PHD IN EMERGING DIGITAL TECHNOLOGIES

A.Y. 2020-21
Course Offer

Embedded Systems
Perceptual Robotics
Photonic Technologies

Curriculum Embedded Systems

1. Neural Network and Deep Learning: Theoretical Foundations
2. Neural Network and Deep Learning: Implementation Issues
3. How to do research
4. System-level Cyber-security
5. Linux Kernel Programming
6. Functional Programming Techniques
7. Advanced Operating Systems
8. Automotive SW systems
9. Real-Time and High-Performance Computing on Linux
10. Survey of Soft Real-Time Systems Research
11. Cloud Computing and Big-Data
12. Cloud Computing and Big-Data Lab

Curriculum Embedded Systems

COURSE TITLE	**Neural Network and Deep Learning: Theoretical Foundations**
LECTURER/S	Giorgio Buttazzo
HOURS	30
CFU	3
FINAL EXAM	PROJECT WORK + WRITTEN EXAMINATION
TEACHING METHODOLOGY	LECTURES
KEYWORDS	Neural Networks, Deep Learning
CONTENTS	The objective of the course is to provide basic concepts and methodologies on the main existing neural models, explaining how to use them for pattern recognition, image classification, signal prediction, data analysis, system identification, and adaptive control. 1. **Introduction to neural computing**. Motivations. Main network models and learning paradigms. 2. **Fully connected networks.** Hopfield networks. Associative memories, Application to optimization problems. 3. **Competitive learning**. Self-organizing maps. Kohonen networks: network model, learning algorithm and main network properties. Examples and applications. 4. **Reinforcement Learning.** The state-box learning paradigm. Temporal credit assignment. The ASE/ACE neural model. Q-learning and SARSA algorithms. 5. **Supervised learning.** The Perceptron: model, properties and limitations. Multi-layer networks. The Back Propagation algorithm. Convergence and generalization. Applications of multi-layer networks to signal prediction, control, and system identification. Examples and applications. 6. **Towards deep networks.** Advantages of increasing the number of neural layers. Problems in training deep networks: overfitting and vanishing gradient. Solutions for deep learning: better loss functions, better activation functions, regularization, and dropout methods. 7. **Deep network models**: Boltzmann Machines, Restricted Boltzmann Machines, Autoencoders, Convolutional Networks. Implementation issues. Examples and applications. 8. **Specific deep neural networks**: LeNet-5, Alex-Net, VGG-Net, GoogLeNet, ResNet, SqueezeNet. 9. **Neural Networks for object detection**. Sliding windows, OverFeet, R-CNN, Yolo. 10. **Recurrent neural networks**. Gate recurrent units, LSTM, Bidirectional networks, Networks for Natural language processing. 11. **Deep Reinforcement Learning**. Deep Q-learning models. Policy gradient and actor-critic methods. 12. **Generative adversarial networks**. Generative autoencoders, GANs, Style Transfer, Semi-Supervised learning. 13. **Sample applications and open issues.**
TIMETABLE	From 13 January(3 hours per week)– 10 week course – until end of March

COURSE TITLE	**Neural Network and Deep Learning: Implementation Issues**
LECTURER/S	Giorgio Buttazzo (16), Alessandro Biondi (14)
HOURS	30
CFU	3
FINAL EXAM	PROJECT WORK + WRITTEN EXAMINATION
TEACHING METHODOLOGY	LECTURES, SIMULATIONS
KEYWORDS	Neural Networks, Deep Learning
CONTENTS	The objective of the course is to provide practical and implementation issues useful to deploy neural networks on a variety of embedded platforms using different languages and developments environments. 1. **Implementing Neural Networks from scratch in C**. General implementation principles. Main and auxiliary functions. 2. **Sample implementations** of common neural network models in C language. 3. **Frameworks for training and inference of deep neural networks.** Overview of the existing frameworks. Common data sets. 4. **Modeling neural networks in Tensorflow and Caffe.** Examples of neural network implementations. 5. **Simulation environments for neural control.** Summary of neural models for control. Overview of the OpenAI Gym framework. Implementation of different RL algorithms in GYM for different application scenarios (gridworld, inverted pendulum, autonomous vehicles, robots, etc.). Overview of the Mujoco environment and related applications. 6. **Genetic algorithms for reinforcement learning.** 7. **Accelerating deep networks on GPGPUs.** Overview of the Nvidia TensorRT framework. Executing a DNN modelled in Caffe in TensorRT. 8. Real-time neural vision. How to accelerate a neural network on TensorRT to detect objects from a video camera. 9. Accelerating deep networks on FPGA. Common frameworks for deploying deep networks on FPGA. 10. **A sample implementation** of a deep neural network on the Zynq platform.
TIMETABLE	From 9 March (4 hours per week) – 8 week course – until first week of May

Curriculum Embedded Systems

COURSE TITLE	**How to do research**
LECTURER/S	Giorgio Buttazzo, Tommaso Cucinotta
HOURS	30
CFU	3
FINAL EXAM	PROJECT WORKS
TEACHING METHODOLOGY	LECTURES
KEYWORDS	Doing research, writing papers, writing project proposals, making presentation.
CONTENTS	The course covers the entire process needed during a research study, from the initial phase in which a new problem is addressed, formalized, and solved, up to the final phase in which the achieved results have to be communicated to the scientific community. The course is divided in six lectures covering the various aspects of research, including writing papers, the publication process, writing research projects, making good slides and presentations. 1. **How to do research**. Meaning of research and typical steps of the research process: key points and common mistakes. 2. **How to write scientific papers**. Setting a good structure. Contains of typical sections. How to describe and present experiments. How to cite work by other people. Figures and visualization issues. Avoiding common mistakes. 3. **Getting into the publication process**. Why to publish? Types of scientific publications and scientific communities. The submission process. Reviewing process and evaluation criteria. How to review a paper. Publishing on Journals. Preparing a revised version. 4. **How to write research projects**. Why writing a research project? Types of research projects. Key elements of a project proposal. Structure of a proposal. Budget Concepts. Example of Projects. 5. **How to make presentations**. Identifying the audience and the main message of the paper. Setting a good presentation structure: what to include and what to leave out. Preparing good slides. Animations, colors, figures. Amount of text. Things to avoid. Having the right attitude when presenting the work. Handling time. 6. **Simulating a small conference**. Paper presentation by the students.
TIMETABLE	From 13 January(3 hours per week)– 10 week course – until end of March

