Amirkabir Journal of Civil Engineering

Amirkabir J. Civil Eng., 55(2) (2023) 65-68
DOI: 10.22060/ceej.2022.20786.7526

Damage detection of model reference adaptively-controlled structures using control force as a damage sensitive feature

H. Shirzadi, M. Bitaraf *

School of Civil Engineering, College of Engineering, University of Tehran, Tehran, Iran

ABSTRACT: Civil infrastructures, nowadays, are an indispensable part of society, and any unpredicted damage can cause severe economic and life loss. Hence, developing smart structures has been the topic of many studies during the past decades. In this article, developing a smart structure by synthesizing structural control and health monitoring is suggested by extracting damage-sensitive features from the active control force. The autoregressive models have been deployed to extract damage-sensitive features in the time domain. Then, quadratic discriminant analysis is utilized to discriminant between different damage states of the structure. The active control force is obtained by two model reference adaptive controllers, namely the MIT rule and Lyapunov stability theorem, to attenuate the structural vibration caused by Gaussian white noise excitations. The proposed approach has been numerically studied on a three-story shear building with active ideal controllers in all floors. Results indicate that the proposed approach can detect the potential damage, as well as its severity and location, precisely.

Review History:

Received: Non. 16, 2021
Revised: Aug. 23, 2022
Accepted: Nov. 29, 2022
Available Online: Dec. 28, 2022

Keywords:

Structural health monitoring
Damage detection
Vibration control
Discriminant analysis
Smart structure

1- Introduction

Civil structures and infrastructures are an indispensable part of today's life, and any damage and failure in them will be catastrophic [1]. These structures are prone to damage due to natural and manmade events [2]. Currently, a large number of the structures in Iran are closing their design life. Hence, developing damage detection methods for them seems necessary. In the last decades, structural vibration control methods have been implemented as a practical approach to attenuate the structural responses and mitigate the potential damage [3]. Different passive, semi-active, active, and hybrid vibration control algorithms and devices have been proposed in the literature and used in practice [4, 5]. Despite the fact that there have been many advances in the field of structural damage detection and health monitoring in the past decades, unfortunately, it has been studied separately, and only a few studies address the synthesis of structural control and health monitoring [6]. Both structural control and health monitoring need a network of sensors, data acquisition transmission, and processing. Thus, it seems reasonable to create smart structures by combing structural health monitoring and vibration control. In the literature, structures mimicking biological systems are called smart structures. In other words, a structure equipped with structural control, structural health monitoring, structural self-repairing, and structural energy harvesting systems is called a smart structure [1]. In this study, the authors suggest combining structural health monitoring and structural vibration control by extracting the damage-sensitive features directly from the active control force.

2- Methodology

In this article, a three-story shear building has been modeled numerically to evaluate the proposed methodology. It is assumed that the structure is equipped with active actuators on all three floors. The actuators are considered ideal so that they can produce the desired control force calculated by the control algorithms without limitation and time delay.

Six damage scenarios are defined to model the damage effects on the structure. The damage is modeled as stiffness loss in columns of each floor. At each story, two levels of damage, i.e., 50 percent and 70 percent stiffness loss, are assumed to be the corresponding damage scenarios.

The structure is then excited with white Gaussian noise with zero mean and unit variance. For calculating the control forces, two well-studied model reference adaptive controllers, i.e., the MIT rule and Lyapunov stability theorem, are utilized [7]. The controllers are adjusted to attenuate the response on the structure to 30 percent of the undamaged structure. The structure is excited at each damage scenario with 50 different Gaussian noises, and the corresponding control force for all

*Corresponding author's email: maryam.bitaraf@ut.ac.ir

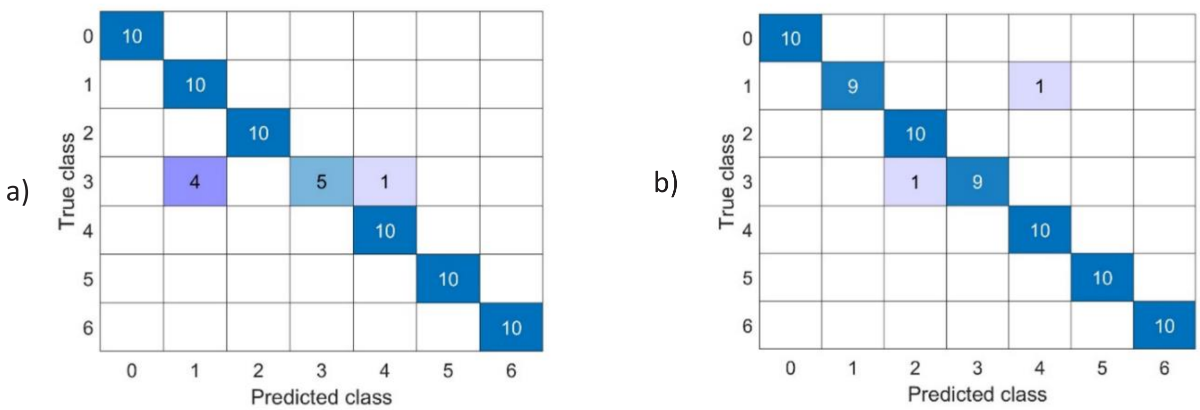

Fig. 1. Confusion matrix of the proposed damage detection algorithm a) when MIT Rule controllers are utilized b)when the Lyapunov stability theorem is used for calculating the control forces.

damage states and controllers is calculated.

