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Damage Detection of Offshore Jacket Structure Using Dynamic Responses Based on Simulated Model, Intact State of Real Model and Deep Auto-Encoder Neural Network

Zohreh Mousavi [1], Sina Varahram[1], Mir Mohammad Ettefagh[1]*, Morteza Homayoun Sadeghi[1], Seyed Naser Razavi[2]

[1] Faculty of Mechanical Engineering, University of Tabriz, Tabriz, Iran.

[2] Faculty of Electrical and Computer Engineering, University of Tabriz, Tabriz, Iran.

ABSTRACT: Since the maintenance and repairing costs of mechanical systems, such as structures and rotating machines are significantly high, one way to reduce these costs is to consider some approaches before any operational work to check for damages in such systems. In this study, a new method is presented for damage detection of offshore jacket structures in the presence of various uncertainties, such as modeling errors, measurement errors and environmental noises, based on the simulated model and intact state of the real model. In the proposed method, real intact structure data is used to update the simulated model parameters. Some parts of the signal that are not related to the nature of the system are removed using the complete ensemble empirical mode decomposition method. Frequency data is extracted from the vibrational signals using the frequency domain decomposition method. A deep auto-encoder neural network is designed to learn the damage-sensitive features from the frequency data and to damage detection of the structure. In order to train the proposed deep network, frequency data of the simulated model and real intact state are used; then the frequency data of the real structure is used to test the proposed deep network. The results show that the proposed method is capable for damage detection of the offshore jacket structure with more accurate results than the other comparative methods.

Available Online:

Keywords:

Condition Monitoring

Offshore Jacket Structure

Model Updating

Deep Neural Network

1- Introduction

Offshore jacket structures are the most general types of offshore structures and play an important role in shallow and medium waters in the oil and gas industry. In addition, they are used as jacket substructure for offshore wind turbines in deep water (30-60 m). Therefore, damage detection of offshore jacket structures is highly necessary in order to ensure their safety.

In recent years, machine learning has been used as an effective tool for damage detection of mechanical systems. Artificial neural networks are a set of machine learning algorithms that are divided in two general categories; Shallow neural networks and deep neural networks. In deep networks, the features are automatically extracted and the accuracy of these algorithms is higher than the shallow networks [1-2].

A new method for damage detection of mechanical systems is presented in this paper. The first aim of this paper is to provide a method for damage detection of mechanical systems in the presence of various uncertainties. One of the benefits of deep learning is that it can learn damage-sensitive features from raw data in the presence of various uncertainties. Accordingly, the second aim of this paper is to design a deep auto-encoder network to learn the damage-sensitive features from raw frequency data. Data collection in industrial environments is difficult and even impossible, and generally only intact data is available [3]. Accordingly, the third aim of this paper is to train the proposed deep network based on the frequency data of simulated model and intact state of the real model, and then to evaluate the deep network with the frequency data of real model. In the proposed method, the simulated model parameters are updated based on the intact data of real model. Some parts of the vibration signals that are not related to the nature of the system are removed using the Complete Ensemble Empirical Mode Decomposition (CEEMD) method [4]. Frequency data is obtained from the vibration signals using the Frequency Domain Decomposition (FDD) method [5]. An offshore jacket structure model in the laboratory is used as a case study to evaluate the proposed method.

2- Methodology

In this section, at first, the simulated and laboratory models of the offshore jacket structure are described. The proposed algorithm for damage detection of the offshore jacket structure is then expressed.

2-1- Finite Element (FE) model of the offshore jacket structure

An initial three-dimensional finite element model of the offshore jacket structure is created using Abaqus software, taking into account the small deformations and linear behavior of the system. The created finite element model in the intact state is shown in Fig. 1. The dimensions of the finite element model are created exactly according to the dimensions of the real structure (Fig. 2). The structure has five stories, all of which are horizontally braced and two middle stories are diagonally braced.

*Corresponding author's email: ettefagh@tabrizu.ac.ir.

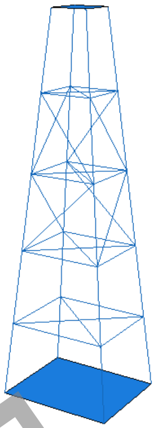

Fig. 1. Finite element model of the offshore jacket structure in intact state.