Curriculum Embedded Systems

COURSE TITLE	**System-level Cyber-security**
LECTURER/S	Alessandro Biondi
HOURS	20
CFU	2
FINAL EXAM	None
TEACHING METHODOLOGY	LECTURES and LABORATORIES
KEYWORDS	
CONTENTS	The course will introduce most of the fundamental attack techniques to modern software systems, discussing the technical details of their implementation, their potential impact, and their strengths and weaknesses. Practical examples of each type of attack will also be presented. Then, the course will focus on attack mitigation techniques, providing a systematic classification of their capabilities, presenting their implementation details and discussing their availability in today's operating systems. Possible attack approaches to bypass such mitigation techniques will be discussed. Guidelines on how to improve the security of a software system will also be presented. Finally, a recent attack targeting smartphones will be introduced as a case-study. The students will be either involved in a software project to consolidate the key concepts presented in the course, or in the study of other case-studies selected by the teacher to be presented in the class-room to engage discussions.
TIMETABLE	2nd semester – July 2021 – 2 lectures per week to be agreed with students

COURSE TITLE	**Linux Kernel Programming**
LECTURER/S	Luca Abeni
HOURS	20
CFU	2
FINAL EXAM	ORAL
TEACHING METHODOLOGY	LECTURES and LABORATORIES
KEYWORDS	Linux, system programming
CONTENTS	This course will introduce the basics of the Linux kernel, allowing students to develop their own extensions and features. After a short theoretical introduction about the kernel execution environment and about concurrent and multi-threaded programming, the students will learn how to write kernel code, and how to synchronize multiple tasks (processes or thread). In some hands-on lessons, the students will write some Linux kernel modules, and will end up developing a simple IPC mechanism (a mailbox based on a char device). Finally, some basic information about the CPU scheduler and its internals will be introduced.
TIMETABLE	1st semester: 12/10, 19/10, 26/10, 9/11, 16/11, 23/11, 30/11, 7/12 (time slots: 9:30 - 12)

Curriculum Embedded Systems

COURSE TITLE	**Functional Programming Techniques**
LECTURER/S	Luca Abeni
HOURS	20
CFU	2
FINAL EXAM	ORAL
TEACHING METHODOLOGY	LECTURES
KEYWORDS	Programming paradigms, non-imperative programming
CONTENTS	This course will present an introduction to functional programming, first considering functional programming as a programming paradigm (that can be applied using a generic programming language), and then using a functional programming language (for example, Standard ML, Haskell or scheme).
TIMETABLE	1st semester: 14/10, 21/10, 28/10, 4/11, 11/11, 18/11, 25/11, 2/12 (time slots: 9:30 -12)

Curriculum Embedded Systems

COURSE TITLE	**Advanced Operating Systems**
LECTURER/S	Luca Abeni
HOURS	20
CFU	2
FINAL EXAM	ORAL
TEACHING METHODOLOGY	LECTURES and LABORATORIES
KEYWORDS	Operating Systems, real-time, microkernels
CONTENTS	This course will present some advanced topics on Operating Systems, assuming some basic knowledge. In particular, the course will focus on OS kernel support for real-time applications, describing the differences between a general-purpose OS and a RTOS, and explaining how a real-time kernel can be implemented in an effective way. Some concepts from real-time theory will be used to explain the features, the requirements and the structure of modern real-time kernels, comparing different alternatives. The course will also discuss OS support for virtualization (and for the cloud in general). Finally, some more advanced OS structures (microkernel-based OSs, unikernels, library OSs) will be presented and discussed.
TIMETABLE	2nd semester: 23/2, 2/3/2021, 9/3/2021, 16/3/2021, 23/3/2021, 30/3/2021, 6/4/2021, 13/4/2021 (timeslots: 9:30 – 12)

COURSE TITLE	**Automotive SW systems**
LECTURER/S	M. Di Natale, TBD
HOURS	30
CFU	3
FINAL EXAM	
TEACHING METHODOLOGY	LECTURES/LABORATORIES/EXERCISES/SIMULATIONS
KEYWORDS	
CONTENTS	The purpose of the course is to provide an overview and examples of the fundamental methodologies, technologies and standards that drive the development of software for automotive applications, including AUTOSAR for the operating system, the definition of SW components and the SW architecture.
TIMETABLE	N.A. - Please contact the teacher

COURSE TITLE	**Real-Time and High-Performance Computing on Linux**
LECTURER/S	Tommaso Cucinotta
HOURS	20
CFU	4
FINAL EXAM	PROJECT WORK
TEACHING METHODOLOGY	LECTURES/LABORATORIES
KEYWORDS	
CONTENTS	This course aims at a deep dive into advanced concepts related to software development and engineering that are needed to build real-time and high-performance applications and networking services on the Linux Operating System. The course is structured with: 1. a part of front lectures overviewing essential concepts and APIs concerning: real-time scheduling on Linux including SCHED_DEADLINE and some extensions recently realized by the RETIS; controlling energy/performance trade-offs for embedded real-time applications through frequency governors and precise DVFS/DPM control; NUMA-awareness, task and interrupt affinity for large multi-core machines and its impact on software performance and predictability; primitives and APIs for high-performance networking, such as DPDK and similar; how to compile the Linux kernel with PREEMPT_RT support and how it can enhance software predictability; 2. a part of project work that is realized by the students under the lecturer supervision, where students will realize a software project mixing together some of the concepts seen during the front lectures, and will build, or contribute to, an application to be used during some demonstration of the real-time capabilities of Linux, enhanced with key real-time technologies realized at the RETIS; alternatively, the project work will also be allowed to implement a simulation of some of the above mentioned features. Given the significant work expected to be carried out autonomously by students at home, I suggest recognizing them 4 CFUs, even if only 20 hours are planned in the teaching room with the lecturer.
TIMETABLE	February – March, 4 hours per week

Curriculum Embedded Systems

COURSE TITLE	**Survey of Soft Real-Time Systems Research**
LECTURER/S	Tommaso Cucinotta
HOURS	30
CFU	6
FINAL EXAM	PROJECT WORK
TEACHING METHODOLOGY	LECTURES/EXERCISES
KEYWORDS	
CONTENTS	This course aims at overviewing key contributions in the literature of soft real-time systems research, focusing on critical reading and discussion. Lectures will focus on presentations of exemplar works that advanced the state of the art of research in some sub-areas of the research in real-time systems, with a significant part of the lectures focusing on stimulating critical discussion among the students of the main positive and innovative aspects of the works, as well as their main limitations, possibly negative aspects as well as possible extensions and improvements. The final exam will consist in the delivery by each student, or small group of students, of a survey manuscript that presents in extended and detailed way key papers published in an area related to the main research focus of the student(s), comparing them also recurring to a reimplementation of the various techniques over which an independent experimental evaluation will be carried out. Given the significant work expected to be carried out autonomously by students at home, I suggest recognizing them 6 CFUs, even if only 30 hours are planned in the teaching room with the lecturer.
TIMETABLE	October – January, 3 hours per week

