POLITECNICO DI MILANO

PhD in INGEGNERIA MECCANICA / MECHANICAL ENGINEERING - 39th cycle

THEMATIC Research Field: DIGITAL-TWIN DEVELOPMENT FOR UAV SWARM HEALTH AND USAGE MONITORING

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	To date, there are various opportunities to effectively harness the capabilities of Unmanned Aerial Vehicle (UAV) swarms. As a dual-use technology, aside from military applications, UAVs can be employed for various civilian applications, including hazard and disaster monitoring, rescue missions, reconnaissance and surveillance.In such contexts, the ability to deploy many small unmanned aerial systems with coordinated and distributed capabilities (known as UAV swarms) could ensure better operational flexibility at significantly lower costs compared to expensive all-in-one platforms available today, especially if those unmanned systems could be recovered for reuse. These would indeed be lower-cost platforms with much shorter operational lifespans. However, the operation of a drone swarm requires addressing several challenges in implementing autonomous capabilities, including: •Swarms must exhibit collective behavior, make autonomous decisions, and interact with the operating environment. •Swarm elements must share a collective logistics management system for support and maintenance. •A communication system is necessary to enable distributed sharing and storage of information. •A distributed system of sensing, information fusion, and extraction of relevant information for operational

	management is required. In this project, the development of Health and Usage Monitoring Systems (HUMS) for UAV swarms, coupled with the implementation of an artificial intelligence-based decision-making process, is crucial to optimize the swarm's performance and the success of its missions. By monitoring the real-time status and usage of individual UAVs, operators can identify potential issues before they become critical and make data-driven decisions to enhance the overall performance of the swarm. The integration of artificial intelligence-based decision-making would further improve swarm optimization by analyzing data to identify patterns, predict outcomes, and formulate recommendations for mission planning and execution. Overall, the combination of HUMS and artificial intelligence-based decision-making is essential for maximizing the efficiency and effectiveness of UAV operations.
Methods and techniques that will be developed and used to carry out the research	Starting from the data available in the literature, a multi-physics model will be created in MATLAB-Simulink-Simscape environment. This model will simulate the signals generated by the sensors under normal conditions of the UAV system. Starting from the reference UAV model, understood as a multi-physics model that considers mechanical, hydraulic, electrical, control aspects, etc. (defined based on the considered platform), the following models will be developed (detailed below): •Modelling of a subsystem subject to degradation/faults: the objective is to generate synthetic data such as anomaly indices of the system. Sensitivity analysis will be performed to identify which parameters are more useful to monitor in order to identify the anomaly. •System of systems modelling (swarm): it is necessary to model the operational management logic of the fleet during a typical mission profile. It is also necessary to simulate the communication system (between drones and towards the base), a key element in the automatic management of the swarm, evaluating the effects that communication errors would have on mission

	management. For this activity, the candidate will use the MATLAB-Simulink-SimEvents software package. •Operational and logistic modelling: the drone swarm is inserted into a higher-level model of mission and logistics-maintenance management, also developed in the MATLAB-Simulink-SimEvents environment. The swarm will be subject to random loads, selected based on the environment and the type of mission. It will also be possible to simulate different maintenance logics, depending on the occurrence of unscheduled events and/or scheduled maintenance events. Depending on the health status of each element of the swarm, it will be possible to simulate the effects that a fleet reconfiguration would have on the final mission target. Finally, the PhD candidate will develop algorithms for surrogate modelling, based on artificial intelligence, and approached for automatic and supervised decision making, e.g. based on reinforcement learning.
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 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 (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 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.
Composition of the research group	1 Full Professors 3 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	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.