Structural Novelty Detection Based on Hilbert-Huang Transform and Principal Component Analysis

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ABSTRACT

Research on vibration-based damage detection methods has been committed to detect the modal parameters which are sensitive to damage. However, the modal parameters are also sensitive to the varying environmental conditions such as temperature. To make the structural damage detection more reliable, it is highly desirable to develop a methodology to eliminate the effect of environmental variations on modal parameters. In this paper, Hilbert–Huang transform (HHT) together with the Principal Component Analysis (PCA) is used for feature extraction of measured response and damage detection. Numerical simulation is conducted on a cantilever beam to investigate the effectiveness of the present approach. It was demonstrated that the combination of PCA and HHT can effectively eliminate the temperature influence. And the residual error of PCA predicted model is effective for indicating the existence of structural damage.

KEY WORDS: Temperature effect; Hilbert-Huang transform; Principal component analysis; Novelty detection; Structural damage detection.

INTRODUCTION

Structural health monitoring process needs to collect the system response signal through some sensors in a long period of time. The features which are sensitive to the structure damage are extracted from the response signal. And statistical analysis of these features are done to distinguish between damage and non-damage structure to achieve the damage identification and structural health monitoring purpose (Doebling, 1996; Farrar, 2004). Structural damage detection methods based on structural dynamics can take the dynamic parameters as the damage characteristic parameters, such as modal frequency, frequency response function, mode shape, modal flexibility etc. However, in the practical application, structural properties will be affected by the environmental factors and operational conditions such as temperature, humidity, temperature gradient, wind and traffic conditions, etc. The structure dynamic parameters may change along with the environmental factors and operational conditions, which could possibly mask the subtle structural changes caused by damage (Sohn, 2007). How to reduce or eliminate the influence of the environmental factors, to obtain the real condition of the structure, has become a key problem in the damage detection and health monitoring.

Currently, there are two main methods that taking into account the influence of environmental factors on the structure damage characteristic parameters. One approach is to establish the correlation between environmental factors and damage characteristic parameters through field tests (Such as the AR model of Z24 Bridge and the linear filtering model of Canyon Bridge ) (Peeters, 2000; Sohn, 1999). This kind of correlation is usually linear relationship obtained by fitting experimental data under the condition of isolating each environmental factor (such as temperature). While the real operation condition of the structures is very complex, so this method obviously has many limitations. Another approach is to directly take into account the effects of environmental factors, making the environmental factors as variables embedded in the damage characteristic parameters (Sohn and Worden, 2001). Then Principal Component Analysis (PCA) is used to eliminate the influence of environmental factors on damage characteristic parameters. A main advantage of this approach is that it does not need to distinguish and measure the impact of various environmental factors.

In this paper, the instantaneous frequency is chosen as the damage characteristic parameter. Due to the characteristics of the environmental loads and structural damages, the signals collected from structures are often non-stationary and nonlinear. The Hilbert-Huang Transform (HHT) method has been demonstrated to process the non-stationary and nonlinear signals with excellent performance (Huang, 1998; Rilling, 2003; Huang, 2005; Wang, 2012). So in this paper HHT is used to extract the modal frequencies from the vibration signals.

The objective of the present paper is to combine the HHT and PCA together to detect structure damage. Firstly, the effects of temperature change and local damage on modal frequency of the structure are compared and analyzed through a numerical simulation example. Secondly, the HHT method is used to get the first two modal frequencies of a cantilever beam model, which is under white noise excitation. Lastly, PCA is applied to the modal frequencies under different temperatures and the influence of temperature can be eliminated. Novelty analysis on the residual error of PCA predicted model is used as a statistical indication of damage.

THEORY OF HHT

The HHT is a powerful time-frequency method, which is used to