and synthesis of sequential circuits in schematic and in Verilog language. Bench test for sequential circuits.

Finite state machines. Verilog description of finite state machines.

Arithmetic circuits. Description of arithmetic circuits in Verilog language.

Timing of sequential circuits.

Introduction to "System on a Programmable Chip" (SOPC). Embedded processors. Standard interfaces. IP Core. Integration of complex systems on FPGAs.

Statistical Learning (CFU 9)

Learning objectives

Students will recognize the role of statistical models and their applications.

Methodologies behind statistical learning methods will cover the analytical solutions of estimation and classification problems as well as the techniques based on data analysis.

Prerequisites

Probability, random variables, linear algebra, programming.

Course contents

Basis. Statistics: sufficiency, completeness. Factorization theorem. Exponential class. Estimators. Quality parameters: bias, mean square error, variance, covariance matrix, consistency. Natural estimators, method of moments. Performance bounds: Cramer Rao Lower Bound.

Estimation. ML estimation: properties and examples, principle of invariance. Signal with unknown parameters in AWGN. ML estimation of the linear model, Asymptotic properties of the ML estimate.

Classification. Binary detection: LRT and LLRT, ML rule. Neyman Pearson criterion. Performance analysis: ROC. Composite hypothesis tests. GLRT and generalized ML rule. ML classification: simple and composite hypothesis.

Bayesian approach. Cost function, risk, Bayesian rules. MAP and ML classification rules. MMSE, MAP estimation of variables and random vectors. MMSE predictor of order N, Bayesian linear model, Wiener filter. LMMSE estimation: orthogonality principle, normal equations, performance.

Introduction to Machine Learning.

Statistical supervised learning. Classification, Bayes classifier. Regression. Overfitting. Performance assessment of a learning machine, generalization error. Validation techniques.

Linear regression. Univariate linear model, Least Squares estimation. Multiple linear regression model, LS solution. Weighted Least Squares. Recursive Least Squares.

Nonlinear approach. Nonlinear regression: Artificial neural networks. Classification and regression trees. Nonlinear classification: Nearest-neighbour classifier.

Model averaging approach. Bagging. Boosting. Random forest.

Applied Thermodynamics and Mechanics (CFU 6)

Learning Objectives

The course aims to provide basic knowledge of applied thermodynamics and mechanics addressing automation and robot systems, for optimal integrated design as concerns thermal (e.g., heat removal) and mechanical performance (e.g., trajectories and load resistance).

Prerequisites

Bachelor (IT first level *"Laurea"*)

Course Content

- Mechanics of a Point Mass:

Model of the point mass; Trajectories; Motion modes; Forces; The basic equations of mechanics; Energy conservation law of mechanics; Angular momentum and torque.

- Dynamics of Rigid Bodies:

Model of a rigid body; Center of mass; Forces and moments; Momentum and inertia forces: Linear and angular momentum, Inertia matrix and inertia forces; Laws of motion: Dynamic equilibrium; Virtual work principle; Lagrange equations; Applications: Lumped-parameter model of a mechanical transmission, Planar four-bar linkage mechanism, Planar five-bar linkage mechanism, Spherical mechanism and Gyroscope.

- Applied Thermodynamics:

Introductory concepts and definition: thermodynamic systems (closed and open), property, state, process; Thermodynamic relation for simple compressible substance: p-v-T relation, thermodynamic property data (tables and charts), equation of state of thermodynamic models (ideal gas and liquid); Conservation of mass for a control volume; First law of thermodynamics; Second law of thermodynamics; Irreversible and reversible processes. Ducts, compressors, fans, pumps.

- Heat transfer:

Conduction: fundamentals and definitions; one-dimensional steady state; transient regime lumped Resistance-Capacity model;

Convection: fundamentals and definitions; mass, momentum, energy balances; external and internal convection; Newton relation; correlations for convection heat transfer coefficient;

Radiation: fundamentals and definitions; ideal emission and absorption; radiative characteristics of surfaces; black and gray body; radiation heat transfer;

Fundamentals of heat exchangers.

