IAF SPACE SYSTEMS SYMPOSIUM (D1)
D CATEGORY "INFRASTRUCTURE" - Extra Session (8)

Author: Ms. Rashika Sugganahalli Natesh Babu
'Space Dynamics Control and Systems Engineering' Research Group, Italy

Mr. Vishnuvardhan Shakthibala
'Space Dynamics Control and Systems Engineering' Research Group, Italy
Mr. Hemanth Hemanth
'Space Dynamics Control and Systems Engineering' Research Group, United Kingdom
Mr. Raktim Ghosh
'Space Dynamics Control and Systems Engineering' Research Group, Italy

AUTONOMOUS FAULT MANAGEMENT IN DISTRIBUTED SPACE SYSTEMS: A THREE-STEP FEEDBACK-LOOP APPROACH INTEGRATING MACHINE LEARNING

Abstract

The next decade in the space market is poised to witness a significant shift with the advent of higher autonomy in satellite operation. Many Space agencies and startups are focusing on integrating machine learning into satellite systems. The transition from monolithic satellites to distributed space systems (DSS), although driven by well-defined reasons, brings forth the complexity of coordinating and managing multiple satellites within the system. Addressing anomalies or faults in a single satellite without affecting the rest of the constellation or fractionated satellite systems is a crucial aspect in the context of model-based systems engineering. This is the right opportunity to study the DSS' system-level architecture development and autonomy in Fault Detection Isolation and Recovery by reducing the delays introduced by human intervention from ground control.

The three-step 'fetch-process-perform' feedback-loop approach implemented in our work is inspired by literature study. FDIR utilizes Model-Based Reasoning with abundant knowledge of subsystem-level and component-level design and behavior to perform diagnosis. The fetch is the step where the overall system-level information and synthetically produced telemetry data of the communication satellite is fed to the Machine Learning block. Process involves anomaly classification, training the data set and mapping with the accurate ML algorithm which gives an input to the last step 'Perform'. This consists of executing the decision taken by ML block and updating the system behavior back in the feedback loop.

The core focus of this paper is the Process step, where behavioral data and telemetry datasets are initially mined to identify abnormal data points. The selection of the appropriate data mining technique depends on the type of anomaly, categorized by system complexity, nature of anomalies, available computational resources, and interpretability of results. K-means clustering is used to cluster the data, followed by further classification. Logical Analysis of Data (LAD) emerges as the most promising algorithm after a comprehensive trade-off analysis among 11 Classification ML algorithms and 7 quantifying parameters. Anomalies are then filtered for detection, classified based on impact, causes, and temporal characteristics, prioritized chronologically, and mitigated using a two-class LAD approach. The outcome from the implementation of our methodologies on chosen communication satellite constellation scenarios showcase its capacity to identify anomalies and take corrective measures. It also illustrates how this framework can be adapted to address challenges inherent in DSS.