POLITECNICO DI MILANO

PhD in INGEGNERIA MECCANICA / MECHANICAL ENGINEERING - 40th cycle

THEMATIC Research Field: INTEGRATING AI AND DIGITAL TWIN MODELS FOR PREDICTIVE MAINTENANCE AND HEALTH MONITORING IN INDUSTRIAL ENVIRONMENTS

Monthly net income of PhDscholarship (max 36 months)
€ 1500.0 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 research focuses on developing and implementing methodologies for a Digital Twin-based monitoring system for industrial applications. This Digital Twin leverages numerical and analytical models to enable the creation of effective and cost-efficient Health and Usage Monitoring Systems (HUMS). The proposed solution integrates real and virtual sensors with a dynamic virtual model of critical subsystems, encompassing both normal operational states and various damage scenarios. This setup facilitates continuous assessment of the expected behavior of the intact system and enables real-time comparison with sensor data to detect anomalies and deviations. Building on methodologies established in prior projects, the research will address various use cases, including (i) load monitoring, (ii) structural damage detection and anomaly diagnosis, (iii) real-time signal filtering for model parameter identification and updating, and (iv) prognostics for damage evolution and system degradation.Advanced statistical methods, signal processing techniques, and artificial intelligence (AI) algorithms will be employed for damage identification and classification, load and overload monitoring, and maneuver recognition. Additionally, analytical and numerical models will be used to predict the residual useful life (RUL) of each subsystem, enabling timely and appropriate countermeasures to mitigate failures and optimize system

	reliability.
Methods and techniques that will be developed and used to carry out the research	The research will employ a combination of data-driven techniques and physics-based approaches to create a comprehensive Digital Twin framework for monitoring industrial systems. This hybrid approach will integrate high-fidelity numerical models, analytical methods, and machine learning algorithms to ensure accurate representation and predictive capabilities of the system's behavior. For the physics-based component, finite element models (FEM) and (semi-) analytical simulations will be developed to replicate the mechanical and structural characteristics of critical subsystems. These models will include detailed representations of operational loads and damage mechanisms, allowing for real-time simulation of both normal and faulty states. This will enable the Digital Twin to predict system behavior under varying conditions and provide a reliable baseline for anomaly detection. On the data-driven side, the research will utilize advanced statistical signal processing and artificial intelligence techniques, such as (deep) neural networks, Gaussian Processes, etc. for pattern recognition, damage classification, and fault prediction. Time-series analysis and feature extraction methods will be used to process data from real sensors, facilitating the identification of key indicators of system health and performance. Data fusion techniques will combine real and virtual sensor data to optimize the Digital Twin's accuracy. Possibly, machine learning models will be trained using both historical and real-time data to enable automated updates of model parameters, improving the predictive capabilities of the Digital Twin over time. Finally, Bayesian inference and filtering techniques will be applied for model parameter estimation and real-time updating, ensuring that the Digital Twin remains robust against uncertainties and evolving system conditions.
Educational objectives	We provide doctoral candidates with high-level scientific training, fostering and refining research and problem-solving abilities. 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 digital-twins and algorithms for structural health monitoring and prognosis. 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 optimisation •Sensor installation, acquisition and data processing •Machine learning algorithms •Bayesian model identification and updating •Methods for diagnosis and prognosis of systems under degradation •System model development and updating (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 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	2 Full Professors 2 Associated Professors 1 Assistant Professors 9 PhD Students
Name of the research directors	Prof. Claudio Sbarufatti

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	750.0 €
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 € 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.