POLITECNICO DI MILANO

# PhD in INGEGNERIA MECCANICA / MECHANICAL ENGINEERING - 41st cycle

## THEMATIC Research Field: META-MEMS-BASED PHYSICAL NEURAL NETWORKS

| Monthly net income of PhDscholarship (max 36 months) |
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| **1500.0**<br>In case of a change of the welfare rates during the three-year period, the amount could be modified. |

| Context of the research activity | |
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| **Motivation and objectives of the research in this field** | The industry of Micro Electro-Mechanical Systems (MEMS) devices is a flourishing field that has fueled technological progress in numerous sectors over the last decades, providing essential sensors, actuators, and components. However, these components often require further processing and elaboration.In response to this context, the objective of this PhD project is to design a MEMS structure capable of processing a mechanical signal using solely mechanical components, thus emulating the behavior of an artificial neural network (ANN) without the necessity for digital operations. This is accomplished by combining deep learning algorithms and metamaterials within the framework of MEMS devices. By integrating principles from both fields, the aim is to create a novel MEMS device that can perform complex signal processing tasks akin to those carried out by ANNs, but using entirely mechanical means.Elastic metamaterials are structured with small-scale unitary elements arranged spatially, resulting in unconventional global dynamic characteristics. Each element functions as a "mirror," capable of refracting or halting waves and vibrations, influencing neighboring elements. From a topological perspective, artificial neural networks (ANNs) and metamaterials exhibit similar structures, wherein interconnected elements produce desired input-output relationships.This project aims to replace digital data processing with a physical neural network operating at the micro-scale. This network comprises interconnected mechanical resonators (the metamaterial) and is capable |

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| | of processing elastic/acoustic signals in situ, thereby providing desired input-output relations without the need for external computational power. |
| **Methods and techniques that will be developed and used to carry out the research** | Throughout the entire duration of the PhD, the candidate will develop theoretical and numerical methods to investigate interconnected metamaterial architectures and, subsequently, will conduct experiments to test the physical network on relevant case-studies. To achieve this, the synergistic interplay between acoustic metamaterials and deep learning necessitates the implementation of custom back-propagation algorithms. These algorithms are designed to optimize physical activation functions, representing the response of each neuron, and the (elastic) interconnections between them in order to produce arbitrary transfer functions. Hence, it is expected that, in addition to the physical realization of a prototype, innovative numerical methods will be proposed for training the network. These methods should enable handling complex dynamics, such as nonlinear behavior and local resonance. In other words, the mechanical design reflects the capability to comprehend both structural mechanics and deep learning theory, which are appropriately integrated to develop metamaterial-based deep learning architectures operating at the micro-scale. |
| **Educational objectives** | The PhD candidate in this program is expected to develop a solid competence in structural dynamics, metamaterials and MEMS structures. The candidate is also expected to acquire (at least) the rudiments of multi-physical modelling and strong coding skills in Matlab/Python/C++. |
| **Job opportunities** | Our last survey on MeccPhD Doctorates highlighted a 100% employment rate within the first year and a 35% higher salary, compared Master of Science holders in the same field.<br>Partners: STMicroelectronics, University of California San Diego, Delft Institute of Technology, ETH Zurich. |
| **Composition of the research group** | 1 Full Professors<br>0 Associated Professors<br>2 Assistant Professors<br>2 PhD Students |

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| **Name of the research directors** | Prof. F.Braghin, Ing. J.Marconi, Ing. E.Riva |

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

| **Scholarship Increase for a period abroad** | |
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| **Amount monthly** | 750.0 € |
| **By number of months** | 6 |

| **Additional information: educational activity, teaching assistantship, computer availability, desk availability, any other information** |
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| Financial aid is available for all PhD candidates (purchase of study books and materials, funding for participation in courses, summer schools, workshops and conferences) for a total amount of € 6.114,50. Our candidates are strongly encouraged to spend a research period abroad, joining high-level research groups in the specific PhD research topic, selected in agreement with the Supervisor. An increase in the scholarship will be applied for periods up to 6 months (approx. 750 euro/month - net amount). Teaching assistantship: availability of funding in recognition of supporting teaching activities by the PhD candidate. 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. |