2-2- Laboratory model of the offshore jacket structure

In this study, an offshore jacket structure model (Fig. 2) designed and installed in the Tabriz University Modal and Vibration Analysis Laboratory. A shaker is used to produce an artificial excitation force. The shaker is connected to one of the vertical columns in the middle section of the third story using a ring type fixture [6]. 12 Accelerometers are mounted on the structure to extract the dynamic responses. Fig. 3 shows the dynamic responses extracted using the 12 accelerometers mounted on the structure.

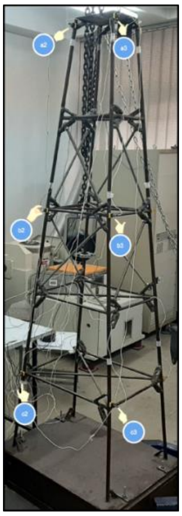

Fig. 2. The laboratory offshore jacket model in intact state.

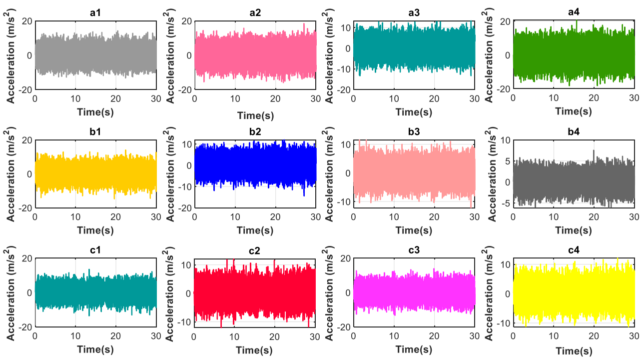

Fig. 3. Extracted dynamic responses using 12 accelerometers mounted on the structure.

2-3- The proposed damage detection algorithm

The major procedure of the proposed damage detection algorithm is listed as follows (see Fig. 4):

(a) Extracting the dynamic responses corresponding to different states of finite element and laboratory models.
(b) Data preprocessing and Finite element model updating [7].
(c) Selecting the Proper Intrinsic Mode Functions (IMFs) using CEEMD method and signal reconstruction.
(d) Generating raw frequency data from dynamic responses using FDD method.
(e) Dividing the data into three parts, namely training data based on finite element model and the intact state of the laboratory model, validation data and testing data based on laboratory model.
(f) Designing a Deep Auto-Encoder (DAE) neural network in order to learn the damage-sensitive features from raw frequency data of the finite element model and the intact state of the laboratory model.
(g) Investigating the performance of the proposed deep network for damage detection of the laboratory structure.

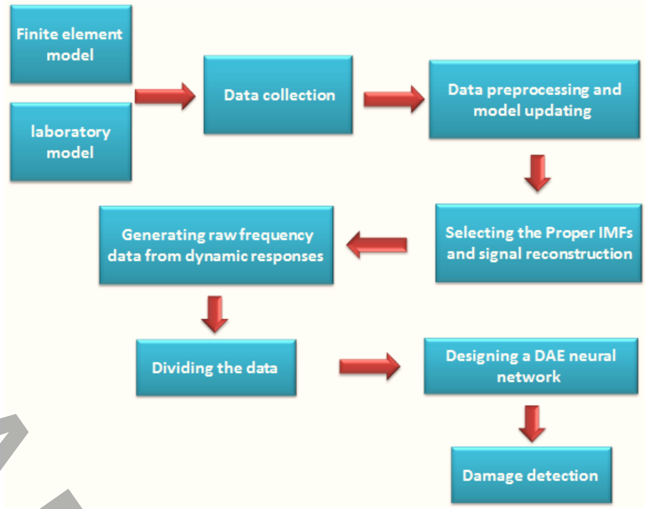

Fig. 4. The block diagram of the proposed algorithm.

3-Results and Discussion

The results of the proposed algorithm for damage detection of the offshore jacket structure are presented in this section. In order to evaluate the accuracy of the results of the finite element model, the mean values of the natural frequencies of the intact structure for both finite element and laboratory models are obtained using FDD method and compared with each other (see Table. 1).

