Damage identification in laboratory cantilever beam using neural networks

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Abstract

This paper presents the application of Artificial Neural Networks (ANN) in the identification of damage in a simple laboratory beam structure. The application of ANNs extends the nondestructive damage identification method by adding parameter to the structure. Damage is identified based on the variations in the dynamic parameters without knowledge of the initial values of the undamaged structure. In the experimental examples ANNs are applied for the analysis of the dynamic response of beam, in order to locate the damage and its extent. The assessment of the state of the structure relies on comparison of the structure eigenfrequencies obtained from the systems with additional masses placed at different nodes.

Keywords: beams, damage, dynamics, inverse problems, neural networks

1. Introduction

Nowadays knowledge of the condition of the structure is considered to be more and more important. The state of the structure and its safety depend to a great extent on the degradation of the structure elements (beams, connections, etc.). Nondestructive methods predict the location and extent of damage in existing engineering structures. Publications on the identification of damage present mainly the approach which implies that the eigenfrequencies and eigenmodes of the undamaged structure are known. Damage is identified based on the variations in the dynamic parameters with respect to the initial values [1]. Some methods require the introduction of external perturbations to the structure. The detection method which provides the global assessment of damage is usually not sensitive to the extent of damage. In the paper by Dems [2] an additional parameter is introduced (e.g concentrated elastic or rigid support, additional mass elastically or rigidly attached to the structure, boundary constraint) in order to increase the accuracy of identification. In the paper by Zhong [3] response-only method for damage detection of beam-like structures using high accuracy frequencies with auxiliary mass spatial probing is presented. This method does not require knowledge of the initial values of the undamaged structure to located damage.

The present paper is intended to provide the analysis of eigenfrequencies with respect to an additional mass and the application of ANNs to damage identification.

1.1. Damage identification proceedings

The scheme of damage identification proceedings is shown in Fig. 1. Basically, we can distinguish two main stages. In the first stage a numerical model (FEM) of the structure considered was built. Then for the selected locations of damage (l_c) and for the selected extent of damage (h_c) with mass M added at different nodes, the dynamic parameters of the structure (${}^m f_n$) were computed. The results obtained were used for training ANNs. At this stage the number and the best location of mass (l_m) as well as the best eigenfrequencies (f_n) were analyzed to improve the identification results. In the second stage the response of the structure (${}^m \tilde{f}_n$) was measured. The vibrations of the structure were caused by an impact. The results obtained were used as the input vector $\mathbf{X} = \{{}^m \tilde{f}_n\}$ for ANNs trained on numerical results. The output vector $\mathbf{Y} = \{l_c, h_c\}$ was described by the location and extent of the damage.

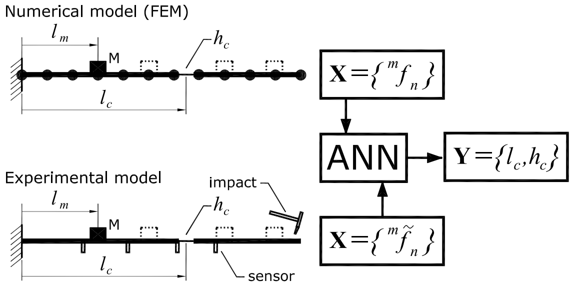

Figure 1: Scheme of damage identification proceedings

In this paper only the data measured has been considered. That approach verifies the quality of proper neural prediction with the experimental data. The model only one type of damage at a time was considered. Changes of eight eigenfrequencies were observed after adding mass and reducing stiffness. The data measured was used for learning and testing ANNs.

2. Experimental model of beam

The model of cantilever beam was measured. The model was made of flat steel (S235JRG2) 10 mm $\times$ 40 mm and 1200 mm length. The damage of the beam was done by the notch 1.2 mm wide and 1.0 mm to 8.0 mm deep. After measuring the notch was welded and ground. The additional mass M = 0.2 kg represented about 5% of the total mass of the models. The number and the best location of the mass were analyzed to improve the results with an acceptable minimal level of error. Vibrations of the models were caused by an impact. The response of the beam was measured in the range of 0.25 Hz to 1024.0 Hz with the step 0.25 Hz. The measurements were done using eight PCB accelerometers attached to the models connected to a multichannel analyser Scadas III with LMS software.

The model was formally divided into 24 parts (Fig. 2). Each part was 50 mm long. Eight of them (triangles A–H) were cut in

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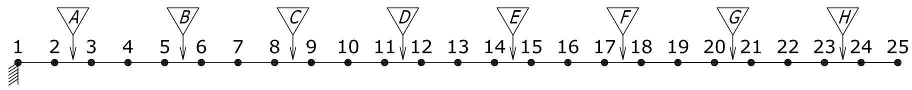

Figure 2: Scheme of notch (triangles A–H) on the laboratory model

the middle. For two notches (A, B) the beam was broken after the deepest cut (8.0 mm) had been made. On the whole 62 cases of damages were studied. The additional mass was attached at 23 points on the beam in turn (nodes 2–24 on Fig. 2). The experiment involved 1426 measurements. As a result 62 patterns to train ANN were obtained.

