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A novel approach for classification of loads on plate structures using artificial neural networks

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ABSTRACT

In this study the location of applied load on an aluminum and a composite plate was identified using two type of neural network classifiers. Surface Response to the Excitation (SuRE) method was used to excite and monitor the elastic guided waves on plates. The characteristic behavior of plates with and without load was obtained. The experiments were conducted using two set of equipment. First, laboratory equipment with a signal generator and a data acquisition card. Then same test was conducted with a low cost Digital Signal Processor (DSP) system. With experimental data, Multi-Layer Perceptron (MLP) and Radial Basis Function (RBF) neural network classifiers were used comparatively to detect the presence and location of load on both plates. The study indicated that the Neural Networks is reliable for data analysis and load diagnostic and using measurements from both laboratory equipment and low cost DSP.

1. Introduction

Manny structural health monitoring (SHM) techniques has been developed for integrity surveillance of aerospace structures [1]. SHM techniques may be conducted in two major approaches: passive and active methods [2]. Passive methods rely on measuring and monitoring system's operational parameters such as temperature, vibration, and stress. Active methods excite a physical property of the structure and detect the problems by measuring the response with proper sensors. Among active SHM techniques, Lamb waves based methods [3,4] and Impedance based methods [5,6] have received considerable attention during the last decade. Lamb waves are ultrasonic guided waves that propagate between two free parallel surfaces. Damages in the structure could be identified by monitoring certain characteristics of transmitted and received signals such as amplitude and energy of signal [7]. The Electromechanical Impedance (EMI) method is another major SHM approach that evaluates the integrity of the structure by measuring the electrical impedance of piezoceramic (PZT) material that is directly related to the mechanical impedance of the host structure [8].

Load monitoring and measurement is essential especially in the area of bolted joints aerospace structures and compensation of environmental and operational influence on the guided-waves based SHM. The problem of load monitoring if not addressed properly could create difficulties in interpreting and monitoring the health of structures leading to false diagnostic and prognostic. Continuous load monitoring on a structure will not only enable the condition based monitoring but also will increase the overall

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safety and reliability of structure [9]. There are some studies in the literature about the effect of load on ultrasonic guide-waves [10,11]. However, majority of these studies were carried out to develop load compensation models for ultrasonic guided waves based SHM with the lamb wave based methods. In this study, for the first time the effect of the load on the system response using the surface response to excitation method is investigated which is a techniques similar to EMI methods.

In practical applications researchers have used impedance analyzers such as HP 4194A through a surface bonded piezoelectric sensor/actuator to detect the presence of damage by monitoring the structural impedance [12]. The impedance analyzers are very expensive, high powered and bulky. Also reliability problems have been reported when they are connected to piezoelectric elements with long wires. Due to these reasons development of low cost miniaturized devices for measuring impedance has been suggested [13]. Another approach to measure the impedance is use of analogue devices such as impedance-to-digital converters (IDCs). These devices are compact and may be suitable option due to high precision analogue processing functions [14]. However, IDCs are not as powerful as impedance analyzers and their amplitude of excitation signal is limited and they are not feasible for in-filed real-time applications. Using the laboratory equipment, a data acquisition system with a programmed real time analyzer may be used to monitor the characteristics of the piezoelectric element with the help of a relatively simple circuit. Digital signal processor (DSP) based circuits have been reported to effectively be able to replace to traditional impedance analyzer and improve the practicality of Impedance method [15–17]. However, the impedance method is a qualitative approach for general evaluations of structural integrity and normally EMI damage indexes do not provide quantitative information about location and size of damage on the structure.

Surface Response to Excitation (SuRE) method is an alternative approach for impedance method with similar characteristics that offers a flexible and low cost implementation [18]. In SuRE method instead of using a single PZT element for both excitation and sensing, the experimentations are conducted with separate set of exciter and sensors. The high frequency surface guided waves are excited (usually within 20–400 kHz) and the response is measured to form the frequency transfer spectrum of response in another location [19]. This allows to exploit the low attenuation property of surface guided waves to cover considerably larger area on the structure for monitoring. Also increasing the number of sensing points using non-contact Doppler Laser Vibrometer (LSV) has allowed to localize structural integrity issues in bolted joints [20]. The efficiency and reliability of SuRE method has been studied for simple structural shapes using various implementation techniques [21].

Composite materials have been preferred for critical applications when maximum strength/weight ratio and corrosion resistance are required. In addition, composite materials with embedded sensors have been considered for aerospace vehicles with powerful structural health monitoring (SHM) capabilities. Piezoelectric materials have been widely used for SHM applications due to their dimension change capability with charge and low price [22].

So far the evaluation of performance of the SuRE method has been limited to calculation of sum of square of differences between the reference and altered spectrum measurement. In order to have a reliable structural health monitoring system capable of practical application in aerospace industries and structures with complex geometries, a more powerful technical approach should be considered [23]. Neural networks have proven to be a strong tools for data classification techniques in health monitoring of aerospace structures. In this study, the experimentations are designed to evaluate the performance of SuRE method in structural health monitoring of aluminum and composite plates using two neural network algorithms; the Multi-Layer Perceptron (MLP) and Radial Basis Function (RBF) were used to classify various load scenarios. Data captured by laboratory equipment and compared to those results of an embedded low cost digital signal processing (DSP) device.

2. Theoretical background

2.1. Surface response to excitation method

In this study Surface response to excitation method (SuRE) was employed through a piezoelectric exciter and sensor for load monitoring of an aluminum and composite plates. The SuRE method monitors the condition of structure actively by exciting the high-frequency surface waves. The structure is excited using a piezoelectric element and the amplitude of response is monitored in another position on the plate.

Frequency spectrums are signature characteristic of a structure and remain consistent when structure is intact. Once the condition of structure changes due to applied load, fatigue crack, corrosion, etc. frequency spectrum changes [19,21,24]. The surface waves are excited with a sweep sine wave over a certain frequency range. Fig. 1 shows time domain response signal when no load was applied on the aluminum plate.

The Fast Fourier Transformation (FFT) was used to calculate the frequency transfer function. First, 1 k–200 kHz range of excitation was applied and the spectrum of the response of excitation is shown in Fig. 2. Since the highest peaks were observed at 140 k–200 kHz, then this range was selected for the experiments.

The spectrogram of the response is showed in Fig. 3. The time-frequency spectrogram correlates the received signal frequency to the time domain during sweep. The red line represents excitation signal with high amplitude and the weaker yellow lines show the reflections from plate edges.

To evaluate the changes in the spectrum, the Sum of the Square of Differences (SSD) of frequency response spectrum with respect to baseline is used. The SSD for each load