ELECTROMECHANICAL IMPEDANCE-BASED DAMAGE DETECTION AND LOCALIZATION EMPLOYING DATA FUSION TECHNIQUES

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Abstract

There is much active research in the area of structural health monitoring (SHM) of lightweight structures to detect small levels of damage. The SHM system should be ideally low-cost, suitable for continuous monitoring, and able to detect minute damage in varying ambient conditions. The ability of the electromechanical impedance method (EMI) to detect damage has been demonstrated. Furthermore, due to high operational frequency, the method is immune to ambient noise. The EMI technique is employed for damage detection and classification in lightweight structures due to its sensitivity to the low scale of damage. However, creating a data processing method that is sensitive to even superficial damage is a challenging task.

This thesis focuses on enhancing the performance of damage assessment for metal and composite structures to sophisticated 3D printed structures for a variety of damage instances utilizing various data fusion techniques. Firstly, the data-fusion based series and parallel connection of sensors were studied and compared in the damaged steel beam structure with a variation of the environment temperature. The parallel connection has shown an advantage over individual and series connections in varying temperature environment conditions while reducing the damage detection measurement time. Secondly, the thesis presented a novel fused quantity (F) based on the resistance (R) and conductance (G) data in a chosen frequency band. It is used for damage quantification and classification in structures made of metal and composites. The new signature under different damage conditions is then quantified using established indices such as the root mean square deviation index (RMSD), etc. Further, A new optimized data fusion approach is proposed which was realized at the sensor level using the principal component analysis (PCA) as well as at the variable level using self-organizing maps (SOMs). In the process, a centralized data-fused baseline eigenvector is prepared from a healthy structure, and the damage responses are projected on this baseline model. The PCA is carried out for sensor network data and the corresponding damage index is calculated to study the information of sensor's impedance (|Z|), admittance (|Y|), R, and G data in the frequency domain. The statistical, data-driven damage metrics are calculated and compared with the RMSD index and used in a fusion-based data classification using SOM. The SOM comparative studies are performed using the Q-statistics and Hotelling's T^2 statistic. The proposed methodology is tested and validated for an aluminum plate with multiple drilled holes of varying sizes and locations. The method demonstrates a significant increase in damage sensitivity for hole location and hole size regardless of the frequency range used. Thirdly, this thesis implements damage localization using a modified probability weight function.

The comparative damage imaging method is applied to the composite plate with impact damage for G and R based fused quantity (F), direct-coupled mechanical impedance (DCMI) signature, and normalized G signature. The approach is further extended to detect multi-damages simultaneously using the network of sensors and used for damage localization in the acrylonitrile butadiene styrene (ABS) plate. Further, a database of the damage indices for numerous damage situations is created using this analytical methodology. Based on several fits, an analytical model is created for the inverse technique's association of distance and angle with the damage index (linear and exponential). The damage scenario with the lowest error in the damage indices is determined by comparing the damage indices obtained from the experiments with this database. The results show that indeed the proposed algorithm works and improves the damage localization using the EMI technique.

But the daunting task in the EMI method is the selection of robust frequency ranges. Finally, in order to solve this issue, an innovative standard deviation approach is used for the selection of effective frequency ranges. The novel nature of the apporach is based on the difference between healthy and damaged state data. Further, a data fusion-based C-index is introduced for damage detection and classification using analytical and experimental data in this effective frequency range. Application of this index for four samples made of metal and composites with different damage scenarios demonstrated the effectivity of the method. The method is suitable for identifying the damage location and damage severity simultaneously.