- Electronic cooling:

Air cooling; Liquid cooling; Finned systems; Heat Pipes.

Multiphysics modelling (CFU 9)

Learning objectives

The course is aimed at providing a broad understanding and a hands-on knowledge of state-of-the-art modeling and simulation tools for different (multi)physics scenarios of engineering interest, including electromagnetics, acoustics and heat transfer.

Prerequisite

General knowledge of mathematics and physics.

Course contents

Generalities on physical modeling. Differential and integral approaches. Time-domain and frequency-domain. Review of basic linear-algebra notions. Review of fundamental equations and observables in selected physical domains: electromagnetics, acoustics, heat transfer. Review of main analytical approaches: separation of variables, asymptotic and perturbation techniques. Review of main numerical approaches: method of moments, finite elements, finite differences. Introduction to COMSOL Multiphysics: interface and general workflow, RF, Acoustics, Heat-Transfer and Ray-Optics modules.

Laboratory: Selected case studies in COMSOL Multiphysics for single-physics and multiphysics realistic scenarios.

Electronics of Digital Integrated Systems (CFU 9)

Learning objectives

The aim of the course is to provide an introduction to modern VLSI. Circuit and system design methods at the lowest design abstraction methods are presented and related to their different fields of application such as computer science (computers, peripherals, memories)

Prerequisites

No prerequisites

Course contents

Introduction to VLSI. Switch-level simulation. CMOS Technology. Integrated circuit layout. Interconnection. Power supply distribution. Euler's graphs and paths. Combinational subsystem architectures: adders, multipliers, ALU, advanced MOS gates. Sequential subsystem architectures: clock distribution, synchronization and metastability. Testing techniques for combinational and sequential systems.

Modern control (CFU 9)

Learning objectives

The student will extend state-space analysis and learns recent advances in control engineering such as pole assignment, observers design, introduction to advanced control topics such as optimal control, and fundamentals of identification techniques.

Prerequisites

Basics of analysis of dynamic systems

Course contents

State-space analysis. Linear systems with multiple eigenvalues. Nonlinear state-space representation. Linearization. Jacobian matrices. Decomposition of system into controllable and uncontrollable parts. Deadbeat response. Pole assignment with state and with output feedback. Use of observer. Introduction to advanced control topics: optimal control. System identification of dynamic systems, least squares. Theory and implementation for system estimation.

Dynamics and Control of Switched Electronic Systems (CFU 9)

Learning objectives

The course aims to provide the tools necessary for the analysis, simulation and control of power electronic converters with applications in electrical systems and electrical DC and AC drives. Numerous exercises developed in MATLAB/ SIMULINK allow the student to study dynamic and steady-state modeling and control behaviors of power converters.

Prerequisite

Knowledge of the fundamental principles of the theory of dynamic systems, electronic devices and elementary analysis of linear circuits.

Course contents

Averaged models, complementary models and discrete-time models for power electronic converters. DC / DC converters buck, boost and full bridge in continuous conduction mode and discontinuous conduction mode. PWM voltage control and current control. AC/DC diodes bridges, single phase and three-phase. Controlled three-phase bridge, AC/DC power converter and inverter. Vector PWM modulation and elimination of harmonics. Inverter regulation for induction motor control. Examples of simulation of power electronic systems with averaged and complementary models. Examples of applications: photovoltaic, LED, traction, synchronization.

Distributed measurement systems (CFU 9)

Learning objectives

The course addresses various aspects of remote data acquisition and processing in distributed contexts, with the aim of providing skills that support a possible project activity.

Prerequisites

Basic knowledge of electronic measurements is required.

Course contents

Definition of distributed system and distributed measurement. Main requirements and problems. General architecture, measurement node, communication interface, and technologies (Ethernet, powerline communication, IEEE-488, WiFi, UMTS, RF, etc.) for implementing distributed measurement systems in static and mobile applications. Client-server and web-based architectures for measurement applications. Network communication protocols for measurement applications. BUS for interfacing sensors, BUS for monitoring and controlling industrial systems.

