Chapter 35
Butterworth Filter Application for Structural Health Monitoring

Ahmed Abdelgawad
Central Michigan University, USA

Md Anam Mahmud
Central Michigan University, USA

Kumar Yelamarthi
Central Michigan University, USA

ABSTRACT

Most of the existing Structural Health Monitoring (SHM) systems are vulnerable to environmental and operational damages. The majority of these systems cannot detect the size and location of the damage. Guided wave techniques are widely used to detect damage in structures due to its sensitivity to different changes in the structure. Finding a mathematical model for such system will help to implement a reliable and efficient low-cost SHM system. In this paper, a mathematical model is proposed to detect the size and location of damages in physical structures using the piezoelectric sensor. The proposed model combines both pitch-catch and pulse-echo techniques and has been verified throughout simulations using ABAQUS/ Explicit finite element software. For empirical verification, data was collected from an experimental set-up using an Aluminum sheets. Since the experimental data contains a lot of noises, a Butterworth filter was used to clean up the signal. The proposed mathematical model along with the Butterworth filter have been validated throughout real test bed.

INTRODUCTION

It is necessary to make sure that the physical structures such as buildings, bridges are structurally safe and sound for the safety of human beings. There are chances that the structure of an instrument is affected by some internal damage, even if it appears healthy from the outside. Accordingly, periodic structural monitoring of complex configurations such as bridge, high-rise structure, and aircraft is necessary (Boukabache et al., 2012). By using only human intervention to find the damage in structural level,

DOI: 10.4018/978-1-5225-9863-3.ch035

high-consequences decisions cannot be made (Mascarenas et al., 2013). So, researchers have proposed many approaches for SHM where limited or no human interventions are required.

SHM is a process where nondestructive evaluations techniques are used to detect location and extent of damage, calculate the remaining life, and predict a potent accident. Different types of sensors such as ultrasonic, piezoelectric, etc. can be used for SHM to generate signals that can travel through solid configurations. The electromagnetic acoustic transducer can generate horizontal mode guided wave, but can only be used in case of magnetic materials. Laser-based ultrasonic instruments are one other method but are expensive and have limited application in engineering (Dai & He, 2014). Guided waves such as Lamb wave can be transmitted and received in solids using piezoelectric transducers (PZT) and these waves can be used for SHM (Boukabache et al., 2012; Park et al., 2010; Giurgiutiu, 2010; Almeida et al., 2014). These Lamb waves are not only reliable due to their sensitivity to changes in structures, but can be much more cost effective as well (Yu et al., 2004; Ciampa et al., 2010). If there is a damage in a structure, the guided waves will be reflected or scattered by the damage. To determine the damage, the difference signal is acquired and compared with a damage free signal. For structural damage localization, irrespective of the geometrical or imaging method used, the key to this process is the acquired time of flight and amplitude of the response to the signal. These factors directly determine the precision of the localization of the damage. The time of flight of these guided waves is linear and is directly dependent on the properties of the material, such as its modulus of elasticity and modulus of rigidity.

However, there are few challenges as variations of the system might cause significant changes in the response of the sensors, masking potential signal changes due to structural defects. Signal processing is one of the key components of SHM (Amezquita-Sanchez & Adeli, 2014) as the signals retrieved from the sensors contain noises such as environmental effect, temperature changes, etc. Various signal processing techniques have been used to improve the SHM performance such as wavelet analysis which can be used to remove noise from the signal and detect damage (Hera & Hou, 2004). For applying digital signal processing, sensors outputs which are inherently analog (continuous), required in the digital form. Sampling is a signal processing technique which is mainly used to convert an analog signal to digital (Kim et al., 2007). If a large number of sensor nodes are used for SHM, an amount of data can be larger in size. Data compression is helpful to handle a large amount of data efficiently (Jindal & Liu, 2012; Park et al., 2010). Fast Fourier transform (Kim et al., 2007; Jindal & Liu, 2012), wavelet transform is used to get the frequency spectrum of sensor's output signal (Park et al., 2010). The advantage of using wavelet transform over Fourier transform is signal can be obtained in the frequency domain as well as in time domain using wavelet (Amezquita-Sanchez & Adeli, 2014). Cross-Correlation (CC) (Kim et al., 2007), Principal Component Analysis (PCA) (Mascarenas et al., 2013), Statistical time series analysis can also be used as strong tools for SHM. CC is a measure of similarity between two signals (For SHM- signals are previously saved from healthy structure and signal from real time) (Dai & He, 2014). PCA uses orthogonal transformation to establish the linear relationship between input and output. Linear input-output relationship developed for a structure can be helpful for SHM process. Statistical Time Series analysis is used to design an approximate mathematical model using input-output data. The mathematical model derived for a structure can be utilized for SHM (Amezquita-Sanchez & Adeli, 2014).

Finite Element Analysis (FEA) simulation software, such as ABAQUS, can be used to simulate guided longitudinal waves. Based on the input of the materials properties such as density and modulus of elasticity, this software can simulate feedback from the sensors used to detect damage in solid configurations. In this paper, two PZT are considered to transmit and receive the signal waves. The proposed model combines both pitch-catch and pulse-echo techniques. One of these sensors (actuator) transmits