Design and development of algorithms and technologies applied to prognostics of aerospace systems

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Summary

Prognostics and Health Management (PHM) is an emerging field that aims to determine the Remaining Useful Life (RUL) of systems, in order to plan in advance the required maintenance interventions. Currently, components are replaced at the end of their design life, which is the result of a tradeoff between maintenance costs and reliability and availability requirements. With a PHM approach, it will be possible to schedule replacements accounting for the actual condition of the system, without decommissioning operable equipment or flying with worn components. In addition, prognostics performed in real-time may allow adapting the operational envelope of a vehicle adaptively, in order to increase the system life without jeopardizing the success of the mission.

Most approaches to failure prognosis available in literature require a significant computational burden, not suitable for real-time computations, and are characterized by a large uncertainty associated to the RUL prediction. This is due in part to the inherent unpredictability of the propagation rate of damages, which is influenced by several variables that cannot be controlled nor measured; another source of uncertainty lies in the errors associated with the fault detection processes.

This study addresses these limitations and provides a comprehensive computational framework for fast and reliable RUL prediction. Physics-based models of the system dynamics are combined with supervised and unsupervised machine learning to obtain surrogate representations of the equipment and allow for real-time evaluations. The method is tested on the RUL prediction task of an electromechanical actuator for aircraft flight controls. This is a challenging and representative case study as flight controls are complex subsystems of a vehicle, and involve the interaction between a number of heterogeneous disciplines, such as mechanics, electronics, fluid dynamics and control theory. Multiple fault modes can affect an actuator at the same time and influence each other, making the fault detection and RUL prediction tasks difficult. Highly detailed physics-based simulations are employed as a simulated test bench for the PHM algorithms. An experimental validation of the numerical models is provided by a physical electromechanical actuator test rig.

The entire proposed PHM process can be executed in real-time, dealing with the hardware constraints that are characteristic of on-board computations. Nevertheless, the proposed algorithm can learn a model of the damage evolution by assimilating online the observation of the instantaneous health status of the monitored system. As a result, the overall accuracy of the RUL prediction process is comparable to most approaches available in literature. The strength of the proposed methodology is its ability to predict the RUL in real-time, without requiring any prior knowledge about the physics of the phenomena affecting the actual propagation of faults, while at the same time retaining a suitable accuracy.

Additionally, innovative sensor technology is discussed as a promising candidate to collect some of the required input data for the prognostic process. Specifically, precise measurements of in-flight aerodynamic loads on the flight control actuators are required for on-board prognostics as they influence significantly the response of the flight control system. Often this information is not available as it cannot be measured reliably and conveniently with traditional technologies. Optical sensors are considered for the task as they permit to achieve high frequency, accurate measurements with a good spatial resolution and a minimally invasive installation. These sensors were assessed experimentally and will provide additional, useful information for the health monitoring algorithms without prohibitive increases in weight, complexity and costs of the aerospace vehicle.