PhD Program in Bioengineering and Robotics

Curriculum: Bionanotechnologies

Research themes

The Bionanotechnology curriculum is related to basic and applied research programs oriented to the comprehension of fundamental phenomena at the nanoscale and to the application of nanotechnologies to bioengineering, biophysics, applied physics, material sciences and life sciences, and to the development of new technologies and approaches as a challenge for the next twenty years. Bionanotechnologies have a broad field of appeal, namely: from cells-to-chip and chip-to-cells technologies to nanobiosensors, from nanodiagnostics to advanced optical characterization and imaging tools, from intelligent drug delivery to artificial tissues, from functional nano-addressable surfaces to smart materials. Among others, research developments include developing new sustainable materials and approaches for packaging and electronics, and implementation of new microscopy techniques for investigating life at the nanoscale. As well, most of the applications are conceived starting from the IIT domains (Robotics, Nanomaterials, Lifetech, Computational Sciences) to numerous others, including technology transfer perspectives. The candidate will be immersed in the frontiers of science and technology.

International applicants are encouraged and will receive logistic support with visa issues, relocation, etc.

Wide-Filed Fluorescence Lifetime Microscopy

Tutors: Giuseppe Vicidomini

Tutors Affiliation: Molecular Microscopy and Spectroscopy, Center for Human Technology, Italian Institute of Technology, https://vicidominilab.github.io

Project Description

Optical microscopy is among the least invasive techniques for visualizing biological structures and functions at near-molecular scales in living cells and organisms. However, many fundamental biological processes relevant to health and disease remain beyond the reach of conventional optical microscopy. Our mission is to design and develop state-of-the-art microscopes and analytical tools that enable biologists to explore living systems with unprecedented spatiotemporal resolutions, reduced invasiveness, and enhanced information content. To achieve this, our projects integrate novel photonics technologies, labelling protocols, optical architectures, spectroscopy techniques, and machine learning approaches. While our primary focus is on technology development, we also collaborate with biologists to test and refine our tools, ensuring they yield new biological insights.

The PhD student will be fully integrated into this mission working on a dedicated project involving fluorescence lifetime imaging microscopy (FLIM).

FLIM is an advanced imaging technique that combines conventional fluorescence intensity measurements with nanosecond-scale temporal dynamics. This dual capability provides detailed structural and functional information about specimens, allowing for the mapping of protein-protein interactions and biochemical reactions in living cells.

In recent years, our group has focused on developing FLIM for laser-scanning microscopy, introducing a novel single-photon detector array composed of a few elements (e.g., 5x5) capable of correlating super-resolved microscopy with fluorescence lifetime imaging [1-3]. However, laser-scanning microscopy suffers from lower temporal resolution (e.g., frame rate) compared to wide-field optical architectures, which require large detector arrays (megapixel).

The aim of this PhD project is to implement a wide-field fluorescence lifetime imaging system with high temporal resolution. This will be achieved by combining innovative optical light - sheet optical architecture with novel large pixellated detector featuring the time-resolved capability.

Requirements: This project is highly multidisciplinary, involving various aspects of the natural sciences. We invite applications from candidates with a Master's degree or equivalent in Engineering, Physics, or related disciplines. The ideal candidate should demonstrate the ability and motivation to work both independently and collaboratively in an interdisciplinary team. Proficiency in spoken and written English is required. Coding skills, particularly in Python, are highly desirable. Experience in microscopy or control systems will be considered a plus.

References: [1] M. Castello et al., "A robust and versatile platform for image scanning microscopy enabling super-resolution FLIM," Nat Methods 16(2), 175-178 (2019). [2] A. Rossetta, et al., "The BrightEyes-TTM as an open-source time-tagging module for democratising single-photon microscopy," Nat Comm 13, 7406 (2022). [3] Tortarolo et al. "Compact and effective photon-resolved image scanning microscope," Adv Photon 6(1), 016003 (2024).

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Development of Sustainable and Flexible Electronic Systems

Tutor: Athanassia Athanassiou

Department: Smart Materials, IIT, Genova, https://www.iit.it/web/smart-materials

Description:

Conventional electronic components, including PCBs, chips, circuits and sensors are rapidly moving towards sustainable, flexible, and non-toxic alternatives. The need to use green materials in this field is rising due to the explosive growth of the number of sensors connected through the internet of things, incorporated in electronic devices and in robotic systems, among other reasons. This tendency is translated in increased use of plastics in consumer electronics and generation of more persistent plastic and electronic waste. Therefore, development of sustainable, flexible, biodegradable, or easily recyclable electronic systems is becoming critical.

The aim of this PhD research program is to design and develop innovative, and sustainable electronic components that can also feature several simultaneous desired properties, such as biocompatibility, flexibility, bending and folding resistance, conformability to irregular surfaces, high sensibility, speed of operation and long lifetime. Use of electrically conductive nanomaterials, such as carbon nanoelements and innovative 2D nanomaterials, in combination with biopolymers or natural polymers and natural fibers will be applied in the fabrication of the electronic components. This PhD program will be implemented in close collaboration with IIT Robotics groups, and the developed electronic components will be adapted to the operation of certain robotic systems, in the form of flexible capacitors, electrodes, sensors, PCBs, and conductive robotic lining with proper circuit and device design. Extensive electrical, mechanical, thermal testing and micro-morphological characterization will be made both to the developed components and to the final systems.

