Physics-Based Digital Twinning for Structural Health Monitoring

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The idea of building a digital replica of a physical platform to optimize in near real-time its operation and/or life cycle management – or more specifically, to perform its structural health monitoring – is not new. It has been the focus of many research efforts during the mid 1990s and early 2000s, particularly in the AIAA and GARTEUR communities, where the idea was intimately linked to the fields of finite element (FE) model updating and damage detection. In those days however, a digital replica was primarily limited to a computational model (e.g., a FE model) – which was recently rebranded as a digital twin prototype (DTP); and model updating was rarely connected to the field of uncertainty quantification (UQ) and performed predominantly using deterministic approaches. Today, the concept of a digital replica has evolved to include the digital twin instance (DTI) – that is, the digital twin of an individual instance of a platform, after it has been manufactured and deployed; and the digital twin aggregate (DTA), which is an aggregation of DTIs that allows for a larger set of data to be collected and processed for interrogation about the physical product. Hence, both DTI and DTA concepts differ from the older DTP concept in their emphasis on data and particularly sensor data. Preliminary forms of such digital twins are often described as the result of the integration of data analytics with the model-based prediction of a few, scalar, quantities of interest (QoIs). This lecture however will first question whether a few QoIs can always be identified to represent the critical state of a newly deployed physical platform in view of monitoring its structural health. Next, it will present a more robust approach for realizing DTIs for structural health monitoring that is based on adaptable, stochastic, low-dimensional but high-fidelity computational models grounded in physics. The proposed approach features novel mathematical ideas for integrating model-form UQ with probabilistic reasoning, projection-based model order reduction, and machine learning. It constructs stochastic, physics-based computational models that self-adapt using information extracted from sensor data; operate in real time; and can be exploited to uncover operational anomalies, perform structural health monitoring, and thus preventive rather than scheduled maintenance. Finally, the lecture will demonstrate the potential of the proposed approach for such applications by illustrating it for a condition-based maintenance problem pertaining to a fighter aircraft jet.