COURSE TITLE	**Cloud Computing and Big-Data**
LECTURER/S	Tommaso Cucinotta
HOURS	30
CFU	3
FINAL EXAM	ORAL
TEACHING METHODOLOGY	LECTURES
KEYWORDS	
CONTENTS	This course provides an overview of the challenges to face, and the technical solutions to embrace, when building large-scale, fault-tolerant, distributed and replicated real-time cloud services. These systems need to be capable of serving millions/billions of requests per second with industrial-grade reliability, availability and performance, and are composed of thousands of components spanning across millions of machines, worldwide. The course focuses on design, development and operations of scalable software systems, including big-data processing and analytics, where the huge volumes of data to handle mandates the use of heavily distributed algorithms. The course covers also basic concepts on architectures of data-centre/cloud infrastructures.
TIMETABLE	November – January, 6 hours per week

COURSE TITLE	**Cloud Computing and Big-Data Lab**
LECTURER/S	Tommaso Cucinotta
HOURS	30
CFU	3
FINAL EXAM	PROJECT WORK
TEACHING METHODOLOGY	LECTURES/LABORATORIES
KEYWORDS	
CONTENTS	Hands-on follow-up to the Cloud Computing & Big-Data course. This is an applied course where students will put in practice the theoretical/abstract concepts acquired in the general course on Cloud Computing & Big-Data. During the practical sessions, we'll have a deep dive on such concepts as: machine virtualization (KVM) and OS-level virtualization (LXC) on Linux; virtual networking and virtual switches on Linux; command-line access to an OpenStack cluster and to basic AWS cloud services including EC2, S3 and DynamoDB.
TIMETABLE	May – July, 3 hours per week

Curriculum Perceptual Robotics

1. Machine learning fundamentals, algorithms and applications through Python
2. Mechatronics
3. Digital Perception
4. Robotics Applications in Industry
5. Computer aided design for 3D Geometric Modeling
6. Advanced Kinematics and Human Interfaces
7. Laboratory of Actuators and Tranducers for Robotics
8. Virtual and Augmented Reality
9. Mechanics of Advanced Transducers

COURSE TITLE	**Machine learning fundamentals, algorithms and applications through Python**
LECTURER/S	Marco Vannucci, Valentina Colla
HOURS	35 Marco Vannucci (25), Valentina Colla (10)
CFU	3
FINAL EXAM	Project work and discussion
TEACHING METHODOLOGY	Lectures and laboratories
KEYWORDS	Machine learning; python; introduction; practical
CONTENTS	The course provides fundamentals in several widely used Machine Learning approaches that are nowadays gaining interest in practical applications. The course covers both theoretical and practical aspects, providing practical examples for solving real world problems, using Python as a programming language with its main packages (Numpy, Pandas, SciKitLearn, Scipy, keras, ...). The main families of techniques that will be discussed include: 3. Decision Trees; the fundamental principles will be introduced and the basic concepts to allow benefits and limitation of this widespread approach to decision support; 4. Ensemble methods applied to clustering classification and regression (e.g. Random Forest); 5. Clustering algorithms (K-Means, Self-Organizing Maps, Growing Neural Gas and their application; 6. Bio-inspired optimization algorithms. The main motivation and ideas will be introduced and most common algorithms will be described in detail, as genetic algorithms, ant colony optimization, tabu search, and particle swarm optimization. 7. Fuzzy logic and fuzzy inference systems. A theoretical background will be provided together with the basic concepts for the design and exploitation of fuzzy inference systems. Neuro-Fuzzy systems will also be presented. 8. Hybrid systems. The main paradigms that combine standard methods and different AI based approaches will be discussed through practical use cases. Finally, the course will show how the methods described above can be used for the development of advanced Machine Learning systems that address tasks referring to real-world problems.
TIMETABLE	2nd semester - TBD – 2 lectures per week

Curriculum Perceptual Robotics

COURSE TITLE	**Mechatronics***
LECTURER/S	Carlo Alberto Avizzano (25), Marco Fontana (15)
HOURS	40
CFU	4
FINAL EXAM	ORAL/ PROJECT WORK
TEACHING METHODOLOGY	LECTURES/LABORATORIES/EXERCISES
KEYWORDS	Microcontrollers, signal processing, actuators, applied mechanics
CONTENTS	The objective of this course is to introduce the basic control theories for digital systems. The course introduces to physical modeling problems and reviews typical architectures for the control of electro-mechanical systems. First, the module introduces modelling techniques for elementary physical systems. Second, the module describes input-output interfaces (sensors, drivers and actuators). Finally, the module reviews a set of common electronics standards for data communication and signal conversion. Practical lessons will use a DSP processor platform and commercial electronics. Laboratory lessons also introduce to the use of instruments for diagnosis and debug.
TIMETABLE	2nd semester - TBD – 2 lectures per week

* activated only with the participation of minimum 3 PhD students

Curriculum Perceptual Robotics

COURSE TITLE	**Digital Perception – part I***
LECTURER/S	Carlo Alberto Avizzano
HOURS	45
CFU	N.A.
FINAL EXAM	PROJECT WORK WITH DOCUMENTED PRESENTATION AND DEMO
TEACHING METHODOLOGY	LECTURES, CLASSROM EXERCISES, HOMEWORK ASSIGNMENTS
KEYWORDS	Computer Vision, Projective Geometry, Python, Deep Learning
CONTENTS	**SYNOPSIS**: The class will provide fundamental of computer vision as tools for metrology, scene analysis, data capture and processing. During the class an ideal setup using basic tools under Linux/Python/OpenCV environment will be proposed, but similar setup with Windows, OSX operating system are also available. The course will offer review analysis of the following topics: • Basic of vision and image management: cameras, videos, and images import/export • Colour management, white balance, HDR, background models • Camera models, lenses, perspective projection, transformations • Spatial, frequency and non-linear filters • Mask, Momentum and Object analysis • Feature types, detection and recognition • Basic of stereo vision • Structured markers and data extraction • Relevant machine learning tools • Review of common deep learning tools in vision The approach is laboratory oriented rather than theoretical; students will be asked to interactively develop concepts during the lessons through practical code development. **PREREQUISITES**: Knowledge of programming, Linux and possibly Python3, Matplotlib, and Numpy (Optionally ScikitLearn). In case of massive application, admission may be subjected to acceptance test **EXAM**: Exams will be performed through the design and discussion of a homework assignment identified in cooperation with the student and, when could be possible, compatible with the research activity-plan of the student. For each exam student should deliver: code and source data to replicate the experiment. A short report that documents the basic theory, the developed work, the achieved results and the contributed novelties. **EVALUATION CRITERIA**: - Theory knowledge - Coding capability - Problem modelling - Appropriate use of tools - Capability to adapt existing tools to use-case - Capability of extend tools and theory beyond what is at state of the art
TIMETABLE	Start in Jan/February 2021 – 6-8 Hours per week

