International program

Spring Semester

Medical Instrumentation & Robotics – 4 credits
Medical imaging basics
Medical robotics
Clinical translation

Medical Image Processing – 4 credits
Biological image processing and bioinformatics
Computer vision
Deep learning

Photonics & Healthcare – 4 credits
Photonics instrumentation for Health
Biophotonics
Biomedical optics

Language Course – 2 credits

French Culture – 2 credits

Research Project – 4 credits

Summer Semester

Paid internship in research – 8 credits

COURSE: Medical Instrumentation & Robotics
4 Credits

Part #1: Medical Imaging Basics – S. Gioux

Objective: During this course, students will learn the fundamentals of various *in vivo* imaging methods that are used in biology and medicine. More particularly, this course will focus on the basis of contrast, as well as detection and processing methods for X-ray and gamma-ray imaging (CT, PET, SPECT), Magnetic Resonance Imaging (MRI), Ultrasound (US) and optical methods (microscopy, endoscopy, fluorescence, endogenous contrast).

Outline: Introduction to medical imaging, Magnetic Resonance Imaging, X-ray, Nuclear imaging, Ultrasounds, Optical imaging

Acquired skills: Following this course, the student will be able to understand the fundamentals (contrast, detection and processing) of the most commonly used in vivo imaging methods in biology and medicine.

Part #2: Medical Robotics – M. de Mathelin

Objectives: The objectives of this course are to provide necessary knowledge in order to start projects in medical robotics; to give an exposure to the specific constraints of an operating room; to present the robotics devices and systems used for computer aided surgery; and to become able to analyze medical procedure in order to provide adapted assistive technologies and systems.

Outline: Fundamental of robotics (modeling - forward, inverse and differential kinematics - visual servoing), Robot vision (vision models, 3D reconstruction, calibration), Medical robotics and computer aided surgery (medical robotics, basis of laparoscopic surgery and NOTES), navigation, augmented reality, virtual reality, haptics and telemanipulation.

Practical work:
- Kinematic control of robot in Cartesian space and image based visual servoing
- Experimental laboratory in the surgical suite of IRCAD

Part #3: Clinical Translation – S. Gioux

Objective: Through this module, the students will acquire knowledge related to the translation process of medical devices and drugs from the concept idea to first-in-human trials and finally to large-scale efficacy trials. This module will use several case examples with the aim of providing all necessary tools to understand the clinical translation process, a mandatory step for all novel technologies aimed at impacting healthcare in the near future.

Outline: Introduction to clinical translation; The global regulatory landscape; Regulations and process for the translation of devices; Regulations and processes for the translation of drugs; R&D methods & organization; From a concept to first-in-human trials; Towards large-scale trials & commercialization; Case examples.

Acquired skills: Following this module, the students will have acquired the necessary basic understanding of clinical translation for devices and drugs, including the development process and the regulatory landscape.

COURSE: Medical Imaging Processing
4 Credits

Part #1: Medical Image Processing - Ch. Collet

Objectives: This lecture addresses image processing and data processing methods for medical image processing. Segmentation, detection, classification, registration and fusion methods are presented, with their main advantages and drawbacks. Students have to implement different methods using Matlab, in order to illustrate on raw images the main approaches developed during the courses.

Outline:
1/ Image representation and storage
2/ Methods for detection, segmentation and then classification
3/ How to develop robust registration methods
4/ Fusion between different imaging modalities

Acquired skills: Knowledge on medical image analysis, Matlab coding using image processing tools, ability to implement image processing chain with Matlab

Part #2: Computer Vision – N. Padoy

Objectives: Learn about the image formation pipeline and about advanced computer vision techniques. Apply these techniques to construct computer vision tools that have applications both in traditional and in medical imaging.

Outline: Pinhole camera model; Geometric principles of mosaicing; 2D transformations and homography; Image warping and interpolation; Detection and matching of interest points; Homography estimation (DLT, SVD); Projection model; Camera calibration; Pose estimation; RANSAC

Acquired skills: Ability to use fundamental techniques of computer vision and optimisation. Hands-on practice using Matlab to develop software that automatically builds image mosaics and estimates the 3D pose of planar patterns for Augmented Reality applications.

Part #3: Deep Learning – N. Padoy

Objective: Learn about the Deep Learning, convolutional neural networks and their applications in the context of computer vision.

Outline: Fundamentals; Loss functions; Back-propagation; Convolutional networks; Activation functions; Training in practice; Network visualization; Architectures for specific applications; Programming frameworks and GPGPU

Acquired skills: Ability to understand and use state-of-the-art deep convolutional networks for classical computer vision tasks. Hands-on practice to define, train.

COURSE: Photonics & Healthcare
4 Credits

Part #1: Photonics Instrumentation for Health – S. Gioux

Objective: Through this module the students will learn the basics of photonics instrumentation for health. The chain of acquisition from light source, to illumination strategies, to detectors will be reviewed and illustrated through case examples from instrumentation used for biological and clinical applications.

Outline: Introduction to instrumentation; Light sources; Optical fibers; Control of light; Image formation; Light detectors; Cameras; Acquisition methods; Case examples: point spectroscopy and fluorescence imaging.

Acquired skills: Following this module, the students will have learned all major instrumentation components used in photonics as well as applied this knowledge to practical case studies where instruments design will be reviewed. Thanks to this module, students have acquired a practical knowledge of photonics instrumentation in concrete cases.

Part #2: Biophotonics – S. Haacke

Objective: Light is a valuable tool for the investigation of composition and internal structure of condensed matter of different kinds. These concepts are readily transported onto biological media, at all length scales: tissue, cells, proteins or DNA. Biophotonics deals with the science and technology of using light for the investigation and manipulation of these entities, benefitting from the most recent advances in optics and laser science.

Outline: After reviewing the basics of light-matter interaction, we'll treat a couple of state-of-the-art examples of established approaches: confocal, multi-photon & sub-diffraction limit fluorescence microscopy, optical coherence tomography, optical tweezers, time-resolved absorption and fluorescence spectroscopy, optical biosensors.

Acquired skills: Students will acquire a general overview of current topics in biophotonics, with the aim of being able to identify present challenges and open questions. From the engineering point-of-view, students are expected to be able to characterize techniques in terms of resolution, sensitivity and robustness, and thus field of applications.

Part #3: Biomedical Optics – S. Gioux

Objectives: The field of biomedical optics is rapidly maturing to become a key player in both research and industry, with strong market opportunities in health-related applications. Through this module, the students will learn the basics of optics applied to biology and healthcare at a mesoscopic and macroscopic scale.

Outline: Introduction to Biomedical Optics; Basics of light-tissue interaction; Microscopy; Spectroscopy; Modeling of light propagation; Diffuse optics; Diffuse optical tomography; Fluorescence imaging; Optical coherence tomography; Flow measurement; Treatment and diagnosis; Photo-acoustic.

Acquired skills: Following this module, the students will have acquired the necessary theory related to light propagation through living media, will understand the basis of contrast and will know the methods used to acquire and process data. Finally, the students will have a comprehensive outlook of applications in health and biology.