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Application of Neural Networks to Damage Detection of Beams and Plates

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I. INTRODUCTION

Beams and plates are thin structures widely used for numerous engineering applications. They often undergo large deformations and severe weather conditions that cause structural damage. The early detection of damages, their localization, and the estimation of their severity are critical for their operation and maintenance. Apart from traditional vibration-based methods, machine learning methods [1] have proven to be more precise, particularly when one deals with noisy data. The current study presents a supervised machine learning strategy for damage localization and severity estimation of the damage that is inspired by vibration-based techniques [2].

II. GENERATION OF TRAINIGN DATA

A major part of the process is the generation of appropriate data, which is used to train the neural network. In the current work, the input of the neural network represents the deformed shape of the structure taken at some instant of time from its forced time response. The deformed shape is represented as a vector that consists of the transverse displacements of the deformed shape measured at several locations.

The data is generated numerically by simulating time responses of damaged beams and plates. The equations of motion of these structures are derived by considering Timoshenko's theory for beams and Mindlin's hypothesis for the plate equation of motion. Geometrical nonlinearity is included in both models. Space discretization is performed by the finite element method, and simulations in the time domain are generated by Newmark's time integration scheme. The damage to the structure is modeled by reducing the thickness of one or more finite elements.

Simulations of damages with different severities located along the entire surface of the elastic structure due to external forces with various excitation frequencies are generated. Transverse displacements of the structure are estimated at multiple locations along the surface of the structure and stored at multiple instants of time. This dataset is used to train the neural network [3].

III. DAMAGE DETECTION OF NOISY TIME RESPONSES

Noise is unavoidable in real applications, and estimation of the capabilities of the neural network for damage detection of time response vibrations in the presence of noise is essential for their further development.

The deformed shapes from the time responses of the damaged structure are shocked by random noise, which is generated from a normal distribution. Noise with different magnitudes is considered. As expected, the accuracy of the neural network tends to decrease with the increasing magnitude of the noise. Nevertheless, it is shown that with sufficiently large training data, the neural network maintains high accuracy levels for time responses with additional random noise.

IV. OPTIMAL LOCATION OF SENSORS

In numerical experiments, one may measure time responses at as many locations as necessary; in real applications, this number is limited. It is essential to obtain a reliable damage detection algorithm with a low number of sensors. The last part of the research deals with a reduction analysis of the number of locations where transverse displacements are measured and stored for further training the neural network. Furthermore, different strategies for the distribution of the sensors, which include non-symmetric locations along the surface of the structure, are investigated.

V. CONCLUSION

The capability of neural networks to localize damages and estimate their severity on plates and beams is investigated by generating training data and predicting damages at unknown locations. The neural network achieved high accuracy in localizing damages that were either smaller than or different from those in the training data, i.e., the neural network accurately predicts both known and new damages.

Additionally, the neural network maintained its accuracy even when noise was introduced into the deformed shapes of the damaged structure.

In the absence of noisy data, the neural network demonstrated high accuracy not only in locating the damage but also in determining its severity. Although the estimation of damage severity tends to show higher severities for the cases with introduced noise, the accuracy of locating the damage remained high, highlighting the applicability of neural networks for structural health monitoring in real-world scenarios.

VI. ACKNOLEGLEMENT

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VII. REFERENCES

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