* activated only with the participation of minimum 3 PhD students

COURSE TITLE	**Robotics Applications in Industry**
LECTURER/S	Paolo Tripicchio
HOURS	30
CFU	5
FINAL EXAM	ORAL EXAMINATION / PROJECT WORK
TEACHING METHODOLOGY	LECTURES/LABORATORIES/SIMULATIONS
KEYWORDS	Industry 4.0, Grasping, Mobile Robotics, Collaborative Robotics, Mixed reality, Deep Learning
CONTENTS	The course will introduce the concepts and emerging research topics on the enabling technologies for the development of advanced industrial solutions in the context of the new industrial revolution. The main topics that will be discussed during the classes will focus on: • Robotic Grasping and manipulation • Motion planning and obstacle avoidance • Logistics and Mobile Robot navigation • Localization and mapping • Deep Learning applications • Collaborative robotics concepts • Mixed reality in the production environments • Smart sensors The final exam will consist of project work and a discussion on involved topics.
TIMETABLE	2nd semester - TBD – 2 lectures per week

COURSE TITLE	**Computer aided design for 3D Geometric Modeling**
LECTURER/S	Prof. Fontana – Prof. Solazzi
HOURS	30
CFU	3
FINAL EXAM	PROJECT WORK
TEACHING METHODOLOGY	LECTURES/EXERCISES/SIMULATIONS
KEYWORDS	CAD modelling, design for manufacturing
CONTENTS	The course will introduce the 3D modelling using CAD software, explaining the feature for creating mechanical components, assemblies, family of components, sheetmetals. The design guidelines for modelling components both by traditional machining and additive manufacturing will be part the course. The software used will be PTC Creo.
TIMETABLE	NA - Please contact the teacher

Curriculum Perceptual Robotics

COURSE TITLE	**Advanced Kinematics and Human Interfaces**
LECTURER/S	Prof. Frisoli – Prof. Solazzi
HOURS	30
CFU	3
FINAL EXAM	ORAL
TEACHING METHODOLOGY	LECTURES/EXERCISES
KEYWORDS	Mechanics of robots, robotics, control and simulation of robots
CONTENTS	The course will provide the student with the basic theory concepts and computational tools to perform analysis, study and basic control of robotic and mobile manipulators. In particular the course will cover the study and modelling of manipulators in terms of direct and inverse kinematics, differential kinematics, statics and dynamic (direct and inverse models) modelling equations. The course will introduce and explain the concepts of Denavit-Hattenberg notation, kineto-statics duality, measures of manipulability, optimization for kinematic inversion in redundant manipulators, basic joint and end-effector position trajectory schemes, pointing out the basic concepts for optimal pose planning of robot manipulators. The course will introduce path planning for robotic mobile vehicles and flighting quadrotors drone dynamics and control, introduction ton manipulator modelling by screw theory and stability analysis of advanced systems interacting with humans (man in the loop). Each lesson will be complemented by exercises proposed in Matlab or ROS (Robot Operative System) environment. A laboratory module will be conducted on Turtlebot platform to introduce the basic aspects of ROS with particular regard to topic and node creation, messaging, Lidar reading, trajectory planning and explaining how ROS can be used for SLAM motion planning. The course will make use of Robotic toolbox and other tools for simulation of robot modelling and control in Matlab and Simulink environment.
TIMETABLE	NA - Please contact the teacher

Curriculum Perceptual Robotics

COURSE TITLE	**Laboratory of Actuators and Tranducers for Robotics**
LECTURER/S	Prof. Frisoli – Prof. Solazzi
HOURS	40
CFU	4
FINAL EXAM	PROJECT WORK
TEACHING METHODOLOGY	LECTURES/LABORATORIES
KEYWORDS	Control, sensor, actuators
CONTENTS	This course is a laboratory course that will introduce by hands-on demos the principles of design and control of actuators, with particular reference to electrical and pneumatic actuators, and sensors of different kind. The student can implement as project work prototypes of actuators implementing series elastic solution, force sensor embedded in actuators or basic actuator designs. The course will involve design for control aspects and the development of control systems for human-machine interfaces. The students will be able to choose a project to implement from design, theory and experimental application and will be encourage to study the problem to achieve a scientific publication.
TIMETABLE	NA - Please contact the teacher

Curriculum Perceptual Robotics

COURSE TITLE	**Virtual and Augmented Reality**
LECTURER/S	Marcello Carrozzino, Franco Tecchia
HOURS	60
CFU	6
FINAL EXAM	WRITTEN EXAMINATION + PROJECT WORK
TEACHING METHODOLOGY	LECTURES + EXERCISES
KEYWORDS	Virtual Reality, Augmented Reality, Networking, Interaction, Immersion
CONTENTS	The course aims at providing a wide overview of technologies and tool needed to setup complete Virtual Environments and Augmented Reality systems. A survey of technologies and applications is presented, followed by an in-depth analysis of techniques and tools used for the multisensorial interactive and immersive rendering. Finally, topics such as networking for remote and shared applications and 2D/3D tracking are introduced. The course also features a lab section leading students to the design and development of a working VR/AR application. At the end of the course, the student will have acquired the knowledge needed to understand how VE systems work and how to develop a simple interactive Virtual Environment and/or AR application.
TIMETABLE	1st semester - TBD – 2 lectures per week

COURSE TITLE	**Mechanics of Advanced Transducers**
LECTURER/S	Marco Fontana
HOURS	30
CFU	3
FINAL EXAM	ORAL / PROJECT WORK In order to successful pass the exam, students have to give an oral exam in which she/he is evaluated on their ability to: 1. describe/explain, using appropriate technical language, the theory of operation and working principle of the different type of transducers that have been presented during the classes; 2. identify the appropriate transducer technology for the different application requirements; 3. solve problems related to the analysis and design of mechanical transducers; 4. present and defend their project/assignment.
TEACHING METHODOLOGY	LECTURES/ EXERCISES The course consists of a series of lectures and practical design lessons. Students will be required to complete a project work in which they apply the acquired knowledge to develop a solution to an open-ended engineering problem. Assignments implementation is conducted by single students or in small groups (depending on the number of attendees).
KEYWORDS	Actuators, energy harvesting, smart materials
CONTENTS	This is a course on analysis, modelling and design of *advanced mechanical transducers* intended as sensors, actuators and energy harvesters. During the course, different transduction principles including electromagnetic, pneumatic, hydraulic and smart material structures are considered. The students start their learning from the constitutive equations, physical principles and advanced analytical tools to describe the response of transducers and study mechanisms that make their implementation possible. Once the student has acquired the basic knowledge to understand and analyse these devices, some more specific engineering implementations are presented and illustrated. After completing the course, the student will be able to: o understand the working principle of several advanced mechanical transducers (sensor, actuators and generators); o choose the suitable transducer technology for a given target application and associated specifications; o analyse and evaluate transducer performances and figure of merit; o design transducer systems and individual components.
TIMETABLE	NA