Advanced Control and Applications (CFU 6)

Learning objectives

The course aims to lead the student to acquire the knowledge necessary for the implementation of control strategies in real engineering systems. Through the use of real case studies, the application aspects related to the implementation of standard controllers and advanced control techniques related to the specific application domain will be addressed.

Prerequisites

Basic elements of the analysis of dynamic systems and automatic controls.

Course contents

Basics on the design of standard controllers. Implementation of standard controllers on real-time platforms. Discretization, event controllers, hybrid systems. Advanced control techniques based on specific application domains including, by way of example, automotive control. Development of project works on the implementation of control systems in real application areas.

Learning for dynamics and control (CFU 6)

Learning objectives

The main objective of the course Learning for Dynamics and Control is to introduce students to the emergent scientific area at the intersection among machine learning, dynamical systems and control theory. During the course, students will investigate data driven algorithms that interact with the physical world. The proposed approach will be aimed to a unitary comprehension of the so-called cyberphysical systems and will be based on concepts of control theory and machine learning. The course is aimed to provide master students with fundamental tools for understanding innovative control techniques master and, at the same time, being able to apply novel concepts proposed by recent advancements of the scientific research for solving their own control problems.

Prerequisites

The course Learning for Dynamics and Control does not have compulsory prerequisities. Nevertheless, since it is a advanced methodological course, it is expected that students have a good knowledge of linear systems and a solid foundation in mathematics, specifically a good knowledge of mathematical programming and probability theory/statistics concepts.

Course contents

Introduction to the course

Fundamental concepts: deterministic optimization, probabilistic policies
Linear systems
Learning applied to control problems

System identification and approaches based on machine learning

Model free methods

Nonlinear systems applications

CURRICULUM: SENSING TECHNOLOGIES

LIST OF EXAMS

First year, first semester (CFU 27)

Real Time Measurements Systems (CFU 9)

Programmable Electronic Circuits (CFU 9)

Statistical Learning (CFU 9)

First year, Second semester (CFU 33)

Optoelectronics and Photonics (CFU 9)

Multiphysics modelling (CFU 9)

Wave-based sensors and diagnostics (CFU 6)

Modern control (CFU 9)

Second year, first semester (CFU 33)

Sensors for Earth Observation (CFU 9)

Nano-Optics (CFU 9)

Optical and Photonic Sensors Lab (CFU 6)

Freely chosen course (CFU 9, to be approved. The suggested course *Micro and Nano Fabrication Technologies*, is automatically approved.)

Second year, second semester (CFU 27)

Earth monitoring and mission analysis Lab (CFU 6)

Internship (CFU 9)

Final examination (CFU 12)

DETAILED COURSE DESCRIPTIONS

Real Time Measurements Systems (CFU 9)

Learning objectives

The course aims at providing tools and methods for the signal processing of data coming from measuring instruments and sensors.

The course then relies on a summary of the signal processing techniques and presents their application to practical cases of measurement data processing through the direct usage of instrumentation.

Prerequisites

Basic knowledge and skills in electronic measurements, signal theory, and programming are required.

Course contents

Summary about sampling, sampling of periodic signals, bandpass sampling, hints about compressive sampling; summary about quantization, properties of quantization noise; measurements on digital signals in the time domain, IEEE Std. 181; summary about Fourier Transform, Discrete-Time Fourier Transform (DTFT), Discrete Fourier Series (DFS) and Discrete Fourier Transform (DFT), FFT algorithm; spectral leakage and windowing; measurement of frequency, phase, and amplitude of sinewave signals by DFT; usage of zero-padding for improving the frequency resolution; interpolated FFT; measurement of frequency and amplitude of sinewave signals based on power evaluation; LMS and RLS adaptive filters; summary of digital filters and their design; short-time Fourier Transform (STFT) and spectrogram; quadratic representations and Wigner-Ville distribution; continuous and discrete Wavelet Transform; introduction to the Digital Signal Processor, DSP Architecture (bus access architectures, Interrupt and DMA, datapath structure, VLIW architecture); fixed-point arithmetic; microcontroller architecture, ARM Cortex-M architecture; serial interfaces (I2C, SPI, UART, VLDS, JESD204B); laboratory activities about signal acquisition and processing with STM32 microcontrollers

