Advanced Diagnostic for Fly-By-Wire Flight Control Systems

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June 7, 2021

The Fly-By-Wire technology (FBW) is adopted as primary flight control actuation system for both legacy aircraft and new-generation ones. In particular, several studies have been conducted over the failure modes of these systems, that are considered both safety critical from a technical perspective and a profitable subject of investigation for all the Maintenance Repair and Overhaul (MRO) companies in aviation industry. The actual testing procedures are typically time-consuming and they need to be upgraded in line with the new Industry 4.0 indications, such as automation and data-collection.

In this framework, this thesis reports the results that have been obtained during a three-years research project in collaboration with Lufthansa Technik, with the final goal to automate and improve the diagnostic accuracy with innovative Machine Learning techniques. The development of a new testing protocol has required the collection of results from different research activities.

The first fundamental step has been the design and implementation of an autonomous testing through a series of concatenated modular signals. These signals include a set of predefined shapes that can be adapted per different types of tested servo-commands, with the goal to collect a set of Health-Features (HF) per each critical unit sub-component. Each signal shape has been designed in order to cover most of the traditional prescribed tests in order to cut the testing time of more than one third.

The collected signals are then automatically stored and analysed by an autonomous feature-extraction algorithm based on signal processing techniques. This software represents the testing protocol core, since it has been tuned in order to extract all the possible information from the measurements that can be used to track any anomalous behaviour of the unit sub-components. During the experimental campaign in the LHT shops in Hamburg, several set of measurements have been collected and analysed in order to refine and validate the HFs extraction techniques from the signals. Furthermore, in order to improve the actual data collection process, an automatic data-collection framework has been built to store correctly all the measurement channels and test results from the experimental campaign. In particular, the extracted HFs from the measured channels are systematically collected in a unique final report that has the double goals of firstly informing the technician about the tested unit health status, and secondly building-up a database of test reports.

All the information from these reports are in fact automatically collected in a unique database which lay the foundation for both any statistical analysis and the training and testing operation for the Diagnostic Module algorithm. This last part of the testing protocol is based on a Supervised Machine Learning algorithm which has to automatically recognize the health status of each unit part from the collected HFs. Firstly, per three target components, a sub-set of optimal HFs have been extracted according to their statistical relevance. Afterwards, these subset of data have been used to tune the algorithms hyperparameter over a specific training set. In this way, the algorithms have been trained to correctly associate the assigned failure labels, and define multi-dimensional decision boundaries for any further classification of new incoming data. The classification performance are then compared by defining specific metrics that can be calculated according to wrongly and correctly recognized classes.

The main achievements of the dissertation can be summarized as follows:

- Definition of an autonomous and adaptable testing procedure for all the analysed project use-cases, e.g. the A320 FBW control systems. Compared with the traditional method, this new protocol reduces of one third the testing time: from 90 to maximum 30 minutes for the most complex unit-under-test. These reference time are actually shorter if other units are considered (for example, the maximum Spoiler testing time is 16 minutes), and they can be improved considering a new test-rig configuration with digital pressure and flow-meter sensors.

- The first core part of the testing protocol is characterized by a sequence of modular signals that have been modularly designed through a Matlab code. This software allows to select the kind of unit-under-test and export the whole configuration file for the measurement-system to automatically set the correct measurement channels. This testing procedure has been firstly designed for a prototyping test-bench, and lately re-adapted, tested and validated in the LHT shops facilities after an extensive measurement campaign. During this phase, all the requirements from the technicians and the technical constraints have been considered to adapt the testing software for the new sequence of signals.

- All the collected measurements have been automatically stored and analysed for the extraction of a predifined set of Health-Features. Each set of HFs is peculiar per each kind of FBW actuator, and it allows to have a complete picture of the health status of the tested unit. This set of parameters includes both most of the traditional checks, prescribed by the maintenance-manual (more than 75%), and new additional ones that are tailored per each unit sub-component. All these features are automatically extracted at the end of each test, based on signal processing techniques, and collected in unique test-reports. These documents are printed and stored in two versions: the first one is then used for data-analysis purposes, while the second one is directly delivered to the test-operator. In this latter version, an extensive troubleshooting instructions list is reported.

- The test-reports are automatically stored in a unique database which collects both the test information, but also additional insights about its repairs and exchanged parts. This data-collection has been developed through a series of Python scripts which automatically collects and combine all the results from the test-reports. These resulting dataframe lays the foundations for the development of a Diagnostic Module based on Machine-Learning techniques.

- The last important achievement regards the implementation of a Diagnostic Module based on Supervised Machine Learning techniques for failure recognition by the collected Health-Features in the test reports. This topic entails the study and comparison of different classification algorithms and relative feature-selection and dimensionality reduction methods. In the end, four different candidates algorithms have been compared in terms of specific performance metrics.