The student will have the opportunity to develop research collaborative projects under the Technologies for Sustainability Flagship, promoted within the new strategic plan of IIT. The work will support the targets of the UN Sustainable Development Goals 9, 11 and 12.

Requirements:

Applicants are expected to have a Master's Degree in one of the following areas: Material Science, Chemical Engineering, Physics, and Electrical Engineering with materials science specialization and specific focus on Electronics. The candidates should preferably have experience in electronics in the form of summer internships or preparation of undergraduate research projects. Excellent English language speaking and writing skills are required.

References:

M. Najafi, et al. Biodegradable polylactic acid emulsion ink based on carbon nanotubes and silver for printed pressure sensors, Scientific Reports, 14(1):10988, 2024

P. Cataldi, et al., Keratin-Graphene Nanocomposite: Transformation of Waste Wool in Electronic Devices. ACS Sustainable Chemistry & Engineering, 7, 12544-12551, 2019

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Development of Sustainable Biocomposite Materials for Food Packaging and Agricultural Applications

Tutor: Athanassia Athanassiou

Department: Smart Materials, IIT, Genova, https://www.iit.it/web/smart-materials

Description:

Managing plastic waste generated by packaging and agricultural products, with a short lifetime, is becoming a serious environmental issue. Such products are derived from petroleum resources, are not biodegradable or industrially compostable, and are impossible to recycle due to heavy contamination and properties' loss.

The project will focus on the development of sustainable biocomposite materials with suitable properties for food containers, and for mulches for agricultural use, or to cover organic municipal waste. The developed materials will derive from renewable resources and will be able to biodegrade or become compost after their use. Additional, specific objectives of this research will be: Transparent and flexible films based on polysaccharide and protein chemistry.

The project will use technologies like extrusion, melt casting, coating, and lamination, all easily scalable to industrial scales. The end of life of the developed materials will be also studied, focusing on possibilities of reuse, recycle or industrial compost. In the last case, the quality of the produced compost will be evaluated. The mulches will be tested for biodegradation in the field and their effect on the quality of the soil will be evaluated. The developed biocomposites will be tested for mechanical durability, water vapour and oxygen transport properties and thermal stability.

The project is of industrial relevance because it follows the concept of circular economy and it resolves enormous, currently unresolved problems, of waste disposal of the plastic containers used for food, but also of the plastic mulches currently used in the agricultural fields. Especially in this period that the restrictions in the use of plastics in various fields, connected with short lifetime applications, are becoming stricter, solutions like the ones proposed in this project are of great need and importance.

The student will have the opportunity to develop research collaborative projects under the Technologies for Sustainability Flagship, promoted within the new strategic plan of IIT.

Requirements:

Applicants are expected to have a Master's Degree in one of the following areas: Material Science, Bioengineering, Chemical Engineering, Chemistry, Physics, and Biology. Excellent English language speaking and writing skills are required.

References:

Danila Merino et al., Blending of polysaccharide-based carrot pomace with vegetable proteins for biocomposites with optimized performance for food packaging applications, Food Hydrocolloids, 152, 109903, 2024

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Hybrid interfaces between nanosensors and neuronal tissues

Tutors: Francesco De Angelis

Tutors Affiliation: Plasmon Nanotechnology, www.iit.it/it/web/plasmon-nanotechnologies/

Project Description

Observing cell signaling within large networks of human neurons is a major challenge that can revolutionize our capability of studying the brain and its physio-pathological functions, as well as of deriving bio-inspired concepts to implement artificial systems based on neuronal circuit or hybrid prosthetics. In the last years, we developed a wide class of multi-functional sensors across the fields of photonics, electronics, mechanics and biotechnologies. We interfaced these sensors with living cells and we investigated both theoretically and experimentally their mutual interactions with a focus on human neurons. The aim is to make an effective interface between living tissues and different classes of nano-sensors hence enabling multiscale and multivariable observation of cell dynamics in human tissues.

Practical applications manly focus on:

- In-vitro sensing platforms of drug toxicity through both bio-photonic and bio-electronic approaches. The developed platforms can be applied to both animal and human tissues with a focus on brain organoids for the investigations of neurodevelopmental toxicology.

- Ultrasensitive sensors in proteomics and genomics for the accurate identification and sequencing of biomolecules (DNA, RNA, proteins) through solid state nanopores (both optical and electronic).

- Next generation of human prosthetics and hybrid devices.

Currently the research unit is composed of about 20 people. Among them, physicists, chemists, biotechnologists, pharmacologists and engineers collaborate in a very multi-disciplinary research group that aims to develop multi-omic approaches for controlling biological systems at the nanoscale and for developing new ways for the identification of biomolecules in complex media.

Requirements: degree in physics, chemistry, engineering, biotechnology.

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