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Real-time monitoring of evolutive structural damage from advanced sensing and simulation

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Abstract

In a digital world with the expansion of connected systems, a still open question is to design smart and autonomous mechanical structures able to perform online control of their health and take anticipated actions during service before downtime of failure occur. This is a critical need in several areas such as transport of energy, for more reliability but also more performance and durability of the employed structures (aircrafts, wind turbines, bridges. . .). Implementing such an advanced structural health monitoring (SHM) technology would permit optimized maintenance and capability to operate in degraded mode, managing the decrease of loading capabilities by adapting the operating plan.

Tracking structural damage and predicting its evolution has been a perpetual engineering issue during the last decades. It was the topic of intensive research works, with both experimental and numerical advances. On the one hand, on-board sensing techniques nowadays permit accurate in situ measurements on displacement or strain fields and thus provide very rich experimental information on the internal damage state of materials (e.g. see the recent review [1] on distributed optic fiber sensing). On the other hand, sophisticated physics-based tools now permit to simulate damage phenomena with high-fidelity and give a relevant virtual image of the material state [2].

The scientific bottleneck for going from smart materials to smart structures is in the monitoring of large complex engineering systems. A shortcoming of data science alone is in the management and interpretation of sensor information with large noisy data sets, and in the prediction of the structural behavior involving localized multiscale and highly non-linear damage phenomena. Moreover, from complex physics-based simulations alone, it is difficult to perform safe command within a changing environment and with real-time requirements in order to be reactive and avoid instabilities faced to damage evolutions.

In this context, and in order to cross the gap, an ERC project called DREAM-ON started in 2021 [3], in which the innovative concept is a synergistic dialog between advanced structural sensing (from embedded optic fibres) and command (from the structure actuators) on the one hand, and the most powerful modeling and simulation tools of computational mechanics on the other hand. This dynamical connection between the mechanical structure in service and an on-board physics-guided simulator, seen as a real-time feedback loop (Figure 1), aims at making benefit of all available knowledge, from

rich data and high-fidelity simulation, and to exploit the best of each to perform early damage detection, precise diagnosis, and appropriate decision-making. It is such that (i) the physics-based model is continuously updated and enriched from in situ observations which are assimilated on-the-fly; (ii) damage diagnosis and predictive command are performed from the simulation in order to drive the system accordingly. This refers to the Dynamic Data Driven Application Systems framework (in short DDDAS) which is a visionary paradigm that constitutes one of the most challenging applications of simulation-based engineering sciences [4]. The DDDAS concept combining data and physics-based models is not new, but achieving a manageable feedback loop for large-scale structures, with highly nonlinear models, numerous data, and various uncertainty sources, entails major research challenges to accommodate real-time, robustness, but also portability issues. The objective of the DREAM-ON project is to develop, implement, and test a light digital platform that combines all these features.

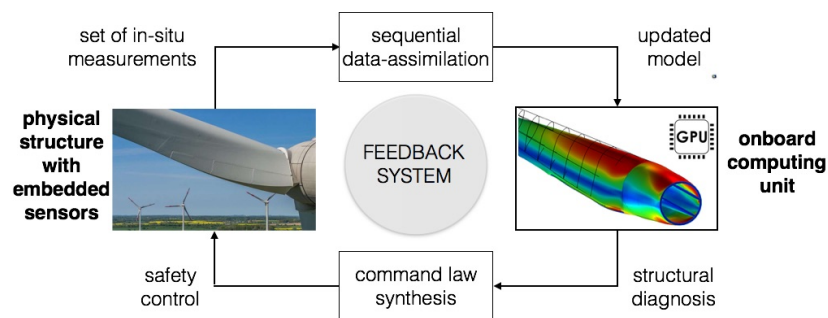


Figure 1: DDDAS concept applied to SHM.

The methodology which is followed in the project is cross-disciplinary, mobilizing skills embracing experimental mechanics, data science, mathematical modelling and simulation, applied mathematics, and computer science. In the presentation, we will show some first advances of the project [5, 6], as well as other recent works of the team on the monitoring of evolutive mechanical systems [7, 8, 9, 10].

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