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A VIBRATION DETECTION SYSTEM BASED ON FIBER SENSOR AND SIGNAL PROCESSING WITH WAVELET TRANSFORM

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ABSTRACT

This paper describes a novel vibration monitoring system using optical fibers, the optical sensor being exploited in this study is based on multimode technology, the active component is an optical device that measures strains by means of detecting changes in the reflected wavelength of light; the benefit of optical fiber sensor is electromagnetic immunity (EMI), reliability, and durability. The intensity-based sensor structure the light intensity from the source is modulated by the transducing device; then it is guided to the detector, translated to electronic signals, which results in time-frequency domain analysis. A variety of time-frequency methods have been developed, including the short-time Fourier transform (STFT), Hilbert-Huang transform (HHT), Wigner-Ville distribution (WVD), and wavelet transform (WT). In this work, the last approach is utilized; thanks to wavelet transform which offers several different valuable mother wavelets that can be employed in the signal analysis, including Haar, Meyer, Morlet, Daubechies, Mexican Hat, Gabor, Gaussian, and others. The new technique, offers a multiresolution analysis domain which shows a potential performance in vibration detection and measurement.

Keywords: Optical fibers sensor, vibration monitoring system, wavelet transform.

INTRODUCTION

Since a few decades ago, fiber optic sensors technology has experimented a revolution by the hand of fiber optic telecommunication product outgrowths with optoelectronic devices [1–4]. The measurement of physical and chemical properties of liquids is essential for many applications in engineering, such as the process monitoring and quality control in food, pharmaceutical and chemical industries, as well on the laboratorial analysis and research activities [1].Optical fibers (OFs) development in 1966 revolutionized fields such as telecommunications and sensing, leading to the creation of high sensitivity and controlled systems based on light guidance. In this sense, the application of optical fiber sensors on the measurement of physical parameters has been widely reported, particularly motivated by its unique advantages, such as high sensitivity, lightweight, and immunity to electromagnetic interference [2]; Other advantages entail their aptitude to be used even in the presence of unfavorable environmental conditions such as noise, strong electromagnetic fields, high voltages, nuclear radiation, in explosive or chemically corrosive media, at high temperatures, among others. Optical-fibers-based sensors are low cost and efficient solutions for several industries due to their high sensitivity, small size, robustness, flexibility, and ability for remote monitoring as well as multiplexing. New areas of opportunities include the potential of replacing the majority of environmental sensors in existence today, as well as opening up entire markets where sensors with comparable capability do not exist.

Ground vibration is a common nature phenomenon also known as underground sound or geosounds; The advanced laser-based measurement techniques have a number of significant advantages over other sensors for monitoring of vibration. In particular, it offers a non-contact perturbation-free means of monitoring test-objects. Such laser and fibre-optic technologies are providing a new approach to vibration monitoring in electromechanical equipment.

In this research, a vibration based fiber sensor for the measurement to Ground vibration is reported. The sensor response is demonstrated first for the detection of the vibration of the sample, thanks to wavelet transform which offers several different valuable mother wavelets that can be employed in the signal analysis, including Haar, Meyer, Morlet, Daubechies, Mexican Hat, Gabor, Gaussian, and others. The new technique, offers a multiresolution analysis domain which shows a potential performance in vibration detection and measurement.

2. INTENSITY-BASED VIBRATION SENSORS

Intensity-based sensor techniques have been studied and implemented in the last 25 years (see Figure 2). A wide range of configurations can be used, such as fiber microbending, fiber-to-fiber coupling, moving masks/gratings, and modified cladding [6, 10–17]. Several sensors have been proposed in relevant researches to record ground vibration caused by debris flow, such as seismometer [1,2], geophone [3–5], microphone [6], accelerometer [7] and hydrophone [8].There are many fibre-optic vibration sensors described in the literature [29–45], those based on interferometric encoding via optical phase modulation offer the highest sensitivity.

3. WAVELET TRANSFORM

The wavelet transform is a powerful tool for multiresolution analysis. The main advantage of using wavelet transform is that it is well-suited to manage different image resolution and allows the image decomposition in different kinds of coefficients, while preserving the image information.

