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Online system identification by sparse component analysis based on wavelet transform

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ABSTRACT: Recently, online identification of structures, only based on the measured outputs during the vibration, has received much attention. One of the most powerful methods of offline system identification is the sparse component analysis (SCA) method which is a subset of blind source identification (BSI) methods. This method by transferring the dynamic responses from time domain to frequency one has led to the sparsity in the data and accordingly the modal parameters of the system are identified. In this research, a Wavelet Transform based Sparse Component Analysis (WT-SCA) method is suggested to identify the system. Then, using WT-SCA and a semi-active tuned mass damper (STMD), an algorithm is presented to achieve a smart structure. The results show that the WT-SCA is able to identify the system momentarily with an acceptable accuracy and also reduce the dynamic responses of a structure equipped with STMD.

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1. Introduction

A smart structure includes structural health monitoring and vibration control strategies. In the last decades, much studies have been conducted on both parts and their merger ways. Vibration-based identification techniques have been considered remarkably in recent decades. In this regard, there are several methods that can be divided into two general categories: identification methods based on the inputs and outputs, and identification methods only based on outputs. Among the most extensively used methods that are widely used in system identification, only based on the output, are BSI methods. Failure in identifying indeterminate condition and also under the influence of time variable inputs like earthquakes are among the problems of these methods. For this reason, the SCA method was introduced to overcome these shortcomings in 2005 [1, 2]. In this way, the only necessary condition is the dispersion of data in a specific space. Also, using a time-frequency-based filter, the data generated simultaneously from multiple source signals are eliminated to avoid an overlap [3]. Different methods such as Short-Time Fourier Transform (STFT) have been used to transmit data to time-frequency domain. However, these methods encounter problems in determining the length and number of windows used to transmit data to the frequency-time domain with deficiencies such as significant sensitivity. The momentary identification of the system in smart structures is particularly important. To solve this problem, in this paper, a WT-SCA is proposed to identify the system momentary.

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In recent years, the combination of both structural health monitoring and vibration control strategies have been highly considered in smart structures [4-7]. The passive tuned mass damper (PTMD) is one of the most used control devices [8-10]. Any changes in the structural modal parameters leads into the outflow of PTMD setting and may have damaging effects on the structure. In the engineering literature, the use of STMD has been suggested to overcome this problem [11-15]. In the second part of this paper, the WT-SCA is proposed to reset the mechanical characteristics of the STMD to deal with any changes in the structure modal parameters. To achieve this goal, an algorithm is used based on the simultaneous combination of both structural health monitoring and semi-active control structures. Finally, using the numerical examples, the performance and accuracy of the WT-SCA method are evaluated.

2. WT-SCA.

2.1. Structural Identification

In BSI methods, the purpose is to determine the source signals based on the output signals, the relationship between them by mixing matrix is as follows.

$$\mathbf{Y}_{(t)} = \mathbf{AS}_{(t)} \tag{1}$$

In equation (1), the values of $\mathbf{Y}_{(t)}$ output signals, $\mathbf{A}$ mixing matrix and $\mathbf{S}_{(t)}$ are equal to output signals. In this case, taking into account the displacement equation and the modal responses of a structure, presented in (2), and comparing the equations of (1) and (2), it can be concluded that only by using structure responses the values of the matrix mode shape and the structure modal responses be retrieved;

$$\mathbf{X}_{(t)} = \boldsymbol{\varphi}\mathbf{q}_{(t)} \quad (2)$$

In equation (2), the displacement response of a structure is the values of $\mathbf{X}_{(t)}$, $\ddot{\mathbf{o}}$ is the modal shape matrix and the modal responses are equal to $\mathbf{q}_{(t)}$. SCA delivers an alternative device to solve equation (1), which also provides the ability to solve these equations in indeterminate conditions. In this method, contrasting the other provided methods, the modal shape matrix does not need to be a reversible (square) one. Moreover, data independence assumption is not taken into account in this method, and the only assumption that data should satisfy is the dispersion in a particular space. In this case, using wavelet transmission the structure responses are transmitted to the time-frequency space and provide the required dispersion to extract the modal parameters. Also, the SSP method has been used to eliminate the fluctuations and data overlapping to increase the identification accuracy. After eliminating the existing fluctuations, the created orientations in the time-frequency space by the fuzzy C-means clustering method [16, 17] will be attributed to the modal structures. In the case of the determinacy of the structure, the modal structure responses are extracted; while in the case of structural indeterminacy, to extract modal responses the optimization algorithm L0-norm has been used [18].

