POLITECNICO DI MILANO

PhD in INGEGNERIA MECCANICA / MECHANICAL ENGINEERING - 38th cycle

Research Area n. 1 - Advanced Materials and Smart Structures

THEMATIC Research Field: DIGITAL TWIN AND ARTIFICIAL INTELLIGENCE APPLICATIONS FOR THE DEVELOPMENT OF HEALTH AND USAGE MONITORING SYSTEMS (HUMS) FOR MECHANICAL, NAVAL AND AERONAUTICAL 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	From civil to mechanical, naval and aerospace engineering applications, structural and non-structural components are subjected to degradation during their lifecycle. In order to assure the safe operation of a given system and extend its operative life, be it a bridge, a car, a ship or an aircraft, it must be properly maintained during its service life. To this aim, different strategies have been used with the aim of (i) diagnosing (i.e., detect, identify, localize and quantify) the presence of any structural changes in the system that may negatively affect its current or future performance and (ii) possibly prognosing (i.e., predicting) their remaining useful life (RUL). In particular, health and usage monitoring system (HUMS) techniques have shown significant advantages with respect to traditional methods based on non-destructive (ND) and scheduled inspections [1], [2]. Indeed, HUMS approaches allow the implementation of real-time condition-based (or even predictive) maintenance strategies through the use of a diagnostic unit, which is permanently installed in the system, and that is able of monitoring it over time, avoiding undesired scheduled downtime and increasing its safety. Moreover, with the extensive and low cost availability of sensors, HUMS techniques have been strongly enhanced, allowing the

	acquisition of a large amount of data of different nature (e.g., accelerations, strains, Lamb waves, etc.) [3], increasing the amount of the extractable diagnostic information. However, these sensor technology advancements have also led to a growing complexity from the signal processing point of view. Indeed, the gathered data are bigger in terms of input dimensionality, and they are often more complex, especially when acquired from intricated systems with external perturbations (e.g., measurement/environmental noise, changing environmental conditions, etc.). To deal with all these challenges, machine learning algorithms have been proposed for several years to extract the most hidden damage features from the gathered signals. In this context, the objective is that of developing advanced HUMS frameworks for modern, complex engineering platforms, such as mechanical, naval or aeronautical, effectively combining the capabilities of high-fidelity models of capturing and representing very complex degradation/fault dynamics with those of machine learning of processing large amount of sensor data and extracting even the most subtle anomaly fingerprint from them. Furthermore, the traditional problem of machine learning-based approaches being black boxes with lack of interpretability will be finally addressed within the recently introduced framework of the explainability of deep networks to answer the growing need for transparent and trustworthy algorithms.
Methods and techniques that will be developed and used to carry out the research	The Ph.D. candidate will develop physics-based and/or data-driven digital twins (DT) models, able to virtually mimic the behavior of the engineering systems under consideration, under different operational and environmental conditions and in presence of several types of degradation, damages and faults. DTs are, in fact, multi-physics models of the system, typically including some high-fidelity modules, replicating the signals observed by the actual sensors on the platform, as a consequence of external stimuli characterizing the operation of the system and the work environment (loads, currents, temperatures, etc.). A DT reproduces the behavior of the system in nominal conditions and, through

	the integration of appropriate degradation and failure models, also in damaged conditions. Using such a DT it is therefore possible to generate signals in non-nominal conditions (degradation, faults, anomalies), normally difficult, if not impossible, to experimentally obtain. The HUMS algorithms, on the other hand, will be based on (i) either available experimental data or (ii) artificial data generated by the numerical/analytical physics-based models (the DTs described above), or (iii) combinations thereof. The idea is that of generating a database of system responses in correspondence of a large variety of healthy and damaged conditions, that can be then used to build the diagnostic and prognostic algorithms, possibly based on advanced machine learning for data processing, such as for example: deep neural networks, convolutional neural networks, physics informed neural networks, graph neural network, transfer learnin, reinforcement learning. Explainability algorithms, such as for example the layer-wise propagation algorithm (LRP) for the CNNs, will be used to enhance the interpretability of the predictions made by the machine learning-based diagnostic and prognostic models.
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	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 **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 9 PhD Students
Name of the research directors	Prof. Francesco Cadini, Prof. Marco Giglio

Contacts
Prof. Francesco Cadini *Phone:* +39 022399 8213 *Email:* francesco.cadini@polimi.it Prof. Marco Giglio *Phone:* +39 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.