3. Application of neural networks

All the neural networks computations were performed using Neural Network Toolbox for Matlab. The input vector $\mathbf{X} = \{{}^m\tilde{f}_n\}$ consisted of the dynamic responses of the structure with an additional mass. The output vector $\mathbf{Y} = \{l_c, h_c\}$ consisted of the location and extent of damage.

The ANN with one hidden layer was applied and the Levenberg-Marquardt method was used in the training procedure. In each case 30% of the patterns were selected as testing ones, the remaining 70% were regarded as training ones. In all the cases, comparison of MSE (Mean Square Error) of testing was used to improve the results with acceptable minimal level of error.

4. Results

The combinations of a set of one, two or three best eigenfrequencies (f_n) with one, two or three best positions of mass (l_m) were analyzed. In all the combinations the identification of extent was better than the identification of location. The best results were obtained for ANN simulations using the input vector $\mathbf{X} = \{{}^7f_3, {}^{21}f_3, {}^{22}f_3, {}^7f_7, {}^{21}f_7, {}^{22}f_7\}$.

The results for the identification of the location of damage are shown in Fig. 3. The figure shows the values predicted from the networks versus the target values. In the case of the proper neural prediction the points are on the diagonal. The results from learning (circle) and testing (triangle) are shown. The Mean Square Errors and the correlation coefficient are also shown.

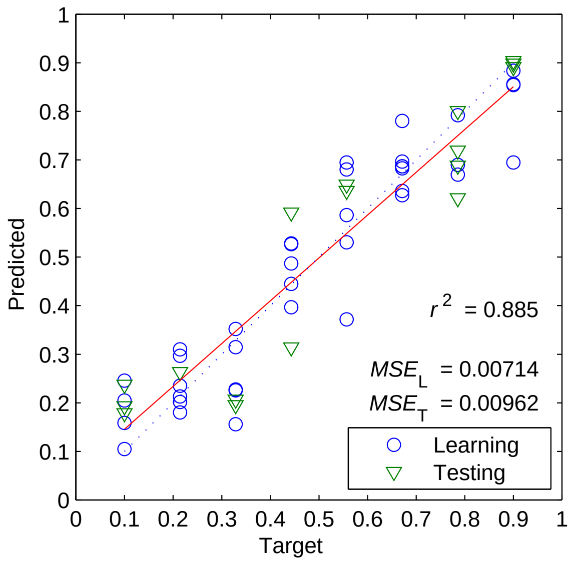

Figure 3: Prediction of the location of damage

The results for the identification of the extent of damage are shown in Fig. 4. These results were not excellent but very promising due to used resolutions of measured (0.25 Hz).

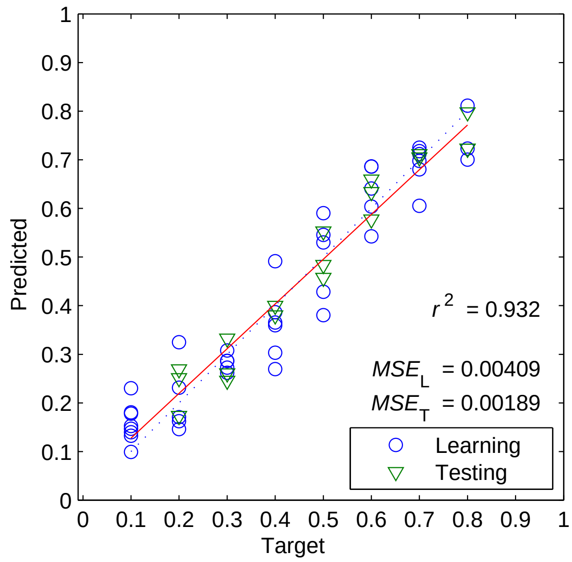

Figure 4: Prediction of the extent of damage

However using the response-only method [3] of the location of damage only one deepest type of damage (Fig. 2 point C) was definitely located.

5. Conclusions

In the proposed method the damage is identified on the basis of the variations in the dynamic parameters without knowledge of the initial values of the undamaged structures. The application of ANNs improves the nondestructive damage identification method the method uses an additional parameter introduced to the structure which increases the identification accuracy. The results obtained show that it is possible to identify damage using the dynamic responses of structures. Artificial Neural Networks are able to identify the location and extend of damage in structures.

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