Curriculum Photonic Technologies

1. Photonic Integrated Circuits
2. Photonics Laboratory for Telecommunications
3. Microwave Photonics
4. Photonics for Switching and Remote Sensing
5. Simulation Techniques for Digital Communication Systems
6. Communication Theory and Digital Transmission
7. Laboratory of Photonic Sensing and Components
8. Network Simulation
9. FPGAs for Communications Networks Prototyping: A Primer
10. Laboratory of Network Software
11. Laboratory of Traffic Engineering
12. Advanced Optical Networking
13. Laboratory of Photonic Integrated Circuits
14. Photonic Technologies
15. Optical Fiber Sensor Systems
16. Integrated Photonic Circuits for Optical Sensing and Biosensing Applications
17. Electromagnetic Fields and Propagation
18. Fundamentals of Applied Optics
19. Design of Optical Communications
20. Fundamentals of Optical Communications
21. Communication Networks and Network Security
22. Optoelectronic Devices for Metrology
23. Laboratory of Photonic Systems
24. Stochastic Processes

COURSE TITLE	**Photonic Integrated Circuits**
LECTURER/S	DR. NICOLA ANDRIOLLI DR. STEFANO FARALLI
HOURS	30
CFU	3
FINAL EXAM	HOMEWORK AND ORAL EXAMINATION
TEACHING METHODOLOGY	LECTURES – EXERCISES - SIMULATIONS
KEYWORDS	Simulation and modelling – Silicon photonics - waveguides - passive devices

CONTENTS	This course will introduce integrated optical devices and circuits. Emphasis will be on the simulation and design of Silicon-based passive integrated devices (e. g., directional couplers, multimode interference couplers, ring resonators, Mach-Zehnder interferometers, edge and grating couplers), exploiting both analytic and numerical techniques. Front lectures will be complemented with exercises using Lumerical and MATLAB software.
	
	Course contents
	
	- Introduction to integrated photonics
	- Waveguide design
	    o Slab waveguide
	    o Rectangular waveguide
	- Numerical tools for photonic integrated circuits
	    o Mode solver
	    o Propagator / FDTD
	    o Circuit solver
	- Optical I/O
	    o Grating coupler
	    o Edge coupler
	- Couplers and splitters
	    o Directional coupler
	    o Y branch
	    o Multimode interference coupler
	- Ring resonators
	- Mach-Zehnder interferometers
	
	Bibliography
	
	C. Pollock, M. Lipson, “Integrated Photonics,” Springer.
	G. Lifante, “Integrated Photonics: Fundamentals,” Wiley.
	L. Chrostowski, M. Hochberg, “Silicon Photonics Design: From Devices to Systems”, Cambridge University Press.
	Amnon Yariv, Pochi Yeh, Photonics: Optical Electronics in Modern Communications, Oxford University Press, 2007

TIMETABLE	From 1/10 to 19/11 – Tue/Thur 8.30-10.30 –available on Didactive

Curriculum Photonic Technologies

COURSE TITLE	**Photonics Laboratory for Telecomunications**
LECTURER/S	Antonella Bogoni
HOURS	30
CFU	3
FINAL EXAM	ORAL EXAMINATION
TEACHING METHODOLOGY	LABORATORIES
KEYWORDS	Optical communication, lasers, optical components, optical fiber
CONTENTS	The course includes 30 hours of laboratory activities in which the student will learn the use of the main optical instruments and components, and the use of characterization techniques for optical components and subsystems. In particular, seven laboratory tests will be carried out regarding the use of laser sources, optical fiber, optical amplifiers, and the creation of transmission and reception subsystems for telecommunications.
TIMETABLE	NA – Please contact the teacher

COURSE TITLE	**Microwave Photonics**
LECTURER/S	Antonella Bogoni
HOURS	30
CFU	3
FINAL EXAM	WRITTEN EXAMINATION
TEACHING METHODOLOGY	LECTURES/LABORATORIES
KEYWORDS	Microwave photonics, 5G, radar
CONTENTS	The course introduces the motivations, basic principles and applications of photonics applied to microwaves. 5G radio systems and radar systems that benefit from the use of photonics will be presented. The course includes a part of lectures and a part of laboratory exercises
TIMETABLE	2nd semester – starting from 15 March 2021 – it will be available on Didactive

Curriculum Photonic Technologies

COURSE TITLE	**Photonics for Switching and Remote Sensing**
LECTURER/S	Antonio Malacarne
HOURS	30
CFU	3
FINAL EXAM	ORAL or WRITTEN EXAMINATION (depending on the number of students)
TEACHING METHODOLOGY	LECTURES
KEYWORDS	Digital Photonics, Optical switching, Nonlinear optics, Optical signal processing, All-optical technologies, Microwave photonics, Dual-band radar, MIMO radar
CONTENTS	The first part course consists in an overview of the main activities carried out in the last two decades concerning how to overcome the main limitations in using electronics for implementing several key-functionalities for applications ranging from optical communications, interconnections and networks. Several technological solutions to implement processing of optical analog and digital signals are detailed, based on linear and nonlinear physical effects in optical fiber and in integrated platforms. Functionalities such as optical signal shaping, regeneration, logic operations of digital signals, signal switching, routing, modulation format conversion, wavelength conversion etc. are described and practical implementations are presented. The second part of the course consists in an overview of how the use of photonics for improving several key performance of radar systems providing flexibility and additional functionalities not achievable otherwise. In particular, coherent multi-band operation, coherent MIMO radar systems and radar-over-fiber MIMO radars will be detailed.
TIMETABLE	From 1/10 to 20/11 – Tue/Fri 11.00-13.00 – available on Didactive

COURSE TITLE	**Simulation Techniques for Digital Communication Systems**
LECTURER/S	Prof. Enrico Forestieri
HOURS	36
CFU	3
FINAL EXAM	WRITTEN EXAMINATION
TEACHING METHODOLOGY	LECTURES /EXERCISES/SIMULATIONS
KEYWORDS	
CONTENTS	The course will cover the most used mathematical methods for performing either standard or advanced simulations, both in the time and frequency domain, and provide the analytical tools for correctly applying numerical simulation techniques. Syllabus: 2. Discrete-Time Signals and Systems o Frequency domain representation o Continuous to discrete and discrete to continouos transformations o Difference equations 3. The z-Transform o Theorems and properties o Relation with the Laplace transform 4. The Discrete Fourier Transform o Theorems and properties o Linear and circular convolution 5. The Fast Fourier Transform o Algorithms o Practical considerations 6. Digital Processing of Analog Signals o Simulation of analog systems o Approximation of analog systems
TIMETABLE	From 5/10 to 28/01/2021 – Mon 14.00-16.00 (more lectures from November) – available on Didactive

COURSE TITLE	**Communication Theory and Digital Transmission**
LECTURER/S	Prof. Enrico Forestieri
HOURS	40
CFU	4
FINAL EXAM	WRITTEN EXAMINATION
TEACHING METHODOLOGY	LECTURES /EXERCISES
KEYWORDS	
CONTENTS	This course module will introduce the students to the fundamental principles of communication theory and data transmission with emphasis on performance, spectral characteristics, and complexity. Syllabus: 7. Data transmission over Gaussian channels 8. System design for bandlimited channels 9. Adaptive equalization 10. Channel and line coding
TIMETABLE	From 6/10 to 20/01/2021 – Tue/Wed 11.00-13.00 – available on Didactive

