A novel natural frequency-based technique to detect structural changes using computational intelligence

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Abstract

Structural changes are usually associated to damage occurrence, which can be caused by design flaws, constructive problems, unexpected loading, natural events or even natural aging. The structural degrading process affects the dynamic behavior, leading to modifications in modal characteristics. In general, natural frequencies are sensitive indicators of structural integrity and tend to become slightly smaller in the presence of damage. Despite this, it is very difficult to state the relationship between decreasing values of natural frequencies and structural damage, since the dynamic properties are also influenced by uncertainty on experimental data and temperature variation. In order to contribute to improving the quality of natural frequency-based methods used for damage identification, this paper presents a simple and efficient strategy to detect structural changes in a set of experimental tests from a real structure using a computational intelligence method. For a full time monitored structure, the evolution of natural frequencies and structural alterations, since they are also influenced by uncertainty on experimental data and temperature variation. In order to contribute to improving the quality of natural frequency-based methods used for damage identification, this paper presents a simple and efficient strategy to detect structural changes in a set of experimental tests from a real structure using a computational intelligence method. For a full time monitored structure, the evolution of natural frequencies and structural temperature are used as input data for a Support Vector Machine (SVM) algorithm. The technique consists on detecting structural changes and when they occur based on the structural dynamic behavior. The results obtained on a historic tower show the capacity of the proposed methodology for damage identification and structural health monitoring.

Keywords: Damage detection; Structural dynamic; Computational intelligence; Structural health monitoring; Vibration monitoring

1. Introduction

Structural Health Monitoring (SHM) is concerned about safety and maintenance of structures. All structures are subject to changes in their environmental and operational conditions by means of natural or artificial factors, as earthquakes, winds, traffic loads, etc. The aforementioned situations can lead to alterations in structural behavior which can be associated to damage occurrence. This way, the main objective of the SHM is to track the changes of the structural behavior in order to prevent damages.

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The structural degrading process affects the dynamic behavior, leading to modifications in natural frequencies, mode shapes and damping ratios. Thus, the use of modal data to the assessment of structural integrity is a classical approach [1]. In the last years, many researches dedicated a considerable effort to this subject and several methods have been developed, such as those based on strain energy deviation [2,3], on changes in curvature [4], or even based on flexibility matrix analysis [5], among others.

In general, natural frequencies are sensitive features of structural integrity and tend to become slightly smaller in the presence of damage. Nevertheless, it is very difficult to state the relationship between decreasing values of natural frequencies and structural alterations, since they are also influenced by uncertainty on experimental data and temperature variation [6,7]. Considering this, the temperature measurements have to be taken into account to avoid false alarms, especially while employing natural frequency-based strategies.

Another approach to detect structural damage is based on machine learning methods. Computational intelligence methods such as Genetic Algorithm, Artificial Neural Network (ANN), Support Vector Machine (SVM), are considered useful tools for solving structural damage assessment problems [8,9]. In this context, the damage detection algorithms work as classifiers, which try to identify damage levels using, as input data, features extracted from dynamic responses.

According to Rytt er [10], the detection methods are classified into four levels: Level #1 - determining whether damage occurs in the structure; Level #2 - identifying the geometric location of the damage; Level #3 - quantifying the severity of the damage; and Level #4 - predicting the remaining service life of the structure. Generally, levels #1 to #4 can be reached in works based on numerical simulations. Nevertheless, when dealing with actual structures, it is a hard task to determine the damage occurrence starting only from modal data. Therefore, robust methods that are able to achieve level #1 are still welcome. Once the structural damage is correctly detected (level #1), inspections can be provided to verify the localization and severity of the damage, achieving levels #2 to #4 in Rytt er’s classification. Thus, the development of a reliable method focused on detecting structural failures sometimes is enough to avoid safety problems.

In view of the foregoing paragraphs, a novel natural frequency-based technique to detect structural changes by using a computational intelligence method is presented in this paper. For a full time monitored structure, the evolution of natural frequencies and temperature are used as input data for a SVM algorithm. The technique consists in detecting structural changes and when they occur based on the structural dynamic behavior. The proposed methodology is validated by analyzing the continuous dynamic monitoring data collected on the historic Gabbia Tower in Mantua (Italy) that was subjected to an earthquake [11,12]. These first results demonstrate that the novel strategy can provide accurate detection results, demonstrating capacity for damage identification and structural health monitoring.

2. Support Vector Machine (SVM) - An overview

Computational learning methods are considered useful tools for solving structural damage assessment problems, once they can recognize similar observations in a database and separate them into groups that share similar characteristics [8,9]. A popular artificial intelligence technology for pattern recognition problem is the SVM, a statistical learning algorithm trained to determine the boundary between two classes of data in a space, where an optimal separating hyperplane is constructed in order to maximize the margin and minimize the misclassification [13]. The maximization of the margin is based on an optimization function to minimize the Euclidian norm of the vector that defines the direction of the separating hyperplane. The training data points located at the margins are called support vectors.

For non-linear binary classification, the inputs are mapped into a high-dimensional feature space through a kernel function. The kernel Gaussian function is used in this paper, which is also called Radial Basis Function (RBF). In this case, the SVM has two free parameters that need to be specified: $\sigma$ from the RBF kernel function; and C, a regularization parameter from the formulation of the margin maximization, used to avoid data overfitting. These parameters are estimated by training the SVM for multiple values of C and $\sigma$. Then, the pair that minimizes the generalization error is chosen.
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