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Experimental study on the crack detection with optimized spatial wavelet analysis and windowing

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ABSTRACT

In this paper, a high sensitive crack detection is experimentally realized and presented on a beam under certain deflection by optimizing spatial wavelet analysis. Due to the crack existence in the beam structure, a perturbation/slop singularity is induced in the deflection profile. Spatial wavelet transformation works as a magnifier to amplify the small perturbation signal at the crack location to detect and localize the damage. The profile of a deflected aluminum cantilever beam is obtained for both intact and cracked beams by a high resolution laser profile sensor. Gabor wavelet transformation is applied on the subtraction of intact and cracked data sets. To improve detection sensitivity, scale factor in spatial wavelet transformation and the transformation repeat times are optimized. Furthermore, to detect the possible crack close to the measurement boundaries, wavelet transformation edge effect, which induces large values of wavelet coefficient around the measurement boundaries, is efficiently reduced by introducing different windowing functions. The result shows that a small crack with depth of less than 10% of the beam height can be localized with a clear perturbation. Moreover, the perturbation caused by a crack at 0.85 mm away from one end of the measurement range, which is covered by wavelet transform edge effect, emerges by applying proper window functions.

1. Introduction

Nowadays crack detection and localization has been a common topic among researchers to enhance the stability, durability and safety of engineering structures. A wide range of damage identification methods have been used in the mechanical and civil engineering researches during last decades. Vibration based methods such as changes in natural frequencies and mode shape curvatures have been employed in order to identify damages in the structures. Also, analyzing the dynamic and static space domain signals of structures which can be obtained by various kinds of sensors (Piezoelectric, Strain gauge, optical sensor and so on) has been emerged as another way of identifying damages in the structures. Fourier Transform was one of the first tools to analyze output signal of the sensors, however, this transformation was not found as a powerful tool providing detailed information about particularly non-stationary signals. Fast Fourier transform, and Wavelet transform are the next generation of tools for signal processing. All these various methods have been employed to improve the damage identification procedure.

A damage changes the physical properties of the structure such as stiffness, mass, and damping ratio. Most damage identification is based on the fact that these alterations can affect the structural deformation and vibrational modal

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properties of the structure such as mode shapes and natural frequencies. Investigation of the change in the vibration natural frequency was the earliest vibration-based method to identify the damage [1–5]. Using space domain signal such as mode shape and deflection as a feature to detect the damage has some advantages over the natural frequency-based method [6,7]. Space domain signals can reveal local information which makes them more sensitive to local defects [8]. Moreover, these local signals are less affected by environmental factors, such as temperature variations, as compared to the natural frequencies of a structure. Over last decades, wavelet transformation has been a popular tool among researchers to analyze the signals to ease the damage detection procedure. The popularity of these methods is due to their ability to identify even small perturbation in signals. In most studies, Beams and plates have been investigated due to the significant numbers of their application in the industry.

Many simulation works have been conducted in this area, for instance, Surace and Ruotolo [9] developed the theory of wavelets and their applications. They used the wavelet transform to analyze vibration response signals of a cracked beam. Liew and Wang [10] presented the application of wavelet transformation in the space domain to identify a crack in the structure. A cracked simply supported beam has been mathematically modeled and spatial wavelet transform has been used to solve the crack detection problem. Finally, based on the results, wavelet-based method eased the crack identification procedure compared to the traditional method (natural frequency change). Wang and Deng [11] performed a study on the crack detection in the plate and beam structures by using Haar and Gabor wavelet families. In their simulations, they considered both dynamic and static loading conditions on the structures. These researches were the interesting start point of using spatial wavelet transform for damage identification in structural diagnosis and structural health monitoring. Xiang et al. carried out numerical studies on the damage detection in engineering structures using a hybrid approach [12–15]. In these works two steps have been performed; first the detection of crack location and the second measuring the damages' severities. Wavelet transformation has been used to detect the damage locations and the relationship between the natural frequencies and damage severities evaluated the severity. Furthermore, Interval wavelets were employed to analyze the finite-length mode shape to avoid edge effect phenomenon. Jaiswal and Pande [16] carried out numerical studies for damage detection in a beam structure by applying spatial wavelet transform to mode shape curvatures. This paper worked on the crack depths larger than%17 of the beam height and cracks were at the distance greater than%17 of the beam length from one end of wavelet analysis range. A wavelet-based technique has been presented for the crack detection in beam structures [17,18]. In these two simulation studies, Timoshenko beam theory has been used to model the beam structure. They conducted spatial wavelet analysis (Gabor family) for the mode shapes of a beam in both single and multiple cracks conditions. Although, results show that this technique worked for cracks larger than 10% of the beam thickness, these studies were limited for cracks located between 10% and 85% of the beam length. These two studies failed to detect cracks close to the measurement boundaries. Previous simulation studies show that wavelet based damage detection methods can detect crack depths larger than 10% of the structure (Beam or plate) thickness. Furthermore, the closest crack to the signal boundary, which has been successfully detected, is located with distance of 10% of the signal length from the signal boundary.

In the case of practical applications, experimental studies are needed verifying the results from the simulation studies. Xu et al. [19] conducted numerical and experimental studies on damage detection in plates using wavelet transform. They made a notch with depth of 50% of the Plate thickness around the middle of the plate. The damage detection was successfully carried out by applying the wavelet transform on the obtained mode shapes by laser vibrometer. Wu and Wang [20] did experimental studies on damage detection of a beam structure with wavelet transform. They used a high-resolution laser profile sensor to measure the deflection profile of a cracked aluminum cantilever beam subjected to a static displacement at its free end. De-noise techniques have been introduced to make the detection more efficient. The smoothed static profile of the cracked beam has been analyzed with Gabor wavelet to identify the crack with depth of 26% of the beam thickness. Using the same method, Wang and Wu [21] also achieved the detection of a delamination in a beam structure by using Gabor wavelet transform on the static displacement of the beam structure. Rucka [22] worked on wavelet-based damage detection technique on a cantilever beam with a single notch. He presented experimental and numerical analysis of damage detection based on higher order modes. The experimental results for detection of the notch with depth of %20 of the beam height showed a clear perturbation at notch location. However, for depths smaller than %20 of beam height, the results were not reliable since they were noisy. Algaba et al. [23,24] used wavelet transform to analyze the mode shape signal of a beam structure. The mode shape signal was obtained by embedded accelometers on the beam structure. In these papers, theoretical and experimental studies were conducted on different crack positions and depths. The experimental studies were based on the crack depths larger than 20% of the beam height. Furthermore, authors studied cracks located between 25% and 75% of the beam length. Reddy and Swarnamani [25] performed numerical and experimental studies on a wavelet-based damage detection and localization method for a plate structure. The mode shapes and strain energy data of the structure have been analyzed in this paper. From previous literature, experimental part of this work only showed successful detection of damage with depth larger than 15% of the plate thickness. Damages in the vicinity of the spatial signal boundaries were not analyzed and studied.

Although many efforts have been devoted to detect and localize cracks by using wavelet transform. Still identification of crack depths smaller than 15% of the beam height have not been achieved experimentally. Moreover, identification process for cracks, which are close to the signal boundaries, is still a problem blocking the application spatial wavelet transformation to some cases of damage detection because of edge effect with large wavelet coefficient values in the vicinity of measurement boundaries in the wavelet analysis. In the previous researches, some methods for edge effect reduction have been