Curriculum Photonic Technologies

COURSE TITLE	**Lab of Photonic Sensing and Components**
LECTURER/S	Dr. Claudio OTON and Dr. Stefano FARALLI
HOURS	40
CFU	4
FINAL EXAM	LAB REPORT EVALUATION (OPTIONAL ORAL EXAM)
TEACHING METHODOLOGY	Laboratory activity with short theoretical introductions
KEYWORDS	Fiber optic sensing, fiber optic components, Optical Test & Measurement Instruments
CONTENTS	The course *Lab of photonic sensing and components* will include characterization of different fiber-optic components and devices used for photonic sensing. The student will first learn how to use the most common components, such as lasers, photo-receivers and passive devices, while during the rest of the course the student will learn how to independently build an experimental set-up and how to practically perform most significant measurements of photonic sensing components, and their sensing response. The class will be sub-divided into smaller laboratory groups in order to allow significant individual work with instrumentation and components. Lab experiments include characterization of optical fibers, light sources, passive components, spectral analysis, optical time-domain reflectometry, fiber Bragg grating sensors (FBGs), Raman-based temperature sensing and fiber-optic gyroscopes.
TIMETABLE	From 7/10 to 9/12 – Wed 14.00-18.00 – available on Didactive

COURSE TITLE	**Network Simulation**
LECTURER/S	Luca Valcarenghi
HOURS	30
CFU	3
FINAL EXAM	ORAL/WRITTEN EXAMINATION / PROJECT WORK
TEACHING METHODOLOGY	LECTURES/LABORATORIES/EXERCISES/SIMULATIONS
KEYWORDS	Simulation, network modelling, event-drive simulation, random variates, confidence interval
CONTENTS	The course will provide basic concepts for simulating a communication network. The course will focus mainly on the following topics: 7. Basic simulation modelling 8. Modelling complex systems 9. Simulation software 10. Event-driven simulation 11. Generating Random Variates 12. Output data analysis Requirements: basic programming (C, C++) Exam: course project
TIMETABLE	From 6/10 to 24/11 – Tue 14.00-16.00/Wed8.30-10.30 – available on Didactive

COURSE TITLE	**FPGAs for Communications Networks Prototyping: A Primer**
LECTURER/S	To be defined
HOURS	30
CFU	3
FINAL EXAM	ORAL/WRITTEN EXAMINATION / PROJECT WORK
TEACHING METHODOLOGY	LECTURES/LABORATORIES/EXERCISES/SIMULATIONS
KEYWORDS	FPGA, Verilog HDL, VHDL, Open CL
CONTENTS	The course will focus on the utilization of Field Programmable Gate Arrays (FPGAs) in telecommunications networks. The course will be organized as follows: 11. What is an FPGA and what can be used for in communications networks 12. Physical implementation of an FPGA 13. FPGA vs ASICs 14. FPGA design flows: schematic-based design flow, HDL-based design flow, modular and incremental design 15. Intellectual Property 16. Design Tools: simulation, synthesis, verification 17. Gigabit Transceivers 18. FPGA market 19. Future FPGA developments Some practical exercises in the lab are also foreseen. Requirements: some basic concept of Boolean logic and programming are required Exam: the exam will be based on a small project
TIMETABLE	2nd semester – March 2021

COURSE TITLE	**Laboratory of Network Software**
LECTURER/S	Dr. Alessio Giorgetti
HOURS	30
CFU	3
FINAL EXAM	WRITTEN EXAMINATION / PROJECT WORK
TEACHING METHODOLOGY	LECTURES/LABORATORIES
KEYWORDS	Network control, Software Defined Networking, SDN, ONOS
CONTENTS	The course introduces the Software Defined Networking architecture with specific reference to the control of Ethernet switch-based networks (using OpenFlow protocol) and the control of WDM optical transport networks (using the NETCONF protocol). After the introduction of the SDN architecture and of the main OpenFlow protocol features most of the lectures are dedicated to practice utilization of software tools to emulate and control an SDN network. Specifically, the open-source ONOS controller (https://www.opennetworking.org/onos/) will be used to enable the practice development and deployment of networking application to be tested on Ethernet networks emulated using the Mininet tool. A basic knowledge of java programming language is recommended. Course Outline: 1. Introduction to SDN (10%) 2. OpenFlow switch-specification (20%) 3. OpenFlow protocol-specification (10%) 4. Architecture of an SDN controller (20%) 5. Laboratory work (40%) a. Control of emulated Ethernet-based networks b. Development of networking applications c. Control of emulated optical networks using NETCONF protocol
TIMETABLE	2nd semester – starting from 15 March 2021 – it will be available on Didactive

COURSE TITLE	**Laboratory of Traffic Engineering**
LECTURER/S	Dr. Andrea Sgambelluri
HOURS	30
CFU	3
FINAL EXAM	WRITTEN
TEACHING METHODOLOGY	LECTURES/LABORATORIES
KEYWORDS	
CONTENTS	The course provides the operation and the enforcement techniques of Traffic Engineering applied to the control and management plane of real IP/MPLS metro-core network domains. Analysis of TE routing and signaling protocols, MPLS forwarding, protection and restoration schemes, Virtual Private Networks are explained through practical use cases and then deployed by means of configuration sessions with Juniper routers. The course also includes an introduction to SDN, segment routing and control of optical networks.
TIMETABLE	2nd semester – starting from 15 March 2021 – it will be available on Didactive

COURSE TITLE	**Advanced Optical Networking**
LECTURER/S	Dr. Nicola Sambo
HOURS	30
CFU	3
FINAL EXAM	ORAL EXAMINATION
TEACHING METHODOLOGY	LECTURES
KEYWORDS	Software Defined Networking, SDN, Optical networks, NETCONF, QoS, QoT
CONTENTS	The course will present the architecture of optical networks for the backbone and metro segments including control and management aspects. The main data plane technologies will be reviewed spanning from the current deployed networks to the expected next generation architectures. The course will be inter-disciplinary including physical layer aspects, node and link architecture, and automation. The main protocols controlling optical networks will be presented and studied. The migration toward higher capacities will be analysed presenting the main issues and the possible solutions proposed by researchers and adopted by vendors and operators.
TIMETABLE	From 1/10 to 26/1/2021 – Thu 14.00-16.00 (more lectures from November and January) – available on Didactive

Curriculum Photonic Technologies

COURSE TITLE	**Laboratory of Photonic Integrated Circuits**
LECTURER/S	Giampiero Contestabile
HOURS	40
CFU	4
FINAL EXAM	ORAL/ PROJECT WORK
TEACHING METHODOLOGY	LECTURES/LABORATORIES
KEYWORDS	Photonic Integrated Circuits, Silicon Photonics, InP Integration Technology, Polymers Nanoprinting, Hybrid/Heterogeneous Integration
CONTENTS	This course will introduce and review the major technologies and foundries for the fabrication of large scale photonic integrated circuits intended for applications in Telecommunication, Data Center Interconnection, Medical, Sensing etc… Building blocks and fabrication technologies will be discussed with a focus on the different foundry models and main open issues.
TIMETABLE	2nd semester – starting from 15 March 2021 – it will be available on Didactive

