POLITECNICO DI MILANO

PhD in DATA ANALYTICS AND DECISION SCIENCES - 38th cycle

PNRR_352 Research Field: PHYSICS-INFORMED LEARNING METHODS FOR ADVANCED PREDICTIVE MAINTENANCE IN AERONAUTICAL APPLICATIONS

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	For future aviation applications, the design of Intelligent Diagnostics systems in Maintenance, Repair Overhaul (MRO) operations is essential to increase productivity and efficiency and to develop new services for the final customers, especially in the fast-evolving field of Urban Air Mobility (UAM), which will require low operational costs to have fleets of thousands of cheap aircrafts. The life cycle of an aircraft is divided into design, production, operation, and decommissioning phases. The operational phase has the highest costs, and the MRO processes are a big part of it, and can play a central role in improving aircraft reliability and reducing maintenance costs. Further, to be applicable and certifiable, the data-driven approaches built for MRO purposes must be explainable, and thus grounded on physics-informed model, augmented with learning capabilities. This research aims to devise learning-based data-driven techniques for modelling complex aerospace systems leveraging physics-informed approaches. In particular, we intend to explore the possibility of designing ensemble learning systems combining different model types, such as white-box, grey-box and black-box models. In fact, particular working conditions can benefit from a physics-based description, while others call for black-box approaches, depending on many factors, such as sub-system

	complexity, available measurements, etc. Being able to efficiently combine different models with different possible architectures can also allow estimating the condition-based reliability of each model, integrating a -priori knowledge and combining models in cooperative way, and understand to which extent physics-informed subsystems need to be complemented to fully black-box models to efficiently carry out the needed learning tasks. In doing so, we also aim at understanding how to merge different models based on the different time-scales of, e.g., usage (usually with a slow evolution) and anomalous (often nearly instantaneous) events. This should lead to develop techniques to mix the different models optimally not only in time but also in frequency domain, and to understand how to devise optimal integration strategies with which to build the ensemble model according to the final task it has to accomplish. The overall system will be developed with attention to its practical applications; therefore, robustness issues will be considered, with respect to different aircraft platforms and missions. Particular attention will be given to the ability of developing efficient flight condition recognition systems, which can follow the aircraft operation over its entire life and map its utilization profile, as well as efficient solutions for the predictive maintenance of the rotating and propulsion subsystems, which are the most critical as far as safety is concerned.
Methods and techniques that will be developed and used to carry out the research	As is clear from the above discussion, the design of effective physics-informed methods for predictive maintenance in aeronautical applications requires a multidisciplinary approach, as only a context-informed design of advanced learning-based methods can enable the desired results. Thus, the research will aim to devise machine learning approaches that will inform the data-analysis with physics- and context-based insights, to make the machine learning (ML) results explainable and interpretable, enabling links

	with the domain experts and strong cross-fertilization of knowledge. In particular, to leverage the combination of existing industrial knowledge and the availability of flight data (and possibly data from test-benches and/or simulators), we aim at developing the ensemble experts with a specific attention to Bayesian learning networks. The Bayesian framework, in fact, is centered on connecting prior knowledge with the explanation of the system evolution within a causal framework. The consideration of this approach could provide a very interesting opportunity to build effective black-box models that can encompass and value the (possibly also physics-based) prior knowledge on the system, and adapt to its dynamic modifications.
Educational objectives	The candidate will have a unique opportunity of working in a multidisciplinary team, made by experts of control theory, dynamic decision making, machine learning and aerospace applications, needed to address the challenging and timely research topic presented above. This entails a growth path for the candidate that will make her/him acquire different competencies ¿ mainly technical and technological in the disciplines mentioned in the methodology description, but also considering the industrial nature of the considered problem, which is key to designing effective and pratical solutions. The research outputs will target publishing on international conferences and journals, with specific attention to all the venues of interest for the different facets of the research.
Job opportunities	Expertise in data analysis, machine-learning and dynamic decision making certainly makes all DADS PhD candidates very appealing for a wide range of high-end positions. These range from the more data-science oriented, to those more related to the industrial field of application of this specific research. Thus, our candidates might apply for positions in private companies, public or private research centers or in academia.

Composition of the research group	2 Full Professors 3 Associated Professors 5 Assistant Professors 20 PhD Students
Name of the research directors	Mara Tanelli

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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

National Operational Program for Research and Innovation	
Company where the candidate will attend the stage (name and brief description)	Leonardo S.p.A. (settore: Aerospazio, Difesa, Sicurezza) https://www.leonardo.com/
By number of months at the company	6
Institution or company where the candidate will spend the period abroad (name and brief description)	
By number of months abroad	0

Additional information: educational activity, teaching assistantship, computer availability, desk availability, any other information

Impresa, presso cui si svolgerà l'attività esterna

- Nome: Leonardo S.p.A.
- Settore: Aerospazio, Difesa, Sicurezza
- https://www.leonardo.com/
- Durata Periodo: 6 mesi
- Le attività previste da questo dottorato, in particolare, si concentrano sull¿adozione di nuove metodologie di apprendimento automatico ¿physics-informed¿ nell¿ambito dello sviluppo di sistemi di manutenzione predittiva e di monitoraggio dello stato di salute e di utilizzo di sistemi in ambito aeronautico. In particolare, si intende impiegate tecniche di monitoraggio che

consentano, ove necessario, la detection in tempo reale di anomalie e di guasti incipienti, che possano aumentare la sicurezza attiva di alcuni sistemi safety critical nel contesto industriale di riferimento, e di rendere più efficiente e sostenibile la fase di manutenzione degli stessi.

Attinenza alla tematiche, alle missioni/componenti prescelte del bando PNRR v. D.M. 352, art.6

- L¿attività di ricerca si colloca nell¿ambito della missione M1C2 - Digitalizzazione, innovazione e competitività nel sistema produttivo del PNRR, con particolare riguardo all¿azione finalizzata agli incentivi per la transizione digitale e per l¿adozione di tecnologie innovative e le competenze digitali da parte del settore private e del sostegno alle filiere e agli investimenti nel settore aerospaziale. Le attività previste da questo dottorato, in particolare, si concentrano sull¿adozione di nuove metodologie di apprendimento automatico ¿physics-informed¿ nell¿ambito dello sviluppo di sistemi di manutenzione predittiva e di monitoraggio dello stato di salute e di utilizzo di sistemi in ambito aeronautico. In particolare, si intende impiegate tecniche di monitoraggio che consentano, ove necessario, la detection in tempo reale di anomalie e di guasti incipienti, che possano aumentare la sicurezza attiva di alcuni sistemi safety critical nel contesto industriale di riferimento, e di rendere più efficiente e sostenibile la fase di manutenzione degli stessi.