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Development of optical sensors and diagnostics algorithms for aerospace systems

By

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A steady push towards more feature-rich, integrated and thus complex systems has been observed, in recent years, in the aerospace sector. This trend can be explained given the many advantages presented by a *smart system*, i. e. a system capable of autonomously performing corrective or even predictive actions when particular conditions occur. In a broader sense, aerospace systems can be generally thought as smart given the very high safety and reliability standards imposed, which implies redundancies and active monitoring of the system status; mitigating strategies (e.g. passive or cold redundancy) are implemented should a critical event occur. However, traditional, cold redundancy based methods have drawbacks, namely reliability reduction, sub-optimal system utilization, weight and cost increase.

The logical evolution is the switch from a corrective to a predictive approach, i.e. performing a mitigating action before a critical event occurs. In this context, the Prognostics and Health Management (PHM) framework is very useful. In brief, the objective of PHM is to give an accurate estimation of the ’health status’ of a system defined in term of prognostics indicators. Said indicators are variable and application-dependent, but the commonality is the embedding of status information and sensitivity to one or more faults that can occur in the system. The concept of Remaining Useful Life (RUL) is important, as it is the main parameter that correlates the actual system health status and maintenance events.

In fact, using a PHM approach, Condition Based Maintenance (CBM) can be achieved. While traditional, preventive maintenance is generally a result of safe-life philosophy, i.e. components are replaced after a predetermined amount of time, independently of the health status, a CBM approach schedules maintenance events when necessary by monitoring the condition of components or systems.

To perform health status monitoring, two approaches are generally used. The first approach is model-based, where either a physical model or a digital twin is used. The other approach is data-driven, where machine learning methods are applied to data generated by the system to infer relations.

Another technology steadily gaining adoption is optical fiber sensors, such as Fiber Bragg Gratings (FBGs), which offers several advantages over traditional, electronic based sensors. FBGs can primarily sense strain by alteration of the reflected Bragg wavelength; this measure can be correlated with other physical quantities when using appropriate fiber coating. Many different FBG-based sensors exist and are used to measure humidity, temperature, pressure, gas and pollutant concentrations and more.

This work aims at integrating FBGs in a diagnostics framework which uses an electromechanic actuator (EMA) as a real test-case. The strain measures measured using FBGs will be used in a machine-learning algorithm to estimate the health status of the system. Additionally, a parallel evaluation can be made for other faults such as electrical partial shorts and static eccentricity. Additionally, several FBG-based sensor designs will be proposed; these sensors could be used as sources of information in the prognostic process. Finally, several reduced order model with varying levels of fidelity will be presented given their usefulness in reducing the simulations computational time for use cases such as real-time monitoring.

In this sense, several fault detection and identification algorithms have been presented, with capabilities ranging from mechanical faults, to partial electric shorts to static eccentricity. All of this models leverages machine learning tools and have been trained using data provided by numerical models of a real system. Preliminary results are good but as always validation on data from real systems is mandatory before deployment on active systems.

On this topic, different MATLAB-Simulink numerical models, with varying levels of fidelity, have been developed for this task. High fidelity models can be used to generate realistic, synthetic data when either data are not available or it is too complex or hard to obtain large amount of data relative to a particular fault with a specific magnitude. The main advantage of this approach is the accuracy of the fault modeling which can be tailored to specific values. Albeit some testing has been performed on validating the model on a real system, additional testing is needed to evaluate the accuracy of the fault modeling included in the models, and to supplement the implementation proposed.

Finally, several FBG-based optical sensors have been proposed, for vibrations, temperature and mechanical strain. These preliminary designs will need further testing to optimize the design in terms of accuracy and robustness. The final objective is to integrate measure obtained by said sensors in a more complete FDI scheme, and possibly further in a prognostics tool that is capable of also evaluating the remaining useful life of components or of the whole system.