Curriculum Photonic Technologies

COURSE TITLE	**Photonic Technologies (PT)**
LECTURER/S	Giampiero Contestabile, Claudio Porzi
HOURS	30
CFU	3
FINAL EXAM	ORAL/WRITTEN EXAMINATION
TEACHING METHODOLOGY	LECTURES
KEYWORDS	
CONTENTS	The course will cover all the active optical building blocks of optical communication systems. A physical description of semiconductor lasers, optical modulators, photodetectors and receivers is discussed. A basic theory of noise in optical communication systems is also presented.
TIMETABLE	From 2/10 to 20/11 – Mon 16.30-18.30/Fri 14.00-16.00 – available on Didactive

Curriculum Photonic Technologies

COURSE TITLE	**OPTICAL FIBER SENSOR SYSTEMS**
LECTURER/S	Prof. Di Pasquale / Dr. Oton
HOURS	30
CFU	3
FINAL EXAM	WRITTEN EXAMINATION
TEACHING METHODOLOGY	LECTURES
KEYWORDS	OPTICAL FIBERS, PASSIVE COMPONENTS, LASERS, PHOTODIODES, PHOTONIC SENSING, FIBER BRAGG GRATING, RAILEIGH SCATTERING, RAMAN SCATTERING, BRILLOUIN SCATTERING, PHOTONIC INTEGRATED CIRCUITS
CONTENTS	After providing the necessary fundamentals on optical components this course will overview the most commonly used optical amplification and optical fiber sensor technologies. In the last few years, a new sector is emerging, which is related to fiber-optic sensors, where optical and fiber-optic components are used for sensing of several physical, chemical and environmental parameters, finding manifold applications over a wide range of industrial fields ranging from energy, structural health monitoring, automotive, railway and aerospace. More in detail, the course module will first provide an overview on fundamental photonic components such as lasers, photodiodes and passive devices. Then the module will deal with photonic sensing technologies including discrete, distributed and quasi-distributed optical fiber sensors as well as photonic integration for sensing.
TIMETABLE	From 2/10 to 27/1/2021 – Fri 16.30-18.30(more lectures from November and January) – available on Didactive

COURSE TITLE	**INTEGRATED PHOTONIC CIRCUITS FOR OPTICAL FIBER SENSING AND BIOSENSING APPLICATIONS**
LECTURER/S	Prof. Di Pasquale / Dr. Velha
HOURS	20
CFU	2
FINAL EXAM	WRITTEN EXAMINATION
TEACHING METHODOLOG Y	LECTURES
KEYWORDS	OPTICAL WAVEGUIDES, AWG, MMI, LASERS, PHOTODIODES, PHOTONIC SENSING, PHOTONIC INTEGRATED CIRCUITS ,INTEGRATED OPTICS, SILICON PHOTONICS, GLASS ON SILICON, FIBER BRAGG GRATING, BIOCHEMICAL SENSING
CONTENTS	Il corso fornirà una introduzione ai principali componenti fotonici integrati in diverse piattaforme tecnologiche quali *glass on silicon*, *silicon photonics* e *semiconduttori III-V* per poi focalizzarli su circuiti fotonici integrati per sensoristica. Verranno in particolare descritte possibile tecniche di integrazione di interrogatori di sensori a reticolo di Bragg (FBG) e circuiti fotonici integrati per la realizzazione di sensori biochimici. After providing the necessary fundamentals on integrated optical components on different technological platforms such as glass on silicon, silicon photonics and III-V semiconductors, , this course will focus on photonic integrated circuits for sensing applications. In particular the course will describe possible solutions for integrating FBG sensors interrogators and to develop biochemical sensors on chip.
TIMETABLE	2nd semester – February 2021 – 2 lectures per week

COURSE TITLE	**ELECTROMAGNETIC FIELDS AND PROPAGATION**
LECTURER	FABRIZIO DI PASQUALE
HOURS	20
CFU	2
FINAL EXAM	WRITTEN EXAMINATION
TEACHING METHODOLOGY	LECTURES
KEYWORDS	Maxwell's equations, plane waves, metallic waveguides, dielectric waveguides, optical fibers
CONTENTS	With the final goal of providing a full understanding of modes propagation in waveguides and optical fibers this course will offer students an introduction to the fundamental concepts related to electromagnetic theory and will then be specifically focused on propagation in waveguides and optical fibers. Topics: 13. Maxwell's Equations 14. Fields in media and boundary conditions 15. Plane wave propagation and reflection 16. Metallic waveguides 17. Dielectric slab waveguides 18. Optical fibers References: 20. David M. Pozar, "Microwave Engineering", third editon, John Wiley &Sons. 21. S. Ramo, J.R Whinnery, T. Van Duzer, "Fields and waves in communication electronics", third edition, ISBN: 978-0-471-58551-0, , John Wiley &Sons. 22. K. kawano, T. Kitoh, "Introduction to optical waveguide analysis", John Wiley &Sons. 23. G.P. Agrawal, "Fiber-Optic Communication Systems", Wiley-Interscience 2002.
TIMETABLE	From 1/10 to 3/12 – Thu 1.00-13.00 – available on Didactive

Curriculum Photonic Technologies

COURSE TITLE	**Fundamentals of Applied Optics**
LECTURER/S	Prof. Ciaramella / Dr. Cossu
HOURS	40
CFU	4
FINAL EXAM	WRITTEN EXAMINATION
TEACHING METHODOLOGY	LECTURES
KEYWORDS	Ray Optics, Wave Optics, Interference, Polarization, Diffraction, Photon Optics, Lasers, Interaction photon-matter
CONTENTS	The course provides the fundamental concepts and basic notions about light waves, their nature, their description and their peculiar characteristics; it will also illustrate the main areas of application. The course is divided into three modules (geometrical optics, wave optics and quantum optics), which correspond to the different descriptions related to the phenomena of propagation and radiation-matter interaction. Main covered topics: 1. Geometrical optics - Snell law - The lens equation and its applications (telescope, microscope etc.) Ray tracing - Matrix Optics - Aberrations - Human Eye 2. Wave optics - Maxwell's Equations - Plane waves - Polarization of light (Jones matrix, Stokes sphere, polarization effects) - Interference (basic definitions, Young experiment, gratings, interference coatings) - Diffraction and spatial Fourier transform - 3. Quantum Optics - Photons - Absorption and emission of light - Spectroscopy - Lasers (theory of lasers, examples of lasers and applications)
TIMETABLE	2nd semester – March 2021