Programmable Electronic Circuits (CFU 9)

Learning objectives

The aim of the course is to teach methods and techniques to implement electronic circuits using programmable components. At the end of the course, the student must be able to transform an idea of application into a working circuit, taking advantage of the most appropriate methodologies and project tools (through the use of commercial development environments, the description in HDL languages and the use of IP blocks) to implement a programmable circuit.

Prerequisites

Fundamentals of Digital Electronics

Course contents

Introduction to Programmable Electronic Circuits. Recalls of digital electronics: combinational circuits and sequential circuits. Programmable Logic Arrays (PLA). Programmable Array Logic (PAL) devices. Sequential Programmable Logic Devices (PLDs). Complex PLDs. Analysis of the main commercial PLD architectures. Field programmable gate arrays (FPGA). Analysis of the main commercial FPGA architectures. Project flow for FPGA. The Quartus Prime development system. The Verilog hardware description language for the synthesis and simulation of digital circuits.

Description and synthesis of combinational circuits in schematic and in Verilog language. Test bench for combinational circuits. Description and synthesis of sequential circuits in schematic and in Verilog language. Bench test for sequential circuits.

Finite state machines. Verilog description of finite state machines

Arithmetic circuits. Description of arithmetic circuits in Verilog language.

Timing of sequential circuits.

Introduction to "System on a Programmable Chip" (SOPC). Embedded processors. Standard interfaces. IP Core. Integration of complex systems on FPGAs.

Statistical Learning (CFU 9)

Learning objectives

Students will recognize the role of statistical models and their applications.

Methodologies behind statistical learning methods will cover the analytical solutions of estimation and classification problems as well as the techniques based on data analysis.

Prerequisites

Probability, random variables, linear algebra, programming.

Course contents

Basis. Statistics: sufficiency, completeness. Factorization theorem. Exponential class. Estimators. Quality parameters: bias, mean square error, variance, covariance matrix, consistency. Natural estimators, method of moments. Performance bounds: Cramer Rao Lower Bound.

Estimation. ML estimation: properties and examples, principle of invariance. Signal with unknown parameters in AWGN. ML estimation of the linear model, Asymptotic properties of the ML estimate.

Classification. Binary detection: LRT and LLRT, ML rule. Neyman Pearson criterion. Performance analysis: ROC. Composite hypothesis tests. GLRT and generalized ML rule. ML classification: simple and composite hypothesis.

Bayesian approach. Cost function, risk, Bayesian rules. MAP and ML classification rules. MMSE, MAP estimation of variables and random vectors. MMSE predictor of order N, Bayesian linear model, Wiener filter. LMMSE estimation: orthogonality principle, normal equations, performance.

Introduction to Machine Learning.

Statistical supervised learning. Classification, Bayes classifier. Regression. Overfitting. Performance assessment of a learning machine, generalization error. Validation techniques.

Linear regression. Univariate linear model, Least Squares estimation. Multiple linear regression model, LS solution. Weighted Least Squares. Recursive Least Squares.
Nonlinear approach. Nonlinear regression: Artificial neural networks. Classification and regression trees. Nonlinear classification: Nearest-neighbour classifier.
Model averaging approach. Bagging. Boosting. Random forest.

Optoelectrincs and Photonics (CFU 9)

Learning objectives

The course deals with the study of optoelectronics and photonics by illustrating the main phenomenological aspects related to the propagation of light and interaction with matter. In addition, the main optoelectronic devices, components and systems for generation, detection and light control, are analyzed with an engineering approach for the purpose of processing information, transmitting data or converting energy.

Prerequisite

Basics of electromagnetic fields

Course contents

Introduction

Recalls of electromagnetic fields: wave equation, plane waves, refractive index, dispersion, velocity group.

