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LEVERAGING MACHINE LEARNING FOR ADVANCED FAILURE DETECTION IN SPACECRAFT ATTITUDE AND ORBIT CONTROL SUBSYSTEM

Abstract

Autonomous failure detection is an escalating necessity in the field of Attitude and Orbit Control Subsystem (AOCS) for spacecraft. The current approach to failure detection in the domain of spacecraft AOCS is increasingly facing limitations. The baseline process uses deterministic tables including several parameters coming from sensors, actuators and AOCS flight software. These parameters are constantly monitored employing fixed thresholds and confirmation times defined by the operator during the FDIR design phase. With a hierarchy approach, this tables try relegating failures to the lowest levels. However, due to the complexity of this subsystem, exceptional occurrences frequently bypass the intended hierarchical progression due to the deterministic design, compelling Ground operators to initiate time-consuming investigations into cause and troubleshooting, thus delaying the satellite's nominal operational resumption. This work proposes a novel approach grounded on Machine Learning (ML), with a focus on multivariate Recurrent Neural Networks (RNNs), to enhance the efficiency and reliability of on-board failure detection processes for the complete AOC Subsystem. The multivariate datasets, sourced from a flight-proven satellite simulator, encompass a high reliable emulation of the functioning of spacecraft, its sensors and actuators. The considered parameters used to train the ML algorithm involve the spacecraft attitude dynamics measured by sensors, control torque commanded by the AOCS flight software controller, and actuator performances delivering the requested torque (i.e. all signals available on-board). Moreover, the system is able to identify and distinguish different attitude variation depending on the satellite operative phase, in particular using information coming from the AOCS Operative Mode and Submode. Then, the peculiarity of the ML method lies in its ability to discern varying patterns of spacecraft dynamics concerning different AOCS operational phases. The proposed ML algorithm performance is compared with respect to the baseline FDIR approach in order to verify if this strategy possibly improve adaptability and prediction capabilities. A complete taxonomy of different anomalies has been produced: the multivariate testing dataset has been realized considering unexpected dynamics changes, or hardware failures of sensors and actuators. These synthetic anomalies enabled us to replicate scenarios that mirror real-world unpredictable exogenous phenomena or hardware malfunctioning, thus challenging the system's detecting capacity. The proposed solution aims to explore the possibility to improve autonomy, flexibility and predictive capabilities in AOCS failure detection.