Data-driven Dynamic Structural Assessment from Sparse Sensor Data

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Abstract

Modern structural health monitoring combines sensor measurements and automated reasoning techniques to support and enable real-time decision processes [1]. In the context of future aircraft design, both these components embody relevant challenges. On one hand, cost and weight of sensing equipment limits the number, quality and type of sensors available on-board, requiring effective sensor placement strategies as well as efficient techniques to extract information from sparse data. On the other hand, efficient computational strategies for the structural assessment must be compatible with the limited resources available on board, yet they must process data sufficient rapidly to support decision-making.

In previous work we proposed a data-driven, adaptive methodology to support real-time structural assessment and decision-making [2]. The strategy is based on an offline/online approach: offline we create a set of surrogate models that are used online to map dynamically from measured data to vehicle capabilities. Our computational procedure combines empirical localization strategies from machine learning (Self-Organizing Maps - SOM) together with reduced-order modelling techniques (Proper Orthogonal Decomposition - POD). Specifically, our online rapid mapping is based on four steps: (i) reconstruction of the POD coefficients of measured quantities from sparse sensor data, (ii) classification of the reconstructed coefficients into the closest SOM subdomain, (iii) approximation of the POD coefficients of capability quantities using local models, and (iv) final capability estimate using POD including the approximated coefficients. The research focuses on the particular case of the structural integrity of a wing panel for an unmanned aerial vehicle that undergoes different damage conditions.

This work considers our specific methodology and analyzes its sensitivity to quantity and quality of sensor measurements. In particular, we explore different levels of sparsity in measured data and reconstructed measurement POD coefficients. Accuracy and runtime are assessed for each online step to investigate the influence of the varied parameters on the procedure's performance for a spectrum of damage cases. Our studies reveal the existence of a saturation level beyond which adding sensors does not significantly improve the accuracy of the final capability estimate. For our specific structural application, the saturation occurs approximately for online sensed locations covering 20% of the grid-points and yields a normalized root mean square error in capability estimate lower than 1.5%. Further results include the possibility to achieve estimation errors lower than 6% by sensing only 5% of the original grid points and processing the measured data in approximately 1.1ms.

References

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