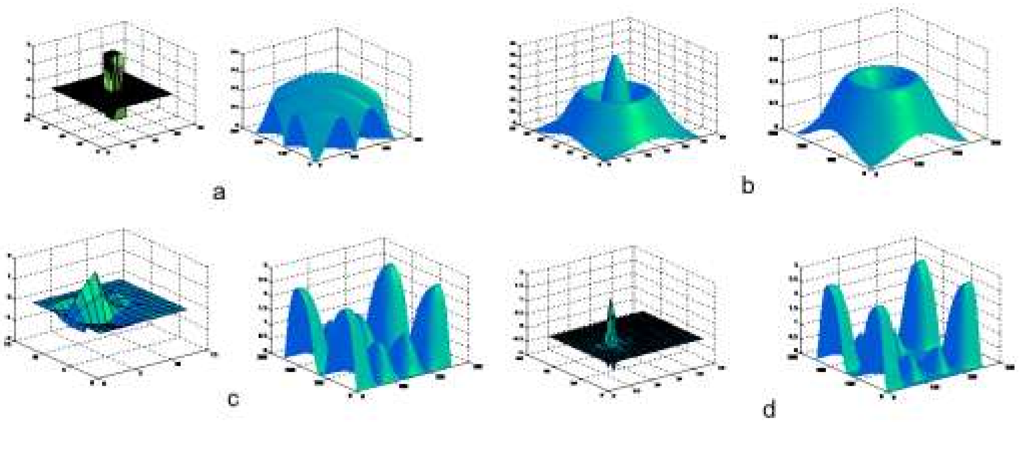


Fig.1. Wavelets and Fourier transforms a) Harr; b) Mexican hat; c) Daubechies; d) Coiflets.

Wavelet transform has been proven to very efficient in signal analysis. It finds applications in different areas of engineering due to its ability to analyze the local discontinuities of signals. The main advantages of wavelets is that they have a varying window size, being wide for slow frequencies and narrow for the fast ones, thus leading to an optimal time–frequency resolution in all the frequency ranges. It can be defined as follows (Grossmann and Morlet (1984)):

$$f(x)=\sum_{i,j} a_{i,j}\psi_{i,j}(x) \tag{1}$$

Where i and j are integers, the functions $\psi_{i,j}(x)$ are the wavelet expansion functions and the two-parameter expansion coefficients $a_{i,j}$ are called the discrete wavelet transform (DWT) coefficients of $f(x)$.

The wavelet transform is an inner product between a signal $f(x,y)$ and a set of wavelets $h^*_{a,b}(x,y)f(x,y)$ given as:

$$W(a_x,a_y,b_x,b_y)=\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} h^*_{a,b}(x,y)f(x,y)dxdy \tag{2}$$

Where $*$ denotes the complex conjugate. A mother wavelet $h^*_{a,b}(x,y)d$ is a finite duration window function that can generate a family of daughter wavelets by varying dilation a and translation b and is given by:

$$h_{a,b}(x,y)=\frac{1}{\sqrt{a_x a_y}}h\left(\frac{x-b_x}{a_x},\frac{y-b_y}{a_y}\right) \tag{3}$$

The mother wavelet must satisfy a certain admissibility condition that it must be oscillatory to have a zero integrated area. In the frequency domain the wavelets are expressed as:

$$H_{a,b}(f_x,f_y)=\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty}\exp[-i2\pi(f_x x+f_y y)]h_{a,b}(x,y)dxdy==\sqrt{a_x a_y}\exp[-i2\pi(f_x b_x+f_y b_y)]H(a_x f_x,a_y f_y) \tag{4}$$

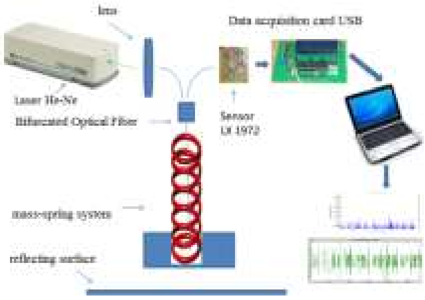
Where $H(f_x,f_y)$ is the Fourier transform of the mother wavelet $h(x,y)$. Both $h(x,y)$ and $H(f_x,f_y)$ should have the same smoothness and concentration in time and frequency domains. For localization of $H(f_x,f_y)$, $H(0,0)$ should be equal to zero and $H(f_x,f_y)$ should vanish above a certain frequency. Thus wavelets are essentially band pass filters.