2.2. Structure control

During extreme environmental excitations, such as wind and strong earthquakes, damages usually occur in structures. Any damage in a structure causes changes in the modal parameters of the structure. In this section, by combining both structural health monitoring and a semi-active control of structures strategies is proposed to develop a smart structure; So that the control system will be robust against these changes.

Numerical example

In order to review the WT-SCA method, 10-story structure is considered with 5% damping ratio. Also, the following strong ground motion records are used: 1) Imperial Valley-04 (El Centro Array # 9, PGA = 1.97g), 2) Sylmar (Sylmar-Fire Station p. 91, PGA = 0.69g), 3) Newhall (Firesta, PGA = 0.32g), and 4) Kobe (KJMA, PGA = 0.06g). Moreover, to investigate the precision of the SSP method in removal of the fluctuations, a fluctuation of 10% has been applied to the structure output. The results indicate that the proposed WT-SCA method has identified the structural modal parameters with a high accuracy. In order to study the proposed design in controlling a ten-story structure equipped with STMD four different performant indicators are used; that respectively indicate the maximum displacement ratio is the maximum inter-story drift ratio, the maximum ratio is the square root

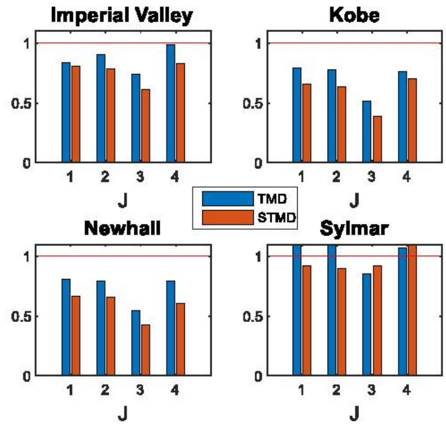

Fig. 1: Performance indicators in ten-story structures.

of sum of squares of displacements and the maximum ratio is the square root of sum of squares of displacements in the controlled case to the uncontrolled case. The results show that a structure equipped with STMD has a more desirable performance in reducing structural dynamic responses rather than PTMD.

3. CONCLUSIONS

In this paper, regarding SCFT shortcomings based on the STFT in the momentary identification of the system, such as the need to properly determine the parameters of the length and number of windows based on each input to transmit data to the frequency domain of the time, as well as the large amount of data, WT-SCA is proposed. In this method, it is only necessary to determine the values of the main wavelet, and in this paper Complex Morlet is utilized. Also, in the second part of this study, a new controller is presented to develop a smart structure by using a combination of WT-SCA and STMD. Using the proposed WT-SCA method, the dynamic characteristics of the structure are identified by the severe earthquake effects. After reviewing the results of numerical examples are presented, it is necessary to note the followings:

- The numerical results show that even in the presence of fluctuations in the measured responses, the proposed WT-SCA method effectively and efficiently identifies the system modal parameters with acceptable momentary accuracy; so that under the influence of different earthquakes of the first mode with a precision of over 99%, and the second and third modes with a precision of over 97% are identified.
- Regarding the presented numerical examples, it is observed that in the event of an earthquake damage, the proposed method is suitable for identifying the moody shape and the structure dominant frequency.
- By using the proposed controller, the hardship and damping of STMD device, based on the identified changes in the structure modal parameters can almost be momentarily readjusted.

The results of the proposed STMD performance review compared to the passive state indicate that the proposed controller is effective against any changes in the system modal parameters caused by strong ground motions.

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