POLITECNICO DI MILANO

PhD in INGEGNERIA DELL'INFORMAZIONE / INFORMATION TECHNOLOGY - 41st cycle

Research Area n. 4 - Telecommunications

THEMATIC Research Field: ADVANCING NEUROPROSTHETICS THROUGH EFFICIENT AND GENERALIZABLE SIGNAL PROCESSING

Monthly net income of PhDscholarship (max 36 months)
1400.0 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	Neuroprosthetic systems restore sensory and motor functions by linking the human nervous system with assistive devices. Their performance depends on accurately decoding neural signals that represent user intent and sensory feedback. Two key modalities are Electroneurography (ENG), capturing peripheral nerve activity, and Electroencephalography (EEG), recording cortical signals non-invasively. ENG offers detailed motor and sensory information but suffers from noise, low spatial resolution, and inter-subject variability. EEG provides high-level cortical intent but with limited specificity. Combining both modalities can enable natural, adaptive control by merging EEG's intent decoding with ENG's fine motor feedback. However, differences in signal origin, variability across users, and computational constraints hinder effective integration. This project integrates physiological modeling and deep learning to develop interpretable, efficient, and generalizable decoding frameworks. A physiologically grounded ENG model will be combined with EEG information to enhance robustness and adaptability. Adaptive deep learning architectures will support real-time decoding, low power consumption, and minimal

	calibration. The ultimate goal is a unified, scalable framework for clinically viable neuroprosthetics capable of robust intent decoding and natural sensory feedback. Objectives: 1. Model ENG propagation and EEG–ENG relations for interpretable decoding. 2. Design efficient deep learning for multimodal neural signals. 3. Apply transfer learning for inter-subject generalization. 4. Enable long-term adaptation to signal drift and plasticity. 5. Optimize algorithms for real-time, low-power operation. 6. Validate on multi-subject datasets. 7. Define clinical translation and deployment pathways.
Methods and techniques that will be developed and used to carry out the research	The research will adopt a structured, multi-phaseapproach that combines physiological modeling,deep learning design, and experimental validationusing both ENG and EEG signals. The objective isto develop a unified and efficient decodingframework that generalizes across users, recordingmodalities, and long-term operation conditions. 1. Literature Review and Data AcquisitionConduct a comprehensive review of ENG andEEG signal processing techniques, withemphasis on neuroprosthetic decoding andmultimodal fusion strategies. Publicly availabledatasets and collaboratively acquired multisubjectrecordings will be used to capture bothcortical intent (EEG) and peripheral neuralresponses (ENG), ensuring diversity in subjectsand experimental conditions. 2. Physiological Signal ModelingDevelop biophysically informed models thatrepresent neural activation, propagation, and thecoupling between cortical and peripheral activity.This phase will identify subject-invariant andmodality-complementary features to supportinterpretable and generalizable decoding. Themodeling framework will integrate both top-

	down(EEG-driven) and bottom-up (ENG-driven)pathways to emulate realistic neurophysiologicaldynamics. 3. Model Design and OptimizationDesign lightweight deep learning architecturescapable of processing multi-modal neural data inreal time. The models will implement efficientfusion mechanisms to combine ENG and EEGinformation streams, enhancing robustness andaccuracy. Event-driven computation and SNNswill be explored to achieve ultra-low-poweroperation suitable for wearable and implantable devices. 4. Transfer Learning and AdaptationDevelop transfer learning and domainadaptation strategies to enable cross-subject,cross-session, and cross-modalitygeneralization. Techniques such as multi-sourceadaptation and continual learning will beemployed to adapt models to new users andevolving signal characteristics without fullretraining, minimizing calibration and ensuringsustained decoding accuracy. 5. Validation and Experimental TestingValidate the developed methods using multisubject,multi-modal datasets under realisticexperimental conditions. Evaluation metrics willinclude classification accuracy, latency, androbustness across sessions and individuals.Comparative analyses between unimodal (ENGor EEG) and multimodal (ENG +EEG)approaches will quantify the benefits of fusionand adaptive modeling. 6. Integration and Clinical TranslationTranslate the algorithms into resourceconstrainedneuroprosthetic platforms byoptimizing implementations for embedded orneuromorphic hardware. This phase will addresscomputational and power efficiency, interfacecompatibility, and compliance with clinical andregulatory standards. Collaboration withindustrial and clinical partners will guidepractical deployment and ensure translationalrelevance.
Educational objectives	1. Acquire expertise in physiological modeling andneural signal processing.

	2.Develop proficiency in designing and optimizing deeplearning architectures for bioelectrical signal decoding. 3.Gain skills in transfer learning and adaptive modelingfor cross-subject generalization. 4.Build competence in implementing efficient, lowpoweralgorithms suitable for neuroprosthetic systems. 5.Strengthen interdisciplinary collaboration skillsbridging engineering, neuroscience, and clinicaldomains. 6. Enhance abilities in experimental validation, scientificcommunication, and publication in international venues.
Job opportunities	Given the multidisciplinary nature of the project and itsalignment with biomedical engineering, neuroscience,and AI-driven healthcare innovation, the PhD graduatewill be well-positioned for research and developmentroles in: - Academic institutions focused on neuroengineeringand signal processing - Biomedical and neurotechnology industries - Clinical research centers developing assistiveneuroprosthetic solutions - Startups and research spin-offs in neural interfacesand rehabilitation technologies
Composition of the research group	1 Full Professors 1 Associated Professors 1 Assistant Professors 0 PhD Students
Name of the research directors	Prof. Umberto Spagnolini

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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	700.0 €
By number of months	6

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

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EDUCATIONAL ACTIVITIES (purchase of study books and material, including computers, funding for participation in courses, summer schools, workshops and conferences): financial aid per PhD student.

TEACHING ASSISTANTSHIP: availability of funding in recognition of supporting teaching activities by the PhD student.
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 AVAILABILITY:
1st year: Yes
2nd year: Yes
3rd year: Yes