PhD Program in Bioengineering and Robotics

Curriculum: BIONANOTECHNOLOGY

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.

1. SMART MICROSCOPY WITH EVENT-BASED DETECTORS AND ADAPTIVE IMAGING INTEGRATION

Tutor: Giuseppe Vicidomini

Tutor's Affiliation: Smart Materials, IIT, Genova, https://smartmat.iit.it/home

Molecular Microscopy and Spectroscopy, Istituto Italiano di Tecnologia, https://vicidominilab.github.io

Project Description

The field rapidly evolves toward *smart* microscopy, where imaging systems can autonomously analyse data in real time and adapt acquisition parameters accordingly. During acquisition, these systems rely on feedback loops that respond to detected events by adjusting key settings, such as imaging speed, resolution, or modality. This smart, adaptive approach enables researchers to maintain optimal imaging performance without the usual compromises between field of view, temporal and spatial resolution, sample health, or signal-to-noise ratio.

This PhD project explores the development of a *smart* microscopy platform that leverages novel event-based detectors, including asynchronous read-out single-photon avalanche diode (SPAD) array detectors and neuromorphic cameras, within a polyfunctional microscope architecture combining both wide-field and laser-scanning modalities. Inspired by biological vision, neuromorphic cameras detect pixel-level brightness changes asynchronously, enabling extremely high temporal resolution while minimising redundant data acquisition. Their unique capabilities make them ideal for real-time detection of fast or rare events across large fields of view. In contrast, asynchronous SPAD array detectors enable photon-resolved microscopy. This highly informative imaging technique captures rich spatial and temporal information at the single-photon level, though over a more limited field of view.

The system will operate in a *smart* feedback-driven mode. (i) Wide-Field Monitoring: The neuromorphic camera continuously scans the entire sample for dynamic events; (ii) Targeted Response: Upon event detection, the system will automatically switch to a laser-scanning modality and redirect imaging to the region of interest.

The PhD candidate will be involved in the optical integration, control software development, and algorithm design necessary for real-time data processing and system-level adaptation.

In particular, the candidate will carry out the following tasks: (i) Literature Review – Perform a critical analysis of the current applications of event-based cameras and SPAD arrays in advanced microscopy; (ii) Optical Design – Acquire practical experience in assembling and aligning multifunctional fluorescence microscopes that integrate wide-field and laser-scanning architectures; (iii) Image Analysis and Reconstruction – Develop or adapt algorithms to reconstruct conventional images from asynchronous event streams and design feedback mechanisms for adaptive, smart microscopy; (iv) System Control – Implement innovative triggering strategies that enable automated switching between imaging modalities in response to detected biological events.

Requirements

- Solid programming skills (Python or equivalent)
- Background in image analysis, computer vision, or real-time signal processing
- Basic knowledge of optics and fluorescence microscopy
- Interest in AI-driven scientific instrumentation

- Degree in physics, engineering, computer science, or a related field

References

D. Mahecic, W.L. Stepp, C. Zhang, J. Griffié, M. Weigert, S. Manley, “Event-driven acquisition for content-enriched microscopy.” Nat. Methods 19(10):1262-1267 (2022) https://doi.org/10.1038/s41592-022-01589-x

G. Tortarolo, A. Zunino, S. Piazza, M. Donato, S. Zappone, A. Pierzyńska-Mach, M. Castello, G. Vicidomini, "Compact and effective photon-resolved image scanning microscope," Adv. Photon. 6(1) 016003 (2024) https://doi.org/10.1117/1.AP.6.1.016003

R. Guo, Q. Yang, A.S. Chang, A.S. et al. “EventLFM: event camera integrated Fourier light field microscopy for ultrafast 3d imaging,” Light Sci. Appl. 13:144 (2024) https://doi.org/10.1038/s41377-024-01502-5

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2. MICRO AND NANOPLASTIC CHARACTERIZATION AND THEIR IMPACT ON HUMAN HEALTH

Tutor: Stefania Sabella/Rosalia Bertorelli

Tutor's Affiliation: Translational Pharmacology Facility, Istituto Italiano di Tecnologia (IIT)

Project Description: the project will be focussed on the development of advanced in vitro technologies to study the interaction of micro-nano plastics and pollutants. Additionally, the most appropriate in vivo models will be selected to study the possible toxic effects of repeated exposure to several plastic formulations, with or without pollutants.

The main responsibilities of candidates will be:

- Biodegradation studies in human artificial body fluids and their toxicological impact
- Assessment of micro and nanoplastics on human *in vitro* models
- Further studies on the most relevant *in vivo* models
- Disseminate the outcomes of this research including peer-reviewed academic publications of international standing.

Essential Requisites:

- A Master Degree in Biochemical engineering, Biological Sciences or equivalent;
- Good handling of cell cultures
- Ability to properly report, organize and publish research data
- Good command of spoken and written English

Optional Requisites:

- Good communication skills
- High motivation to learn
- Spirit of innovation and creativity
- Ability to work in a challenging and international environment

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