PhD in INGEGNERIA MECCANICA / MECHANICAL ENGINEERING - 38th cycle

Research Area n. 1 - Advanced Materials and Smart Structures

THEMATIC Research Field: COUPLING DEEP-LEARNING AND PHYSICS-BASED MODELLING FOR PROGNOSTICS AND HEALTH MANAGEMENT (PHM) OF 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	The maintenance of engineering systems is critical in controlling degradation and promoting corrective actions, especially for complex platforms that involve significant structural components such as mechanical, civil, naval, and aerospace systems. Keeping these systems operating safely reduces the likelihood of accidents and extends their lifespan, saving costs and resources. The study of the health state of structures involves two steps: (i) damage diagnosis, i.e., damage is detected, localized and quantified in this first step of the process and (ii) damage prognosis, i.e., after damage has been diagnosed, the remaining useful life (RUL) of the damaged structural system is predicted. To enhance performance, prognostics and health management PHM systems might be used. PHM systems could provide improved accuracy compared to traditional non-destructive (ND) inspections and allow for real-time condition-based and predictive maintenance strategies. The use of data fusion techniques, along with the availability of low-cost sensors to acquire diverse diagnostic signals (e.g., ultrasonic guided waves, accelerations, strains), has further improved the accuracy of damage diagnosis and prognosis frameworks [3]. However, this has increased the need for complex and

	heavy data processing and storage operations, which is where machine learning (ML) comes in as a promising solution. More specifically, due to the needs of processing increasingly complex and rich signals and, at the same time of being robust with respect to confounding factors, such as changing environmental and operative conditions, deep learning techniques are gaining more popularity in the PHM community. As such, there have been various studies published in the field that use deep learning algorithms to uncover hidden features in diagnostic signals with the goal of enhancing the accuracy of damage diagnosis and prognosis frameworks.In recent times, research has shifted towards incorporating high-fidelity, physics-based and multi-physics models and deep learning algorithms to effectively capture the complex dynamics caused by damage and accurately detect even minor deviations from the normal functioning of engineering systems.Interpretability and explainability of deep learning models are also crucial considerations in the development of PHM systems, especially for engineering systems where safety is a critical factor. Ensuring a high level of trustworthiness in the algorithms used is imperative in these cases.
Methods and techniques that will be developed and used to carry out the research	The Ph.D. candidate's research will involve the creation of high-fidelity, multi-physics models of complex engineering platforms. These models will enable the candidate to conduct numerical simulations that accurately reflect the behavior of real systems, taking into account various environmental and operational factors. The models will allow for the virtual acquisition of diagnostic signals through virtual sensor networks. They serve as virtual counterparts of real engineering systems, reproducing their behavior under various stimuli, environmental conditions, and, more importantly, in the presence or absence of damage. These simulations provide access to signals that would otherwise be difficult to obtain experimentally. The Ph.D. candidate will examine these signals, along with experimental data, to identify and extract damage-related features. These features will drive deep learning algorithms and form the basis of the prognostics and health management (PHM) system

	framework. The deep learning-based algorithms will be trained on experimental data, numerical data, or a combination of both, acquired under varying conditions. The datasets must include signals representing both healthy and damaged conditions of the system. The Ph.D. candidate will then establish the damage diagnosis and prognosis frameworks based on the trained ML algorithms. Such 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 and other available ones.
Educational objectives	Our PhD program provides advanced scientific training to enhance research and problem-solving skills. Upon completion of the program, the candidate will be equipped to conduct original research independently or as part of a team in the field of health monitoring and prognosis of complex engineering systems. The candidate will further build on theoretical, numerical, and experimental skills acquired during their master's studies. Opportunities for visiting and collaborating with project partners will also be provided. Specifically concerning the PHM field of application, the candidate will get command in the disciplines of: - PHM 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, multi-physics system model development
Job opportunities	A recent survey showed that PhD candidates are 100%

	employed after one year, in national and international companies and academic and non-academic research institutions, engaged in innovation, research and technical development. On average the survey showed that people earning our PhD title obtain a 35% higher salary than the corresponding employers with a Master of Science degree. 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 10 PhD Students
Name of the research directors	Prof. Francesco Cadini, Prof. Marco Giglio

Contacts
Prof. Francesco Cadini *Phone* 022399 8213 *Email* francesco.cadini@polimi.it Prof. Marco Giglio *Phone* 022399 8234 *Email* marco.giglio@polimi.it phd-dmec@polimi.it

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.