The Auto-Regressive (AR) method is then utilized to extract damage-sensitive features from the control force. Herein the AR(3) model's coefficients are used to train a machine-learning algorithm to identify the damaged state of the structure. Since there are three actuators in the structure, there will be three control forces. The corresponding AR(3) coefficients are combined to create a vector of damage-sensitive features. Several classification algorithms, namely, decision trees, linear and quadratic discriminant analysis, Support vector machines with different kernels, and K nearest neighbors, were tested for this particular classification problem. The quadratic discriminant analysis was selected due to higher accuracy for the training data sets. The training data sets comprise 80 percent of the total data, and the remaining 20 percent is deployed to test the trained classifiers. The K-fold method is utilized to prevent overfitting.

A three-step algorithm is suggested in this study, namely, detecting potential damage, finding the location of damage, and calculating the damage's severity to identify the structure's damage state. In the first step, the data of the undamaged structure and damaged structures with different damage scenarios are utilized for training a classifier. If all three classifiers predict the unknown data as undamaged, the unknown data is labeled undamaged. Otherwise, the data is fed to the next step classifier. The second step is in charge of detecting the location of the damage. A classification model based on the damage location is trained to achieve this objective. At each story, there are two damage levels, and in this step, both of them are combined and labeled as the location of the damage. As a result, there will be three clusters. The trained classifier is then utilized to determine whether the damage is at the first, second, or third story. After that, in the last step, three different classifiers are trained to quantify the damage severity at each story. For example, when the damage is identified on the first floor in the second step, the data from different damage levels on the first floor is used to train the classifiers.

3- Results and Discussion

The remaining dataset was selected as a test dataset and was utilized to evaluate the proposed damage detection algorithm's performance. The unknown damage state of the test data set is then identified using the output of the trained classifiers. Based on the true class and the predicted class for the test dataset, the confusion matrix is shown in Figure 1. In this figure, class 0 shows the undamaged structure, classes 1, 2, and 3 show mild damage in the first, second, and third stories, respectively, and classes 4, 5, and 6 show severe damage in the first, second and third stories. The results indicate that the proposed methodology can accurately detect the potential damage in the structure. The algorithm correctly predicts all the damaged and undamaged cases for the MIT rule and Lyapunov stability theorem controllers. And in terms of predicting the location and severity of the damage has an accuracy of 93 percent and 97 percent for the MIT rule and Lyapunov controllers, respectively.

4- Conclusions

This paper suggested a new methodology for structural health monitoring of actively controlled structures. A numerical model of a three-story sheer building was developed to evaluate the proposed method, and the control forces were calculated for 50 Gaussian noise inputs for six damage scenarios. The results indicated that extracting damage-sensitive features directly from active control force can be utilized for damage detection of controlled structures. The proposed method can detect potential damage at the structure and locate and quantify the damage.

References

[1] Y.-L. Xu, J. He, Smart civil structures, CRC Press, 2017.

[2] J.P. Amezquita-Sanchez, H. Adeli, Signal processing techniques for vibration-based health monitoring of smart structures, Archives of Computational Methods in Engineering, 23(1) (2016) 1-15.

[3] C.R. Farrar, K. Worden, Structural health monitoring: a machine learning perspective, John Wiley & Sons, 2012.

[4] B. Spencer Jr, S. Nagarajaiah, State of the art of structural control, Journal of structural engineering, 129(7) (2003) 845-856.

[5] T. Soong, B. Spencer Jr, Supplemental energy dissipation: state-of-the-art and state-of-the-practice, Engineering structures, 24(3) (2002) 243-259.

[6] J. He, Y.-L. Xu, S. Zhan, Q. Huang, Structural control and health monitoring of building structures with unknown ground excitations: experimental investigation, Journal of Sound and Vibration, 390 (2017) 23-38.

[7] K.J. Åström, B. Wittenmark, Adaptive control, Courier Corporation, 2013.

HOW TO CITE THIS ARTICLE

H. Shirzadi, M. Bitaraf, Damage detection of model reference adaptively-controlled structures using control force as a damage sensitive feature, Amirkabir J. Civil Eng., 55(2) (2023) 65-68.

DOI: 10.22060/ceej.2022.20786.7526