Doctoral Dissertation
Doctoral Program in Aerospace Engineering (37.th cycle)

On the development of a population-based SHM strategy for aerospace structures

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Summary

The effectiveness of data-driven Structural Health Monitoring (SHM) techniques for aerospace structures is often constrained by the challenge of data scarcity. These algorithms necessitate the availability of the dynamic response data from undamaged and damaged conditions, coupled with the assumption that the training and test datasets originate from the same domain. The population-based approach to SHM (PBSHM) addresses this limitation by facilitating knowledge transfer on damage states across a population of structures through transfer-learning methods, with a particular emphasis on domain adaptation. However, meaningful inferences from such data-sharing are only feasible when the structures and associated datasets exhibit sufficient similarity in their topology and attributes. Consequently, the PBSHM framework consists of two primary phases: the similarity assessment and the exploration of effective transfer learning strategies. Furthermore, it is crucial to understand the interdependence of these phases. Structural attributes may impact PBSHM performance, particularly within heterogeneous populations, yet their influence on the similarity metrics and knowledge-transfer outcomes remains underexplored.

This Thesis explores the development of a PBSHM strategy for a heterogeneous population of aerospace structures, proposing novel techniques to tackle the influence of structural attributes on PBSHM outcomes, thereby enhancing both core phases of the PBSHM framework. The key contributions of the current study are presented as follows.

Similarity Assessment. This study introduces two innovative strategies for estimating attribute effects on distance metrics. Various methodologies for similarity assessment are explored, starting from the initially proposed techniques that focus exclusively on topology. Hence, an approach based on Graph Matching Networks (GMNs) is proposed to integrate attributes into the distance metrics. Subsequently, a method based on weighted Euclidean distances is developed to maximise the correlation between the similarity values and transfer learning performance to improve predictive accuracy.

Knowledge sharing approaches and experimental validation. This Thesis presents different knowledge-sharing approaches, encompassing the Transfer Component Analysis, Statistic Alignment, and Joint Distribution Adaptation, employed to enhance damage identification in a population of structures. These approaches were experimentally tested and validated through an experimental campaign involving a heterogeneous population of laboratory-scale aircraft. The campaign included testing under varying conditions to assess the effectiveness of the proposed methods across different structural and operational scenarios.

Integration of data from different sources in PBSHM. Handling data from diverse sources is paramount in PBSHM to achieve accurate results. Therefore, the present study proposes a method based on the inverse Finite Element Method (iFEM) to extract the dynamic features from strain data and integrates this tool into the PBSHM framework, enhancing knowledge transfer by harmonising fibre-optic strain measurements to vibration-based features and providing reliable source data to inform diagnostics on the aircraft population, tested using three different sensor setups.