PhD in INGEGNERIA MECCANICA / MECHANICAL ENGINEERING - 41st cycle

THEMATIC Research Field: AUTOMATIC DECISION-MAKING ALGORITHMS AND DIGITAL TWIN INTEGRATION FOR OPTIMAL MAINTENANCE MANAGEMENT

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	With the introduction of Structural Health Monitoring (SHM) and modern diagnostics and prognostics techniques, exploiting the information they provide is crucial to reducing operational costs and attracting the interest of companies across many different industrial fields. The research activity focuses on developing and implementing algorithms and methodologies for optimal maintenance management of complex systems. Those systems can be related to a single entity or to an entire fleet, and their management is optimised given the interdependence of components and subcomponents. Maintenance practices are studied by simulating and analysing the whole life cycle, which should be modelled to reflect the states and transitions experienced by the real system. Maintenance is optimised through an automatic decision-making algorithm developed by leveraging the system's life cycle numerical model. This model is used as a virtual environment for training an Artificial Intelligence (AI)-based agent capable of handling maintenance and related tasks, minimising operational costs while maximising asset availability. The goals of the research activity presented can be summarised as follows: •Modelling the life cycle of a complex system, considering the integration between different maintenance approaches (schedule and condition-based), and making

	a performance assessment to evaluate the management effectiveness. •Develop AI algorithms for automatic decision-making for maintenance optimisation. •Test and compare the performance between different agents to validate the obtained methodology and determine which one is more effective and implementable in future real-world scenarios. Finally, the developed methodologies can be combined to create a Digital Twin for the life-cycle management of the analysed system.
Methods and techniques that will be developed and used to carry out the research	The research will employ a combination of statistical, numerical, and physics-based approaches to model the studied system and its evolution throughout its life cycle. The model must include all possible states and actions that can be experienced and must provide meaningful statistics to analyse the resulting performance. Discrete Event Systems (DES), for example, can be used to simulate long time periods without excessively increasing computational burden. The modelling activities focus on the definition of four main elements: (i) States, (ii) State Space, (iii) Transitions (or Actions), (iv) Process Functions and (v) Decision Policies.The first four elements are imposed by the system's nature and associated processes; meanwhile, the Decision Policies depend on user behaviour and can be optimised. Decision-making tasks can be optimised using AI methodologies that maximise a reward function representative of life-cycle costs. Reinforcement Learning (RL) is a powerful and versatile tool for solving automatic decision-making problems. Both single- and multi-agent approaches can be tested to determine the most effective strategy for the given case study. Analysing the effects of different reward function formulations, state space definitions and Deep RL architectures, the research explores which configuration is optimal, providing a deep understanding of the involved methodologies and techniques. While integrating different algorithms within the DES, the State Space formulation

	can vary accordingly to the agent's requirements. The algorithms obtained are validated on a separate case study, and other decision-making approaches are compared to highlight the strengths and limitations of the work.Finally, by developing a model-updating algorithm through Machine Learning (ML) methods and coupling the trained agent with the life-cycle digital replica, a Digital Twin for life-cycle management tool can be created.
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's studies. Opportunities will be offered for visiting periods hosted by project partners for scientific cooperation.Specifically concerning the HUMS field of application, the candidate will gain command in the disciplines of: • Complex systems life-cycle modelling and conceptualisation. • Statistical analysis. • Machine/Deep Learning. • Reinforcement Learning for automatic decision-making (single and multi-agent) • Model updating and Digital Twin development.
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 expertise developed during the PhD will allow covering positions for design and integrity assessment of advanced systems and components in automotive and mechanical companies involved in the green transformation.

	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	--

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, fundingfor 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 activitiesby the PhD candidate. There are various forms of financial aid for activities of support to theteaching practice. The PhD student is encouraged to take part in these activities, within the limits allowed by the regulations.