PhD in INGEGNERIA MECCANICA / MECHANICAL ENGINEERING - 38th cycle

Research Area n. 1 - Advanced Materials and Smart Structures

THEMATIC Research Field: MACHINE LEARNING AND DIGITAL TWIN MODELS FOR MONITORING THE STRUCTURAL HEALTH OF ENGINEERING PLATFORMS

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	Maintenance of engineering systems is crucial for controlling degradation during the lifecycle and, eventually, driving corrective actions. This is particularly important in case structural platforms, such as mechanical, naval and aerospace platforms, are considered. In fact, assuring the safe operation of such systems decreases the likelihood of accidents, and extending their operative life reduces costs and wastes. Frameworks set up to study the health state of structures involve the following subsequent steps: 1. Damage diagnosis - Damage is detected, localized and quantified in this first step of the process. 2. Damage prognosis - After damage has been diagnosed, the remaining useful life (RUL) of the damaged structural system is predicted. Health and usage monitoring systems (HUMS) have been employed to boost the performance of such frameworks. In fact, not only using HUMS for damage diagnosis and prognosis has been proved to provide better accuracy than traditional non-destructive (ND) and scheduled inspections [1, 2], but it also allows adopting real time condition-based and predictive maintenance strategies. In fact, HUMS rely on the information gathered through permanently installed diagnostic units for real time structural health monitoring. Moreover, recently, the

	accuracy of damage diagnosis and prognosis frameworks has been further improved by using data fusion techniques, thanks to the availability of low-cost sensors to acquire diverse diagnostic signals (e.g., ultrasonic guided waves, accelerations, strains) [3]. Such data fusion techniques, however, have introduced the requirement of complex and heavy processing operations, along with the demand of large space to store data. Finally, depending on the type of acquired signal, processing operations also need to be robust to confounding factors, such as changing environmental and operative conditions. Given the complexity of data handling and processing, machine learning (ML) has been identified as a promising solution. Several contributions have already been published in the literature that present ML algorithms to extract hidden features of diagnostic signals, with the purpose of improving the performance of frameworks for damage diagnosis and prognosis. In this context, researchers are focused on exploring new solutions, and improving already existing ones, for developing HUMS frameworks for engineering platforms. Recently, research contributions have started moving towards the combination of high-fidelity models and (possibly explainable) machine learning algorithms to effectively describe complex dynamics due to the presence of damage, and to identify even the smallest deviation from the normal operative regime of engineering systems.
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 and digital twin (DT) 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. DTs will generally be multi-physics, will include high fidelity models of the sub-systems of engineering platforms and will allow acquiring diagnostic signals through virtual networks of sensors. In fact, DTs are virtual counterparts of real engineering systems, and are set up to reproduce the behavior of such systems

	under external stimuli, environmental conditions and in presence (or absence) of damage. That is, DTs allow numerically acquiring signals that would otherwise be complex to obtain experimentally. The Ph.D. candidate will need to study such signals, along with experimental observations, in detail to identify and/or extract damage-related features, which will then be used to drive ML algorithms and set up HUMS frameworks. ML algorithms will be trained over experimental data, numerical data, or a combination of both, acquired in different conditions. That is, datasets will need to include both signals describing healthy conditions of the system, and signals affected by the presence of damage. The Ph.D. candidate will finally set up the damage diagnosis and prognosis frameworks based on the trained ML algorithms. Such ML-based frameworks will include state-of-the-art solutions, such as: - Deep learning (convolutional neural networks, physics-informed neural networks, graph neural networks) - Transfer learning - Reinforcement learning The ML algorithms involved will be made explainable and interpretable through explainability algorithms, such as the layer-wise relevance propagation (LRP) algorithm for CNNs.
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 and prognosis 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. Specifically concerning the HUMS field of application, the candidate will get command in the disciplines of: - HUMS system optimization - Performance assessment

	- Sensor installation, acquisition and data processing - Advanced machine learning algorithms (deep learning, transfer learning, explainability methods, etc.) - Bayesian model identification and updating - Methods for diagnosis and prognosis of systems under degradation - High fidelity system model development (digital twin)
Job opportunities	Our last survey on MeccPhD Doctorates highlighted a 100% employment rate 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 0 Assistant Professors 9 PhD Students
Name of the research directors	Prof. Marco Giglio, Prof. Francesco Cadini

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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.