POLITECNICO DI MILANO

PhD in BIOINGEGNERIA / BIOENGINEERING - 41st cycle

THEMATIC Research Field: SPINAL+: DEVELOPMENT OF ADVANCED AI-DRIVEN SIGNAL PROCESSING FRAMEWORKS FOR DECODING BIOHYBRID SPINAL CORD ORGANOID INTERFACES

Monthly net income of PhDscholarship (max 36 months)
1450.0 In case of a change of the welfare rates during the three-year period, the amount could be modified.

Context of the research activity	
Motivation and objectives of the research in this field	The integration of bioengineered spinal cord organoids (SCOs) with nanoelectronics generates complex, high-dimensional electrophysiological data that presents significant interpretability challenges. While biohybrid interfaces hold great promise, the stochastic nature of in vitro and in vivo neuronal spiking activity often hinders the establishment of stable, deterministic communication channels. Current methods frequently lack the computational robustness to accurately model these non-stationary biological signals or to efficiently couple them with electronic systems in real-time. Consequently, there is a critical need for advanced signal processing frameworks and adaptive AI architectures capable of decoding neuronal firing patterns. Developing these algorithmic foundations is essential to bridge the gap between biological information flow and digital interpretation, ensuring that biohybrid devices can operate with the precision and reliability required for clinical application. This research aims to develop, optimize, and validate a comprehensive computational framework for interpreting electrophysiological signals within the Spinal+ system. The specific aims include: • Establishing baseline computational models for in vitro spiking neuronal cells to define the theoretical limits and expected behaviors of the organoid-chip interface.

	• Defining signal processing requirements and extraction protocols to identify stimulus-response features and transmission metrics from raw electrophysiological data. • Designing and implementing advanced AI architectures, utilizing techniques such as spike sorting, point-process modeling, and supervised learning (e.g., LSTM, GRU), to decode the information flow within the spinal cord. • Quantifying integration efficiency by developing benchmarking metrics that assess the quality and stability of the coupling between biological organoids and nanoelectronics. • Validating algorithmic accuracy through rigorous comparison with in vitro and in vivo recordings, adapting models to handle the increased complexity of biological noise and signal variability. • Refining models for clinical readiness by establishing optimized data analysis protocols that ensure system safety, reliability, and real-time responsiveness in preparation for clinical trials.
Methods and techniques that will be developed and used to carry out the research	The research will combine computational neuroscience, advanced signal processing, and machine learning methodologies applied to high-dimensional electrophysiological data. The main methodologies consist of: • AI Framework and Architectures: Development and implementation of state-of-the-art supervised learning algorithms, specifically Recurrent Neural Networks (e.g., LSTM, GRU) and machine learning pipelines. These architectures will be optimized to decode temporal dependencies in neuronal patterns and manage the information flow within the spinal cord model. • Advanced Signal Processing and Feature Extraction: Definition of computational frameworks to extract stimulus-response features related to information transmission. This involves the application of spike sorting techniques and signal processing algorithms to isolate and interpret relevant electrophysiological events from raw bio-signals. • Computational Modeling of Neuronal Activity: Point-process modeling and design of original algorithms to model in vitro spiking neuronal cells. This includes

	establishing baselines using existing data to simulate the stochastic behavior of organoid activity.. • Performance Benchmarking and Quantitative Analysis: Definition and calculation of quantitative metrics to assess the integration efficiency of the organoid-chip coupling. This includes statistical analysis and data visualization to validate the computational feasibility and responsiveness of the system.• Validation and Clinical Optimization: Rigorous validation of the AI models against data collected from in vitro and in vivo experiments. The process involves adapting algorithms to the complexity of biological signals and refining the data analysis protocols to meet regulatory standards for future clinical trials. The PhD project will be carried out in cooperation with Manava+.
Educational objectives	This doctoral program provides high-level scientific training designed to cultivate advanced research and problem-solving abilities. In particular, the candidate will be trained to design, draft, and execute original research at the intersection of AI and neural engineering, developing the skills to lead projects or collaborate within multidisciplinary teams. This educational path leverages the didactic curriculum of the Phd in Bioengineering (https://www.phdbioengineering.polimi.it), enriched by workshops and the industrial perspective provided by the cooperation with Manava+.
Job opportunities	The technical expertise and interdisciplinary skills developed during this doctoral program are suitable for national and international academic institutions, research centers, and high-tech companies specialized in neural engineering and biomedical technologies. The curriculum's combination of computational neuroscience, machine learning, and bio-signal analysis prepares candidates for various professional environments. Potential career trajectories include: R&D systems engineer, neural data scientist, bio-signal processing specialist, postdoctoral fellow.

Composition of the research group	1 Full Professors 0 Associated Professors 1 Assistant Professors 2 PhD Students
Name of the research directors	PROF. RICCARDO BARBIERI

Contacts

Prof. Riccardo Barbieri
Riccardo.barbieri@polimi.it

Additional support - Financial aid per PhD student per year (gross amount)	
Housing - Foreign Students	--
Housing - Out-of-town residents	--

Scholarship Increase for a period abroad	
Amount monthly	725.0 €
By number of months	6

Additional information: educational activity, teaching assistantship, computer availability, desk availability, any other information

Educational activity:
The student will be encouraged to attend to courses at POLIMI or abroad 2 / 3in International Schools.
Teaching assistantship: There are various forms of financial aid for activities of support to the teaching practice. The PhD student is encouraged to take part in these activities, within the limits allowed by the regulations.
Computer and desk availability: the student will be allowed to access facilities of the DEIB.