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ROBUST FAULT DETECTION AND ISOLATION ALGORITHMS FOR TVC SYSTEMS: AN EXPERIMENTAL TEST

Abstract

Programs for achieving commercial rocket reusability are arising across the globe, including European initiatives like CALLISTO, Themis, Miura 5, and Ariane Next. Central to rocket reliability are effective onboard Fault Detection and Isolation (FDI) mechanisms, particularly for Thrust Vector Control (TVC) systems relying on Electro-Mechanical Actuators (EMAs). The nonlinear dynamics of EMAs, mainly due to the electric motor and mechanical transmission and the presence of vehicle-induced loads, pose significant FDI challenges. The local TVC control system requires several sensor measurements, usually including an LVDT stroke displacement sensors, electric motor encoders, and current sensors, to meet operational and performance standards. This work focuses on detecting faults in these sensors to maintain an adequate TVC closed-loop performance and ensure an accurate nozzle deflection tracking. To this goal, a model-based FDI system based on the nullspace approach is employed as a baseline and successively optimized. A similar workflow has already been applied and consolidated in the aircraft industry: thus, this research showcases its adaptability and potential. Noticeably, model-based methods allow addressing a larger class of faults simultaneously by comparing measurements against model predictions and generate residual signals to identify faults against set thresholds.

This paper details the problem formulation, the modeling of EMA-based TVC systems including the mechanical loads from the rocket nozzle, and the FDI synthesis. It further discusses how the presence of certain sensors influences fault detectability and isolability. The initial filter solution enables the perfect decoupling of control variables and vehicle-induced loads from the fault residuals, while, in a successive step, the filter is robustified to account for model uncertainties.

The second part focuses on the dedicated Hardware-In-the-Loop (HIL) setup used to test the FDI system. The TVC benchmarking assembly consists of a nozzle and two orthogonal EMAs. A motor drive allows for current and velocity closed-loop tracking, whereas an external microcontroller implements the position controller and the FDI digital filters while logging the relevant quantities. All the employed hardware components are detailed throughout the paper. More importantly, the precautions to implement the filters on onboard computers are also highlighted, including remarks regarding the computational aspects. The experimental results confirm the FDI filter's ability to maintain acceptable residuals in fault-free conditions and accurately identify faults through artificially-altered sensor readings, effectively decoupling vehicle loads from residuals for accurate fault detection. This finally underscores the potential of the proposed FDI system in enhancing the reliability and safety of reusable launch vehicles.