Function	Definition
Haar	$h_{a_x,a_y;b_x,b_y}(x,y)=\begin{cases}\frac{1}{\sqrt{a_x a_y}}, & \text{If } 0\le\frac{X-b_1}{a_1}<\frac{1}{2}\wedge 0\le\frac{y-b_2}{a_2}<\frac{1}{2}\\ \frac{-1}{\sqrt{a_x a_y}}, & \text{If } \frac{1}{2}\le\frac{X-b_1}{a_1}<1\wedge\frac{1}{2}\le\frac{y-b_2}{a_2}<1\\ 0, & \text{Otherwise}\end{cases}$
Mexican hat	$Mexh_{a_x,a_y;b_x,b_y}(x,y)=\frac{\left[1-\left(\frac{x-b_x}{a_x}\right)^2-\left(\frac{y-b_y}{a_y}\right)^2\right]\exp\frac{\left[\left(\frac{x-b_x}{a_x}\right)^2+\left(\frac{y-b_y}{a_y}\right)^2\right]}{2}}{\sqrt{a_x a_y}}$

Table 1. Wavelet Haar and Mexican-hat.

4. PRINCIPLES AND FIBER OPTIC SENSOR CONFIGURATION

A schematic of the fiber sensor is show in Fig. 2. The light emitted by the He-Ne laser source is launched into 3m length standard multimode bifurcated fibers coated with polymer buffer. The transmitter is a light beam (laser), which has a regulated power supply that meets the conditions and characteristics of the laser to the operating voltage and current. The laser used was a Laser He-Ne 10mW with a wavelength of 633nm, and whose features were analyzed, calculation of wavelength, polarization, Gaussian distribution with experimental method [32].



(a)

(b)

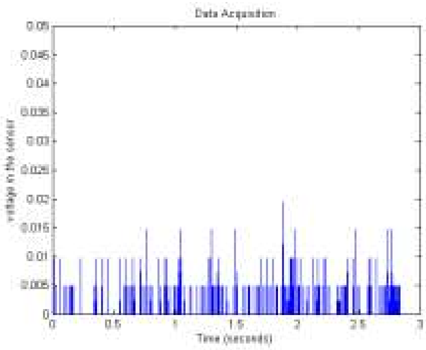
Fig. 2. Configuration of the fiber sensor: (a) Schematic block, (b) Vibration sensor implantation

The system consists of a diffuse optical fiber, a conventional laser He-Ne 633nm, 10mW of power, an ambient light sensor LX1972, a USB data acquisition card design with PIC18F2550 USB microcontroller, LCD screen for viewing and notebook for data analysis. The principle used in the detection of the lambda is based on specular reflection and absorption. The optoelectronic device designed and built used the absorption and reflection properties of the vibration under study, having as active optical medium a bifurcated optical fiber, which is optically coupled to an ambient light sensor, which makes the conversion of light signals to electrical signals, procedure performed by a microcontroller, which acquires and processes the signal and send to notebook.

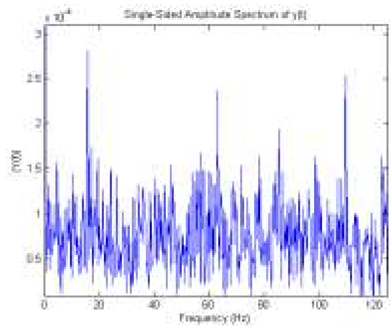
5. SIGNAL PROCESSING AND ANALYSIS

Fast Fourier transform (FFT) is often applied to transform time series data into the frequency domain to reveal the spectral behaviors of periodic signals. The ground vibration signals detected by the fiber-optic sensor were compiled by the data acquisitions card (USB DAQ card) for subsequent signal processing by a computer notebook and MATLAB toolboxes.

Experiemental results from a vibration detection system based on fiber sensor and signal processing with wavelet transform are shown in Fig. 3. The data in time domain, FFT spectrum, and wavelet transform haar level 1 are shown in subfigures (a), (b), and (c) respectively. In Fig. 4. Show the wavelet spectrum of Daubechies (a) Leve 1 1db and (b) Level 1 3 db. In Fig. 5. Show the wavelet coefficients of Haar Leve 1 (a) and Daubechies 1db Level 1 (b).