After ensuring that the finite element model is accurate, the frequency data of the reconstructed signals of the finite element model and intact state of the laboratory model are used as the training data of the proposed deep network for extracting the damage-sensitive features. Then, the frequency data of the reconstructed signals of the Laboratory model is used for evaluating the proposed deep network. This study is based on 5 states in 3 scenarios for both finite element and laboratory models. The created finite element models for different damage states of the structure are shown in Fig. 5 which the braces marked with red color are removed in each damage state. Also, the confusion matrix [8] of the proposed algorithm is shown in Fig. 6.

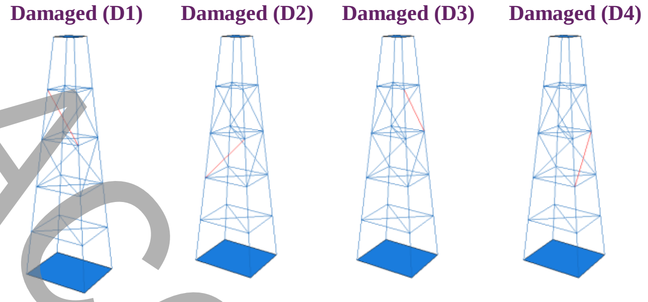

Fig. 5. The FE models for different damage states.

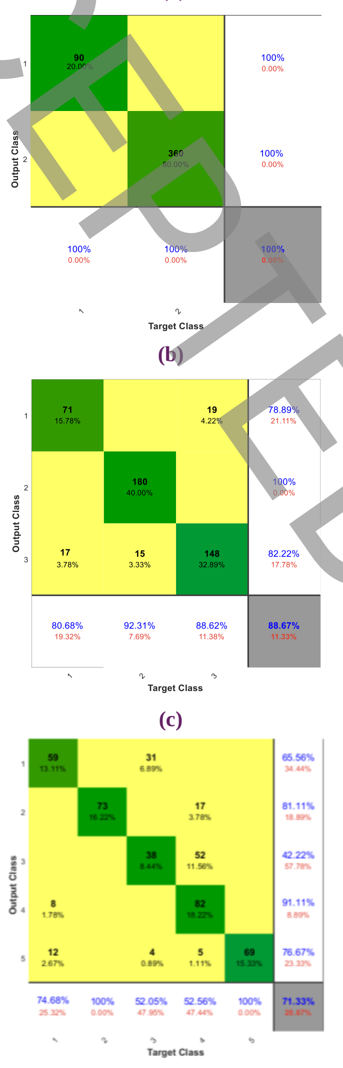

Fig. 6. Confusion matrices of the proposed algorithm (a) Scenario of 2-Class; (b) Scenario of 3-Class; (c) Scenario of 5-Class.

4. Conclusions

This paper presents a new damage detection method based on the finite element model and the intact state of the real model, in the presence of different uncertainties using deep network. The finite element model parameters are updated on the basis of real intact state. Some parts of the signals which are not related to the nature of the system are removed using the CEEMD method. To train the proposed deep network, only the frequency data of the finite element model and the real intact state are used. After that, the frequency data of the real model is used to evaluate the proposed network. Frequency data is extracted from vibration signals using FDD method. An offshore jacket structure in the laboratory environment is used to evaluate the proposed algorithm. The results show that, the proposed deep network is able to detect the damages of the real structure using the finite element model data and the real intact state.

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Table 1. Comparison of the mean values of the natural frequencies for the intact structure using different methods before and after updating.

Mode No.	Natural Frequency (Hz)			Error (%)	
	Laboratory Model	FE Model		FE Model compared with Laboratory Model	
	Based on FDD	Based on FDD		FDD-FDD	
		Before updating	After updating	Before updating	After updating
1	14.25	14.98	14.46	5.1%	1.5%
2	-	-	-	-	-
3	51.36	53.93	52.10	5.0%	1.4%
4	80.13	80.84	80.36	0.88%	0.29%
5	-	-	-	-	-
6	104.33	103.56	104.15	0.73%	0.17%