PhD in INGEGNERIA MECCANICA / MECHANICAL ENGINEERING - 39th cycle

THEMATIC Research Field: USE OF DEEP LEARNING ALGORITHMS AND DIGITAL TWINS IN SURROGATE MODELLING AND SIGNAL PROCESSING FOR HEALTH AND USAGE MONITORING OF COMPLEX ENGINEERING SYSTEMS

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	Monitoring complex engineering systems, especially safety-critical ones as mechanical/aeronautical structures, energy harvesting and storage systems, civil infrastructures, etc., is crucial for tracking degradation and driving maintenance actions to avoid catastrophic failures. In most application areas, due to safety-related reasons, traditional maintenance strategies are based on scheduled inspections to evaluate the health state of the systems. Although this approach guarantees satisfactory safety levels, it is costly and is characterized by avoidable downtimes. In fact, the system is often found in healthy conditions, and no further restoring/replacement actions are needed. Recently, more complex strategies have been proposed in the literature. The most promising approach consists of installing sensors on the system for acquiring diagnostic/prognostic signals in real time. Such signals are then processed through dedicated algorithms to perform damage detection, localization and/or quantification and, eventually, prediction of remaining life. Satisfactory performance has been shown to characterize machine learning-based processing methods. However, training such algorithms requires generating large datasets of experimental and/or numerical data, which is generally costly and, usually, unfeasible. Moreover, when numerical simulations are used to generate training data, high-fidelity is required for

	retaining the effect of damage on the diagnostic signals, and for guaranteeing accurate damage diagnosis and prognosis. This makes generating numerical models for health monitoring expensive, and running simulations with such models often turns out to be prohibitive. In this context, the Ph.D. candidate will work, on one hand, on the development of surrogate models of complex models (and associated numerical solutions) to generate larger high-quality datasets, thus making data-driven approaches cheaper and deployable at industrial level. Such surrogate models should retain the fidelity of the numerical simulations, while reducing the computational burden. On the other hand, the candidate will focus on the development of advanced diagnostic and prognostic tools, stemming on the enhanced database generation described above and on improved signal processing capabilities offered by machine learning tools. In particular, two main very promising machine learning-based tools will be studied and, eventually, combined, for developing algorithms for damage diagnosis and prognosis: 1. Deep learning algorithms as surrogate models of numerical simulations and for signal processing. 2. Digital twins as virtual counterparts of real systems, which are set up to study the behavior under varying environmental and operative conditions, and in presence of damage.
Methods and techniques that will be developed and used to carry out the research	In order to carry out his research, the Ph.D. candidate will have to develop high-fidelity models of engineering systems. This will allow the Ph.D. candidate to numerically study the behavior of real systems through validated numerical simulations, even taking into account the effect of different environmental and operative conditions affecting the system under consideration. Such models may require modeling multiple physics, i.e., they will consist of high-fidelity numerical sub-models, and will allow acquiring diagnostic/prognostic signals through virtual networks of sensors. The Ph.D. candidate will need to study such signals, along with experimental observations, in detail to identify damage-sensitive

	features that may be used for health and usage monitoring of engineering systems. Furthermore, the Ph.D. candidate will need to acquire knowledge about digital twins. This class of tools consists of multi-physics numerical models of the sub-systems of engineering platforms, and allows acquiring diagnostic signals through virtual networks of sensors. The high-fidelity models developed within the research project will be leveraged to ensure that the signals acquired through digital twins are accurate enough for damage diagnosis and prognosis.Finally, the research project will also require studying deep learning algorithms for structural health monitoring. The algorithms will serve as (i) surrogate models of complex models and associated numerical simulations, and as (ii) diagnostic/prognostic algorithms. Examples of state-of-the-art methods that could be used for those aims are physics-informed neural networks and graph neural networks. The machine learning algorithms involved will be made explainable and interpretable through explainability algorithms, such as the layer-wise relevance propagation algorithm.
Educational objectives	We provide doctoral candidates with high-level scientific training, fostering and refining research and problem-solving capabilities. At the end of the PhD cycle the candidate will be able to plan and carry out original research by working in a team or leading a research group active in the field of health monitoring of complex engineering systems. The candidate will strongly enhance both theoretical and experimental skills acquired during master studies. Opportunities will be offered for spending visiting periods hosted by project partners for scientific cooperation. The candidate will acquire knowledge in the disciplines of: •Advanced machine learning algorithms (deep learning, transfer learning, explainability methods, etc.) •Algorithms for damage diagnosis: damage detection, localization and quantification •Performance assessment •Sensor installation, acquisition and data processing •Surrogate modeling

	•Surrogate modeling
Job opportunities	Our last survey on MeccPhD Doctorates highlighted a 100% employment rate in national and international companies and academic and non-academic research institutions, engaged in innovation, research and technical development within the first year and a 35% higher salary, compared to Master of Science holders in the same field. Specifically, the skills and know-how developed during the PhD will allow to cover positions for design, maintenance and integrity assessment of advanced systems and components in aerospace, automotive and mechanical companies.
Composition of the research group	1 Full Professors 3 Associated Professors 2 Assistant Professors 9 PhD Students
Name of the research directors	Prof. Francesco Cadini, Prof. Marco Giglio

Contacts
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Additional support - Financial aid per PhD student per year (gross amount)	
Housing - Foreign Students	--
Housing - Out-of-town residents (more than 80Km out of Milano)	--

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
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 euro 5.707,13.

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. 700 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.