Geometric optics: Snell's law, total internal reflection, Fresnel equations, intensity, reflectance, transmittance

Interference: spatial and temporal coherence, Fabry-Perot interferometer, anti-reflective coatings, optical resonators, Michelson interferometer, Mach Zehnder interferometer

Diffraction principles: Fraunhofer diffraction, diffraction gratings

Prims. Angle of minimum deviation

Planar waveguides and optical fibers

Planar waveguides: propagation in dielectric waveguide, single-mode and multi-mode guides, dispersion in waveguide-

Optical fibers: step-index optical fibers, optical fiber propagation, numerical aperture, optical fiber dispersion, single-mode and multimode optical fibers, attenuation in optical fiber, gradient refractive index (GRIN) fibers, optical fiber manufacturing processes

Coupled modes theory. Optical coupler.

Photonic Bandgap structures: Bragg gratings, photonic crystals, photonic crystal fibers

Optoelectronic components

Polarization: propagation in anisotropic media, retarding plates, polarizers and isolators

Optical modulators: electro-optical effect, acousto-optical effect

Basics of quantum mechanics and semiconductor physics

Thermal radiation. Blackbody. Modes of electromagnetic radiation in a cavity. Classical theory of the blackbody radiation (Rayleigh-Jeans formula). Radiation quantization: Planck's formula. Photoelectric effect. Linear and angular momentum of a photon. De Broglie’s hypothesis. Heisenberg's principle The Bohr atom.

Basic theorems and postulates of quantum mechanics: Schrodinger equation, statistical interpretation of the wave function, moment wave function. The atom.

Introduction to semiconductor physics: band structure, band gap, state density, doping. Direct gap and indirect gap. Semiconductors III - V.

Junction pn. Heterojunctions. Energy band diagrams

Light emitting diode (LED)

LED: operating principle, Homojunction LED, Heterojunction LED

Quantum well (QW) LED: single QW, multiple QW.

Materials, wavelength, and typical structures.

Internal and external quantum efficiency, extraction efficiency, power conversion efficiency, brightness and luminous efficacy.
SLED, ELED, white LEDs.

Photo Detectors

Operating principle of pn photodiode, photodiode regime and photovoltaic regime.
Quantum efficiency and responsivity.
Pin photodiode. Avalanche photodiode (APD). Schottky photodiode. Heterojunction photodiode. Superlattice APD.
Figures of merit for a photodiode. Photodiodes circuits
Image sensors (CMOS and CCD)
Photovoltaic cells

Laser

Laser principle of operation: stimulated emission, population inversion, 3-level laser and 4-level laser.
Erbium doped fiber amplifier (EDFA): physical concept and amplification system.
HeNe laser
Pulsed lasers: Q-Switching and Mode Locking
Laser diodes: operating principle.
Heterostructure laser. QW laser.
Distributed Bragg Reflector (DBR). Distributed Feedback (DFB) Laser. External cavity laser (ECL)
Vertical cavity surface emitting laser (VCSEL)
Superluminescent and Resonant Cavity LEDs

Raman Spectroscopy

Non linear optics. Raman effect. Basics of Raman Spectroscopy. Raman probes.

Multiphysics modelling (CFU 9)

Learning objectives

The course is aimed at providing a broad understanding and a hands-on knowledge of state-of-the-art modeling and simulation tools for different (multi)physics scenarios of engineering interest, including electromagnetics, acoustics and heat transfer.

Prerequisite

General knowledge of mathematics and physics.

Course contents

Generalities on physical modeling. Differential and integral approaches. Time-domain and frequency-domain. Review of basic linear-algebra notions. Review of fundamental equations and observables in selected physical domains: electromagnetics, acoustics, heat transfer. Review of main analytical approaches: separation of variables, asymptotic and perturbation techniques. Review of main numerical approaches: method of moments, finite elements, finite differences. Introduction to COMSOL Multiphysics: interface and general workflow, RF, Acoustics, Heat-Transfer and Ray-Optics modules.

