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Dimensionality Reduction in Modal Analysis for Structural Health Monitoring

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Abstract : Autonomous structural health monitoring (SHM) of many structures and bridges became a topic of paramount importance for maintenance purposes and safety reasons. This paper proposes a set of machine learning (ML) tools to perform automatic feature selection and detection of anomalies in a bridge from vibrational data and compare different feature extraction schemes to increase the accuracy and reduce the amount of data collected. As a case study, the Z-24 bridge is considered because of the extensive database of accelerometric data in both standard and damaged conditions. The proposed framework starts from the first four fundamental frequencies extracted through operational modal analysis (OMA) and clustering, followed by density-based time-domain filtering (tracking). The fundamental frequencies extracted are then fed to a dimensionality reduction block implemented through two different approaches: feature selection (intelligent multiplexer) that tries to estimate the most reliable frequencies based on the evaluation of some statistical features (i.e., mean value, variance, kurtosis), and feature extraction (auto-associative neural network (ANN)) that combine the fundamental frequencies to extract new damage sensitive features in a low dimensional feature space. Finally, one class classifier (OCC) algorithms perform anomaly detection, trained with standard condition points, and tested with normal and anomaly ones. In particular, a new anomaly detector strategy is proposed, namely one class classifier neural network two (OCCNN2), which exploit the classification capability of standard classifiers in an anomaly detection problem, finding the standard class (the boundary of the features space in normal operating conditions) through a two-step approach: coarse and fine boundary estimation. The coarse estimation uses classics OCC techniques, while the fine estimation is performed through a feedforward neural network (NN) trained that exploits the boundaries estimated in the coarse step. The detection algorithms vare then compared with known methods based on principal component analysis (PCA), kernel principal component analysis (KPCA), and auto-associative neural network (ANN). In many cases, the proposed solution increases the performance with respect to the standard OCC algorithms in terms of F1 score and accuracy. In particular, by evaluating the correct features, the anomaly can be detected with accuracy and an F1 score greater than 96% with the proposed method.

Keywords : anomaly detection, frequencies selection, modal analysis, neural network, sensor network, structural health monitoring, vibration measurement
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