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Title

Sensor fault detection and isolation for electro-mechanical actuators in a reusable launch vehicle TVC system

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Abstract

In the current European context, Reusable Launch Vehicles (RLVs) development is gaining a high momentum. To bring reliability to sufficient standards, performing Fault Detection and Isolation (FDI) mechanisms are essential to enable the onboard software to notice an ongoing performance degradation. This paper introduces a model-based FDI approach for an RLV Thrust Vector Control (TVC) system operated by Electro-Mechanical Actuators (EMAs). We focus on the sensors required for the EMA embedded control system.

EMAs are becoming increasingly relevant in the aerospace sector, mainly because they contain a large fraction of the overall hardware mass and space. Their applicability has been proven over the last decade, for instance, with the European VEGA launch vehicle [1]. An EMA is composed by the power drive electronics, an electrical motor, and a mechanical power transmission stage to convert the rotational motion into a linear one. Several measurements are required for correct operation and to comply with damping and response speed requirements, thus a LVDT stroke displacement sensor, a motor angular rate sensor and a current sensor are normally included.

Faults affecting these devices must be detected and counteracted. The 'hardware redundancy' concept, mostly adopted by industry, compares duplicative signals generated by various, often identical, sensing units; for RLVs this is unfavorable because additional hardware causes an undesired increase in mass, space, costs and, more generally, does not guarantee sufficient information on the type of ongoing fault. This justifies the use of model-based FDI methods, that generate a residual signal as difference between measurements and the predictions of adequate mathematical models. These residuals can then be used to establish if a fault has occurred when compared to suitable thresholds.

In this work, one of the most consolidated strategies for FDI is considered and applied for the first time to an EMA-based TVC system. It employs the nullspace approach proposed by Varga [2]–[5] to detect and isolate additive faults affecting the mentioned sensors. The main advantage of the method is that, by using linear synthesis models in LTI or LPV form [6]–[8], it enables the direct decoupling of both disturbances and inputs from the residuals, and provides linear residual generators of minimal order, reducing the implementation costs on the final hardware; additionally, uncertainties can also be effectively accounted for. Numerically stable algorithms are used to determine the left nullspace basis of a rational transfer matrix and then synthesize the residual generators.

The paper starts with a detailed formulation of the problem and the whole EMA-based TVC system modelling, including the mechanical load exerted by the rocket engine. Thereafter the FDI synthesis framework is introduced and the application of the nullspace-based synthesis strategy is thoroughly described, including considerations about

isolateability of the faults. The residual generators' performance is then assessed in fault-free and faulty scenarios. Lastly, the proposed solution capabilities are benchmarked at the example of an RLV mission scenario using a high-fidelity TVC physical model implemented in the Modelica modeling language. This choice allows a realistic fault injection and propagation directly at component level.

References

[1] C. Carnevale and P. Resta, “Vega Electromechanical Thrust Vector Control Development,” in *43rd AIAA/ASME/SAE/ASEE Joint Propulsion Conference Exhibit*, Cincinnati, OH, Jul. 2007. doi: 10.2514/6.2007-5812.

[2] A. Varga, “The nullspace method - a unifying paradigm to fault detection,” in *Proceedings of the 48h IEEE Conference on Decision and Control (CDC) held jointly with 2009 28th Chinese Control Conference*, Dec. 2009, pp. 6964–6969. doi: 10.1109/CDC.2009.5400458.

[3] A. Varga, “New computational paradigms in solving fault detection and isolation problems,” *IFAC Proc. Vol.*, vol. 45, no. 20, pp. 983–998, Jan. 2012, doi: 10.3182/20120829-3-MX-2028.00299.

[4] A. Varga, *Solving Fault Diagnosis Problems*, vol. 84. Cham: Springer International Publishing, 2017. doi: 10.1007/978-3-319-51559-5.

[5] D. Ossmann, H.-D. Joos, and P. Goupil, “Enhanced Sensor Monitoring to Maintain Optimal Aircraft Handling in Case of Faults,” *J. Guid. Control Dyn.*, vol. 40, no. 12, pp. 3127–3137, 2017, doi: 10.2514/1.G002341.

[6] A. Varga and D. Ossmann, “LPV model-based robust diagnosis of flight actuator faults,” *Control Eng. Pract.*, vol. 31, pp. 135–147, Oct. 2014, doi: 10.1016/j.conengprac.2013.11.004.

[7] S. Hecker, A. Varga, and D. Ossmann, “Diagnosis of actuator faults using LPV-gain scheduling techniques,” in *AIAA Guidance, Navigation, and Control Conference*, Portland, Oregon, Aug. 2011. doi: 10.2514/6.2011-6680.

[8] D. Ossmann and F. L. J. van der Linden, “Advanced sensor fault detection and isolation for electro-mechanical flight actuators,” in *2015 NASA/ESA Conference on Adaptive Hardware and Systems (AHS)*, Montreal, QC, Jun. 2015, pp. 1–8. doi: 10.1109/AHS.2015.7231162.