Laboratory: Selected case studies in COMSOL Multiphysics for single-physics and multiphysics realistic scenarios.

Wave-based sensors and diagnostics (CFU 6)

Learning objectives

The course is aimed at providing a broad understanding of physical, mathematical, computational and technological aspects underlying wave-based approaches for sensing and diagnostics.

Prerequisites

General knowledge of mathematics and physics.

Course contents

Review of fundamental mechanisms of wave interactions with matter. Possible physical domains of interest and observables. Forward and inverse modeling. Elements of inverse theory: differential and integral formulations, inverse source and inverse scattering, ill-posedness, regularization, fundamental limitations. Weak-scattering regime.

Inversion techniques. Reflectometry. Radar-based sensing. Echography. X-ray and diffraction tomography. Super-resolution approaches. Magnetic resonance imaging.

Laboratory: Numerical solution of inverse-scattering problems. Millimeter-wave radar sensors.

Modern control (CFU 9)

Learning objectives

The student will extend state-space analysis and learns recent advances in control engineering such as pole assignment, observers design, introduction to advanced control topics such as optimal control, and fundamentals of identification techniques.

Prerequisites

Basics of analysis of dynamic systems

Course contents

State-space analysis. Linear systems with multiple eigenvalues. Nonlinear state-space representation. Linearization. Jacobian matrices. Decomposition of system into controllable and uncontrollable parts. Deadbeat response. Pole assignment with state and with output feedback. Use of observer. Introduction to advanced control topics: optimal control. System identification of dynamic systems, least squares. Theory and implementation for system estimation.

Sensors for Earth Observation (CFU 9)

Learning Objective

After completion of this course, students should be able to:

1. Understanding the fundamentals of Earth remote sensing system from space, using multispectral, hyperspectral and radar systems.

2. Understanding and managing parameters of the Earth remote sensing systems and how they affect the quality of the data.

3. Assessing and using laboratory subsystems for Earth remote sensing.

Prerequisite

Bachelor (IT first level *Laurea*) in Engineering or in Physics.

Course contents

Introduction. Earth observation from space. Climate variables and how they affect the Earth system.

The role of Earth observation systems. Classification of optical and microwave remote sensing systems. Active and passive sensors.

Radiative quantities. Blackbody. Planck's law. Asymptotic Wien and Rayleigh-Jeans laws. Wien's displacement law.

Stefan-Boltzmann law. Emissivity. Kirchhoff's law. Planck's law and Wien and Rayleigh-Jeans approximations.

Introduction to optical systems laboratory.

Optical remote sensing. Radiation-matter interactions in the atmosphere. Radiative transfer. Interferometers.

Laboratory experiments on multispectral and hyperspectral sensing.

Radar remote sensing. Synthetic aperture radar (SAR). Geometry. Range and azimuth resolution of a real aperture radar.

Radar impulse. Impulse compression. SAR Resolution in range and azimuth. Sensor parameters and sizing. Range focusing.

Stationary phase method. Azimuth focusing. Interferometry.

Laboratory experiments on parameterization and design of a SAR sensor. Generation of raw data of a point target.

Range migration. Focusing on a target point.

Satellite orbits. Elements of astrodynamics for low orbit satellites. Orbital perturbations. Atmospheric drag.

Orbital elements. Orbit propagators.

Laboratory with orbit prediction with orbit propagators.

Space platforms. Cubesats and small satellites. Satellite subsystems. Attitude determination and control.

On-board computer. On board data handling. Communication subsystem.

Laboratory experiments with cubesat TEIA-ESAT space laboratory platform.

Nano-Optics (CFU 9)

Learning objectives

The course is aimed at providing an advanced knowledge of the physical mechanisms underlying the light-matter interactions at the nanoscale, and their analytical and numerical modeling.

Prerequisites

General knowledge of electromagnetics and numerical simulations.

Course contents

Review of electromagnetic fields and waves. Multipolar expansion. Angular spectrum representation. Resolution limits in classical optics. Dispersion models: Drude, Lorentz. Mie scattering theory in cylindrical and spherical geometries. Resonance of small nanoparticles.

