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AI FOR SATELLITE ANOMALY DETECTION: ON-GROUND OPERATIONAL FEEDBACK AND DEVELOPMENT OF ON-BOARD EXPERIMENTS

Abstract

Anomaly detection is a key element of space operations. Numerous monitoring methods, of varying degrees of complexity, have been developed to detect unusual behaviors in satellite telemetry. From a simple out-of-limit check to the monitoring of a spike in the data frequency domain, their outputs are being used to anticipate possible in-flight anomalies from the ground, or to engage automatic on-board reconfiguration actions to avoid failure propagations. Nevertheless, whether they are implemented on-ground or on-board, these "legacy" monitoring methods have demonstrated some limitations, especially with respect to anomalies with unexpected signatures that were not anticipated in the design phases.

After a state-of-the-art analysis and benchmarks to evaluate different Artificial Intelligence (AI) techniques to fill this gap, CNES has developed and tuned its own Machine Learning (ML) tool, based on a One-Class Support Vector Machine (OC-SVM) algorithm: NOSTRADAMUS. NOSTRADAMUS complements the already existing on-ground monitoring methods, as well as the expertise of spacecraft engineers, to improve the detection of atypical behaviors in satellite telemetry. With more than 6 years of operational use, NOSTRADAMUS has demonstrated its capability to detect new types of anomalies and is now being deployed on more and more CNES missions, including Earth Observation satellites and Mars instruments. Ongoing and future studies will continue to improve its performances and to extend its use to satellite constellations through the implementation of Transfer Learning (TL) solutions.

In parallel, CNES is working on a Space Experiment for Satellite Artificial intelligence Monitoring (SESAM) based on the NOSTRADAMUS algorithm to demonstrate the technical and operational feasibility of an AI to detect anomalies directly on-board a spacecraft. The interest of such applications lies in the possibility to interface with the FDIR and engage actions based on the algorithm outputs, as quickly as possible after the detected anomaly. Envisioned actions include satellite and equipment reconfigurations but also oversampling onboard acquisition of telemetry parameters for more observability on the

ground. A light version of the SESAM experiment is currently being tested on-board OPSSAT (ESA) and new versions are being developed to be implemented on AeroSat (CNES) in 2024.

This paper will describe briefly the high-level functioning of NOSTRADAMUS with a focus on its operational tuning. Lessons learned will be explored and the associated areas of improvement under CNES study will be synthetized. The SESAM experiment will also be presented, along with the OPSSAT first results and the current further developments for the AeroSat mission.