POLITECNICO DI MILANO

PhD in INGEGNERIA AEROSPAZIALE / AEROSPACE ENGINEERING - 40th cycle

THEMATIC Research Field: ANOMALY DETECTION AND CHARACTERIZATION TECHNIQUES IN SATELLITE BEHAVIOUR

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	Over the past two decades, reliance on space infrastructure has grown significantly, elevating these systems to the status of critical assets. Satellites now play a vital role in providing global positioning, navigation, intelligence, and communication services, capabilities essential for both civil and military operations. These space assets face a range of threats, both accidental and deliberate, with the increasing variety and scale of these risks establishing space as a conflict domain on par with land, sea, and air. Consequently, there is a rising demand for robust military Space Situational Awareness (SSA) capabilities. Such capabilities enable states to monitor activities in space, execute precise missions, and ensure that military SSA data remains reliable and free from bias or manipulation. However, only a handful of countries have achieved a fully operational, comprehensive, and independent military SSA capability. The U.S. Department of Defense shares some space-related information with allies on a selective basis and with limited fidelity, but this approach creates dependencies and imposes constraints. At the industrial level, the European market for military SSA is fragmented, primarily national in focus, and reliant on non-European services or solutions. To fill this gap, it is necessary to develop a European infrastructure for management of military SSA data which is capable of detecting threats to critical space assets and that defines a guideline for the management and mitigation of such menaces. This PhD study aims at developing novel

	anomaly detection techniques that must be flexible enough to consider several pieces of information, describing the comprehensive status of the target, in terms of orbital and attitude dynamics. For this specific application signal processing techniques and machine learning are expected to prove crucial in designing effective methods that could translate the operator experience into a process as much automatic as possible, relieving them from the effort of continuously fine-tuning detection thresholds.
Methods and techniques that will be developed and used to carry out the research	This PhD thesis will focus on developing spacecraft anomaly detection and characterization techniques. After a deep study and investigation of the significant data that have to be included in the analysis, pre-processing steps will be taken to turn raw information into the optimal shape to highlight out-of-nominal behaviour and the design of the actual detection model will take place. The first phase will involve the analysis of the wide literature on anomaly detection methods, encompassing very diverse applications. Both classical statistical signal analysis methods will be investigated as well as machine learning, including both supervised (Sequential Neural Networks) and unsupervised learning techniques (Auto-encoders). Part of the survey will be devoted to thresholding, proving crucial when it comes to the anomaly detection sensitivity. Once a comprehensive overview of the field is obtained, the specific application, and corresponding data, will be the focus of the analysis. This step is expected to lead to a tailored pre-processing pipeline to optimize the features ingested by the developed models for improved detection purposes. An important aspect to consider is the noise level and uncertainty in the data on which anomalies are being identified. These sources of error should be retrieved from the available datasets and modelled as part of the nominal behaviour of the target. The training should include this aspect via loss function and at the same time the output anomaly score should take prediction confidence and uncertainty sources into account for a robust assessment. Once the selected pipeline is designed, an extensive testing campaign is foreseen to consolidate the results. Both synthetic and real nominal

	data can be used to start assessing the performance of the developed methods by realistically simulating anomalies. The following step is instead to test the same algorithms on real out-of-nominal data. A particular focus has to be devoted to processing time as well, as one key aspect to grant is responsiveness. In the final stages of the program, the research will delve into a first characterization of the anomaly event type. This task could be performed by analysing the affected parameters type and ranges or by remapping them to a different set of coordinates specifically highlighting a phenomenon (e.g., transforming shifts in orbital parameters to possible manoeuvres).
Educational objectives	The educational objectives of this PhD focus on developing a deep understanding of spacecraft dynamics and data to represent its evolution, encompassing the processing steps behind them. The candidate will gain a comprehensive knowledge of statistical methods for signal analysis and processing, both traditional and machine learning-based. Exploration of diverse neural network architectures, such as convolutional or recurrent neural networks, is also foreseen as part of the activity. A key aspect of the research path is also investigating the best way to apply unsupervised learning techniques for detection purposes. The focus of the PhD candidate's activity will be to find an optimal latent representation of the data, tailored to the specific kind of dataset and application. In this way, they will be able to cope with the typical lack of labelled anomalies in real-case scenarios, finding an effective workaround. A fundamental aspect of this PhD is its interdisciplinarity, blending space engineering with signal processing, data science and artificial intelligence. This integration enables the student to develop strategies that are both theoretically sound and practically applicable, ensuring they are well-equipped to design robust and responsive detection systems for spacecraft data. The program also nurtures advanced research capabilities, encouraging critical thinking, experimentation, and hypothesis testing to contribute impactful knowledge to the field. Additionally, the student will be guided to consider ethical and strategic dimensions

	of space defence technologies, preparing them to address global challenges responsibly. By the end of the program, they will be well-prepared to assume leadership roles in academia, industry, or governmental organizations, driving innovation in space systems engineering and contributing meaningfully to advancements in space situational awareness and spacecraft data science.
Job opportunities	The program is supported by funding from an EDF project and is conducted within the framework of an international consortium comprising multiple firms. This setup provides the candidate with valuable opportunities to collaborate with industry partners, gaining firsthand insight into the professional landscape they will enter upon graduation. The demand for skilled space data scientists is rapidly increasing within the industry, driven by a strong push from international agencies and companies toward data collection, organization, processing, and storage both before and during space operations. By the end of this program, the candidate will have fully developed the expertise and skills necessary to meet these growing needs, positioning them for a successful and impactful career in the field.
Composition of the research group	0 Full Professors 2 Associated Professors 3 Assistant Professors 16 PhD Students
Name of the research directors	Pierluigi Di Lizia

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
The PhD candidate will receive a desk, possibly through a hot-desking procedure, and a personal computer, if needed. Apart from the compulsory ones, the PhD candidate will have the opportunity to follow additional courses and receive economic support to attend summer schools and participate in conferences. There will be the possibility of paid teaching assistantship.