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Damage Identification on Thin-Walled Structures Using the inverse Finite Element Method and Data-Driven Approaches

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ABSTRACT

Structural health monitoring (SHM) refers to the process of tackling damage identification by observing a structure over time, measuring its response through dedicated sensors, extracting damage-sensitive features, and analyzing them to infer structural integrity. Driven by its life-safety and economic impact across different sectors, SHM has motivated intensive research into its enabling strategies.

The SHM inverse task, i.e., inferring structural integrity from in-situ sensor data, is commonly addressed through two complementary paradigms: data-driven and model-based. In data-driven SHM, damage is inferred directly from measurements using statistical and machine-learning tools; in model-based SHM, structural integrity is assessed by relying on physics-based or mathematical models to predict the expected structural response and by interpreting deviations between model predictions and measured data as indicators of potential damage.

Among model-based techniques, the inverse Finite Element Method (iFEM) has gathered significant attention because of its capability to reconstruct, in real time, the full-field displacements and strains of a structure from onboard strain sensor data without requiring knowledge of the external loads or the structure's material. Despite the extensive iFEM literature and the growing interest in data-driven approaches, however, systematic couplings between these strategies remain limited.

To address this gap, this work proposes a hybrid SHM framework which is demonstrated on a thin-walled, built-up aerospace structure. Full-field displacements and strains reconstruction is performed via iFEM, and sensor number and accessibility constraints are mitigated by leveraging the newly developed single-sensor-based (SSB) iFEM formulation, which enables accurate reconstructions with sensors deployed in a single-sided configuration.

The damage identification problem is then tackled in two stages: damage detection via novelty detection on iFEM-derived features, and damage assessment via neural networks trained to map these features to damage parameters. Different solutions are explored at each stage, outlining the potential avenues paved by the combination of iFEM with data-driven methods.

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