Merging machine learning and physics based approaches for designing a digital twin - application to an electromechanical actuator for reusable launchers

Supervising team

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Context of the work

Europe is developing reusable launchers in the framework of different projects. To ensure launcher reliability, it is necessary to evaluate the state of health of the different parts of the launcher once it comes back to earth without dismantling it. The present project addresses the development of a systematic methodology to achieve this goal for the electromechanical actuators (EMAs) used to orientate the nozzle and the fins notably.

A model-based simulator of an electromechanical actuator (EMA) is currently used to complement the available experimental dataset (mostly in healthy operation) with synthetic data (of both healthy and faulty operating modes). There is however a mismatch between experimental data and synthetic data (i.e. generated by the simulator). Indeed, the simulator is based on simplified models of healthy operation and faults.

Objective of the thesis

The goal is to improve the current model-based simulator to generate more realistic data (ultimately to better train the health monitoring system).

The main idea of the project is to achieve this goal by **integrating a data-driven approach to the current simulator**[1] in order to generate more realistic synthetic data (i.e. more similar to the limited experimental dataset we currently have and ideally to future experimental data). This way, future experimental data on natural degradation, defects and parameter variations (due to production variability, temperature change, etc.) could be exploited. The data-driven approach could for example be based on an **adversarial machine learning approach** [2], and on **neural networks while enforcing adequate closed-loop performance** [3].

The core challenges of the project lie in the limited available experimental dataset and in mitigating the impact of the data-driven approach. The latter point is essential for aerospace applications. Indeed the data-driven approach must not completely alter the physics-based models as the simulator must still be based on physics for ensuring explainability. This stems from the need for certification of the approach, which means that interpretability of how the method operates is required.

Work to be done

The student should

1. perform a bibliographic search on data-driven techniques for synthetic data generation, ideally for hybrid digital twins (i.e. digital twins based on both physics and experimental data).

2. study the EMA models in healthy and faulty states and get acquainted with the current simulator in MATLAB/Simulink

3. process the experimental measurements that will be provided to her/him in order to determine the most relevant features and/or identify parameters to update and relevant constraints

4. compare the most promising data-driven approach for this application in terms of performance and ease of updating once new data are available.

References :

[1] Massager, Louise, and Michel Kinnaert. "Modelling of electromechanical actuators in reusable launchers for health monitoring purposes." Internal report, 2024.

[2] Goodfellow, Ian J., et al. "Generative adversarial nets." Advances in neural information processing systems 27 (2014).

[3] Banderchuk, Ana, Daniel Coutinho, and Eduardo Camponogara. "Combining robust control and machine learning for uncertain nonlinear systems subject to persistent disturbances." *2023 62nd IEEE Conference on Decision and Control (CDC)*. IEEE, 2023.