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DATA-DRIVEN FAULT DETECTION AND ISOLATION FOR SMALL SPACECRAFT

Abstract

The increasing numbers and complexity of small spacecraft and missions demands improved autonomy for fault detection, isolation, and recovery (FDIR). Traditional rule-based methods such as limit checking possess limited ability to perform onboard diagnosis, thus resulting in spacecraft dropping quickly into safe mode when problems occur. It is then up to operations staff to interpret telemetry and isolate the root cause, something that could prove overwhelming to operators of large constellations of small satellites.

Data-driven approaches based on data mining of telemetry have emerged out of the field of machine learning and provide more capable and informative ways of detecting faults. Meanwhile, static and dynamic Bayesian networks have become a popular formalism for combining diverse fault signals, system knowledge, and even past data to perform root cause diagnosis under uncertainty. These approaches also possess a level of computational efficiency that is appropriate for flight hardware.

Unfortunately, while data-driven techniques to fault detection enjoy important advantages over traditional methods, many of these algorithms are susceptible to a high rate of false positives. By incorporating multiple data-driven fault detectors as nodes in a dynamic Bayesian network (DBN), we show that the number of false positives can be reduced and root causes for faults more robustly determined. We consider the specific application to the attitude determination and control subsystem (ADCS) of a generic small satellite. Due to the complexity of this subsystem, it is often the subject of anomalies. A six degree of freedom spacecraft simulator has been developed to provide a realistic model of ADCS for small satellites, including sensors, attitude and orbit dynamics, actuators, power generation, and flight software. The simulator also includes the ability to inject simulated faults into any of the aforementioned components. The performance of several common data-driven fault detection methods such as long short-term memory and k-Nearest Neighbors is assessed using this simulator, as is the ability of the DBN to correctly isolate root causes and reject false positives.

Data-driven approaches to FDIR are particularly attractive for small satellites because large constellations provide a wealth of telemetry data for training capable fault detectors. The demonstration of data-driven fault detection and subsequent isolation with Bayesian networks on a high fidelity spacecraft simulator therefore advances the potential to apply these methods to streamline operations for small satellite constellations.