Plasmonic cavities and nano-antennas. Plasmonics and surface polariton waves. Coupled surface plasmon polaritons. Flatland optics in 2D materials. Nanolasers and spasers. Quantum effects. Periodic structures and Bloch theorem. Photonic crystals. Scattering anomalies: Fano resonances, anapoles, bound states in the continuum. Metamaterials and metasurfaces: generalities, homogenization, and main applications.

Laboratory: Numerical study and design of nanostructures in COMSOL Multiphysics.

Optical and Photonic Sensors Lab (CFU 6)

Learning objectives

The main objective of the course is to provide students with knowledge relating to methodologies, technologies and application tools in the field of optical and photonic sensors for:

- structural monitoring,

- environmental monitoring

- biomedical diagnostics

- industrial automation

The objective is to train master engineers capable of designing, building and characterizing innovative sensors and monitoring systems based on optics and photonics, and understanding the issues related to them. The course includes lectures aimed at illustrating the main methodologies and technologies underlying the main new generation optical and photonic sensors accompanied by numerous laboratory exercises, dedicated to the preparation and management of complex setups for the characterization of optical and photonic sensors, the use of advanced micro and nanotechnologies, the processing and analysis of data produced by sensors and multi-parametric monitoring systems.

The course is therefore aimed at training master engineers capable of developing and managing optical and photonic sensors and sensor systems, starting from the technical specifications deriving from the each specific application domain.

Prerequisites

Optoelectronics and Photonics,

Course Contents

Introduction to the basic concepts for the measurement of quantities of interest (physical, chemical, biological) through the use of light.

- Multiparametric fiber optic sensors

- Imaging

- Linear and non-linear spectroscopy

- Interferometry

Laboratory lessons

- Fiber optic sensors based on long pitch fiber optic gratings (LPG): Introduction to LPGs and their application to sensing. Fabrication and spectral characterization of an LPG. LPG as temperature and humidity sensor. LPG as refractive index sensor. Characterization of an LPG-based refractive index monitoring system.

- Fiber optic sensors based on Bragg gratings (FBGs): Introduction to FBGs and their application to sensing. Spectral characterization of an FBG. FBG as a temperature, strain and vibration sensor. Characterization of an FBG-based monitoring system for structural health monitoring

- Interferometry, introduction to interferometry, Fabry-Perot interferometer: characterization of optoelectronic components and a Fabry-Perot interferometer. Characterization of a fiber optic accelerometer based on a Fabry-Perot interferometer. Mach-Zehnder Interferometer: Implementation of a fiber optic Mach-Zehnder interferometer for the interrogation of sensors in which the quantity of interest is encoded in the optical wavelength.

- Nanophotonics for biomedicine. Introduction to Lab on Fiber Technology. Development of an optoelectronic setup for the optical and morphological characterization of nanosensors. Characterization of nanoplasmonic biosensors, Functional characterization of a plasmonic device as a biological sensor for medical diagnostic applications.

- Raman Spectroscopy and Imaging Measurements carried out under the Raman microscope and related data analysis.

- Infrared spectroscopy Measurements carried out on the FTIR spectrometer and related data analysis.

- Label-free diagnostics. Measurements carried out using Biacore and related data analysis.

Earth monitoring and mission analysis Lab (CFU 6)

Learning objectives

Addressing mission requirements.

Understand environmental, civil and security applications of remote sensing.
Understand EO mission requirements for specific needs and finding the best payload to address a remote sensing problem.
Learning advanced methods and tools for processing real data.

Prerequisites

Sensors for Earth observation

Course contents

Introduction to the Copernicus observation programme.

Terrestrial and satellite monitoring sensor networks. Environment and Earth observation. Mission analysis.

Multispectral data processing laboratory. Applications on land, ocean and atmosphere.

Radar data processing laboratory. SAR interferometry. Large and small scale deformations. Applications.

Advanced satellite data processing techniques (machine/deep learning, some concepts of quantum computing applied to remote sensing