Curriculum Photonic Technologies

COURSE TITLE	**Design of Optical Communications**
LECTURER/S	Prof. Ciaramella
HOURS	30
CFU	3
FINAL EXAM	WRITTEN EXAMINATION
TEACHING METHODOLOGY	LECTURES
KEYWORDS	Optical Systems, Bit Error Rate, OSNR, chromatic dispersion, Polarization Mode Dispersion, Kerr effects
CONTENTS	The objectives of the course are to provide the basic elements of the design of an optical transmission system. The course provides a detailed analysis of the transmission issues that must be considered in the design of today's high-capacity optical systems (metro, long-haul, ultra long-haul). The various transmission impairments are described in detail, including accumulation of optical noise, chromatic dispersion, polarization mode dispersion, nonlinear effects (Brilluoin and Raman scattering, Self-Phase Modulation, Cross-Phase Modulation, Four Wave Mixing) . Recent coherent systems and FTTH (Fiber To The Home) transmission systems are also introduced.
TIMETABLE	From 1/10 to 19/11 – Mon 11.00-13.00/Thu16.30-18.30 – available on Didactive

COURSE TITLE	**Fundamentals of Optical Communications**
LECTURER/S	Marco Secondini
HOURS	30
CFU	3
FINAL EXAM	PROJECT WORK/ORAL EXAMINATION (presentation of the project)
TEACHING METHODOLOGY	LECTURES
KEYWORDS	Optical communications; digital communications; optical fibers
CONTENTS	This course provides an overview on the field of optical communication systems. The fundamentals of modulation and detection of optical signals and their transmission through optical fiber links are presented on an introductory level. The most common modulation formats (e.g., amplitude and phase modulation) employed in optical communications and the related transmitter and receiver structures are described. The noise properties and performance of different detection strategies (e.g., direct detection, differential detection, coherent detection) for different modulation formats are investigated. Finally, the most relevant fiber propagation impairments (attenuation, dispersion, nonlinearity) are described and their impact on system performance is discussed.
TIMETABLE	2nd semester – starting from 15 March 2021 – it will be available on Didactive

COURSE TITLE	**Communication Networks and Network Security**
LECTURER/S	Prof. Castoldi/DR. Cugini
HOURS	60
CFU	6
FINAL EXAM	WRITTEN EXAMINATION
TEACHING METHODOLOGY	LECTURES
KEYWORDS	Internet, protocols, routing, networks
CONTENTS	This course aims at providing students with a guided and critical overview of the communications network protocol evolution as well as of the fundamental concepts of network security. The course will mainly focus on the TCP/IP architecture of the current Internet and on the Ethernet protocol in Local Area Networks (LANs). Most common routing protocol and strategies will be analysed and the relevant protocol formats studied for use in the global Internet. Furthermore, the most recently introduced standards will be presented. Protocols (e.g., MPLS) and algorithms for traffic engineering and resilience will be discussed. This course will then provide an overview of the most relevant security concepts, threats, and best practices for Layer 2 and IP/VPN security, including Public key infrastructure (PKI). Finally it will focus on emerging technologies such as blockchain in software defined networking, quantum cryptography and quantum key distribution.
TIMETABLE	From 2/10 to 27/1/2021 – Wed 16.30-18.30/Fri 8.30-10.30 (more lectures from November) – available on Didactive

COURSE TITLE	**Optoelectronic Devices for Metrology**
LECTURER/S	Prof. Sorel
HOURS	30
CFU	3
FINAL EXAM	ORAL/WRITTEN EXAMINATION
TEACHING METHODOLOGY	LECTURES/EXERCISES
KEYWORDS	Optical metrology; optical measurements; optoelectronic devices
CONTENTS	Optical metrology is concerned with the technology and the science of using light for the measurement of a variety of quantities and variables. It builds on the principle that the measurand, i.e, the quantity to be measured, can alter any of the wave properties of light, such as amplitude, phase, wavelength, frequency, and polarization. Following the invention of the laser in the ‘60s, instrumentation and optoelectronic devices for optical metrology experienced a phenomenal growth that gained wide acceptance in engineering applications. Ultimately, such technological developments led to the construction of engineering masterpieces such as the LIGO interferometer for measuring gravitational wave, which is the most precise instrument ever built, capable of measuring the distance of the nearest start (4.2 light years away) to an accuracy smaller than the width of a human hair. The course will provide an introduction to optoelectronic devices for optical metrology from basic principles and physical limitations to the design of systems for the measurement of several variables and quantities. The course will also discuss practical examples and applications that have marked milestones in the science of measurement including laser interferometers, velocimeters, particle size analyzers, Moire’ techniques, optical coherence tomography and optical gyroscopes. An overview on future trends will be presented with a focus on using optoelectronic integrated devices for the development of more compact and cheaper metrological solutions. Finally, the course will examine how optoelectronic and photonic technologies are having a profound impact on the rapidly growing area of quantum metrology.
TIMETABLE	2nd semester – starting from 15 March 2021 – it will be available on Didactive

COURSE TITLE	**Lab of Photonic Systems**
LECTURER/S	G. Cossu, M. Rannello
HOURS	30
CFU	6
FINAL EXAM	ORAL
TEACHING METHODOLOGY	LECTURES/LABORATORIES
KEYWORDS	Optical Sources, Modulation; Detection; MATLAB
CONTENTS	**Optical Sources**: lasers, leds. Lab experience **Modulation of the light**: Direct/external modulation. Waveform generators. Lab experience **Modulation formats**: NRZ, OFDM… Lab experience **Receive the optical signal**: photo-receivers; Oscilloscopes; Electrical spectrum analyzer; BER Tester. Lab experience **Advanced MATLAB features**: remote acquisition; code optimization. Lab experience
TIMETABLE	From 23/11 to 29/1 – Mon/Wed 11.00-13.00 (more lectures from January) - available on Didactive

COURSE TITLE	STOCHASTIC PROCESSES
LECTURER/S	Piero Castoldi
HOURS	30
CFU	3
FINAL EXAM	WRITTEN EXAMINATION
TEACHING METHODOLOGY	LECTURES/EXERCISES
KEYWORDS	Probability, random events, random signals
CONTENTS	The course will review probability theory and random variables to reach an in-depth description of discrete-time and continuous time stochastic processes describing real phenomena and all relevant properties and exercises on most relevant topics. The specific content is detailed as follows: • Probability theory, conditional probabilities, event properties, random variables, distribution and density functions, repeated trials, random points • Conditional PDF and pdf, function of a random variable, two random variables, joint PDF and pdf, independence, functions of two random variables, • n random variables, Markoff sequences, Markoff chains • Stochastic processes, statistics, stationary and ergodic stochastic processes • Random points in time, Poisson processes • Transformation of stochastic processes, LTI systems, Power spectrum of stochastic processes • Transfer function of LTI systems, Hilbert transform, spectral representation of processes, white noise Exercise on most relevant cases will be solved in class.
TIMETABLE	From 5/10 to 25/1/2021 – Mon 8.30/10.30(more lectures from January) – available on Didactive