(a)



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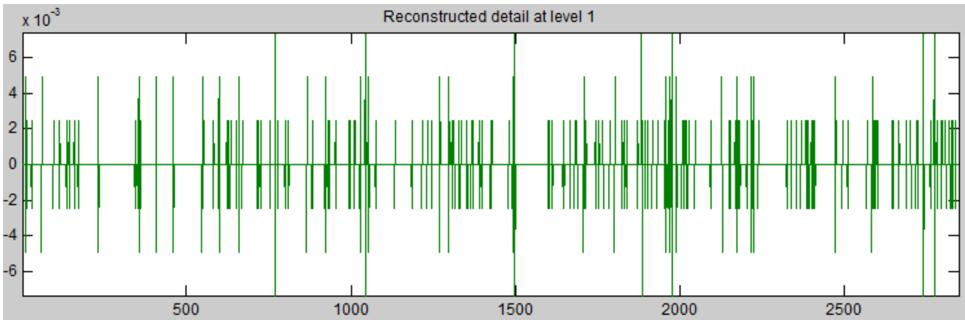
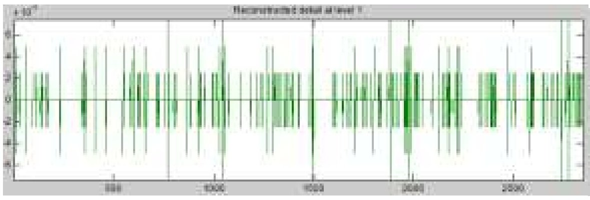
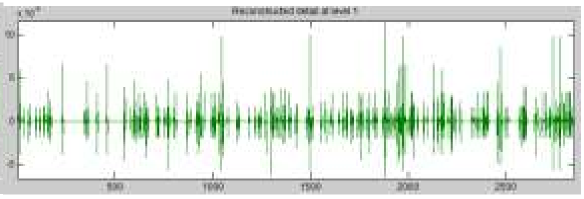


(c)

Fig. 3. Background noise detected by fiber optic sensor: (a) time-series data, (b) FFT spectrum, and (c) Wavelet spectrum (Haar Level 1) .

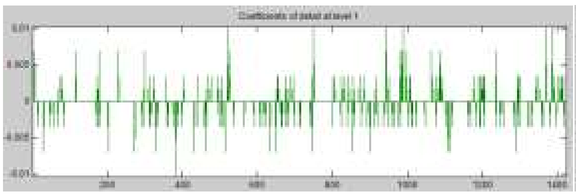


(a)

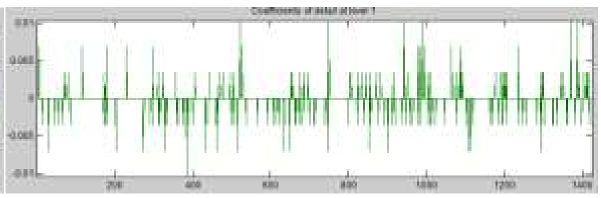


(b)

Fig. 4. Wavelet spectrum Daubechies: (a) Leve 1 1db and (b) Level 1 3 db.



(a)



(b)

Fig. 5. Wavelet coefficients: (a) Haar Leve 1 and (b) Daubechies 1db Level 1 .

Subfigure (c) in Fig. 3 shows peak spectrum around of 18, 60 and 110Hz. The experimental results show that the proposed fiber optic sensor will suit for monitoring vibrations.

Figures 4 and 5 show the wave form reconstruction spectrum using wavelet transform Haar and Daubechies with different level.

6. CONCLUSIONS

This paper has reviewed the main optical fiber sensor techniques for vibration measurement. An overview of the different techniques used in vibration sensors was presented. Intensity-based sensors were presented in first place, showing the setup used for vibration measurement. The vibration may be generated by earthquakes, debris flows, landslides, and rock impacts on the ground. This type of sensors can be used both in reflection and transmission modes; however, the high dependence of the measurement accuracy to the source power level is a weak point of in front of the other techniques presented in this paper. Vibration sensing system of this research detect the signal, after Wavelet (Haar and Daubechies) transformed, the spectrums of time–frequency domain show that peak value of fiber optic sensor; is possible to say that optical fiber sensors can provide accuracy, durability, and economic configurations for vibration measurement, thus increasing the range of applications and opening new research fields.

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