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Identification of Cracks in a Structure Using Fibre Optic Sensors

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Abstract - **Fibre optic sensors modulate some of the features in the light wave used in the optical fibre. The features such as intensity and phase modulation are the most commonly features used in an optical fibre as a sensor. And an OTDR (optical time domain reflectometry) is a common system used to detect the change in these features. In this paper we study the change of these features in crack detection applications using AR filter coefficients and Kurtosis implemented with wavelet decomposition.**

Keywords - **Fiber optics, Light wave, sensor, Filter, carack identification**

I. INTRODUCTION

A conventional optical fiber line testing system, which uses OTDR based on a single wavelength source, is used to detect failure in an optical fiber [1]. OTDR testing is the only method available for determining the exact location of broken optical fiber in an installed fiber optic cable when the cable jacket is not visibly damaged. It provides the best method for determining loss due to individual splice, connector or other single point anomalies installed in a system. It also provides the best representation of overall fiber integrity [2].

An OTDR is also known as optical radar [3] . In the same way as an radar locates distant objects, the OTDR can also locate defects and problems in an optical fiber. Although their method is different where radar used radio frequency (RF) signal scanned over an area, meanwhile an OTDR used short pulses of light transmitted down a narrow fiber, but both techniques rely on signals reflected back to a receiver. Typical targets that an OTDR can detect and locate include connections, splices, cracks and bends along a fiber that can extend for over 100 km. OTDR can also measure characteristics such as total fiber loss, connector insertion loss and loss per unit length. These days, OTDR works with multimode fibers that conduct light at wavelengths of 850 nm and 1300 nm and with single mode fibers that conduct light at 1310 nm, 1550 nm and 1625 nm (or 1650 nm) wavelengths[6].

However, OTDR has some disadvantages. The OTDR signatures are sometimes difficult to interpret and hence, it is not presently recognized as a standard attenuation measurement method. For single-mode fiber, OTDR has low signal-to-noise (SNR) ratios and this limits the lengths that can be measured using a laser diode source. The resolution of the best and currently available OTDR's is of the order of 100 m, hence, it is impossible to resolve the first one or two splices in an installed fiber link. Also OTDR's do not measure loss directly, as with the cut-back method, but the loss is inferred from the measured backscatter signature of the fiber. Differences in the backscatter capture coefficient along the fiber link produces inaccurate loss values, especially when the fiber spot-size are different, and many times a splice gain is reported. This can be eliminated by averaging two bidirectional measurements, but only at the cost of doubling the time and effort required to make the attenuation measurement [4]. It is important to be able to locate any fiber break after the installation of the network. Furthermore, a simple and effective monitoring configuration is highly desirable for timely failure detection along the fiber link [1]. A particular problem in this regard is that a failure occurred at the drop region must be located without affecting the service to other customers [5]. The monitoring should be performed constantly while other channels are still in service to maximize the link utilization [1]. Therefore, an optical line monitoring and testing system is essential for failure detection to improve the service reliability and reduce the maintenance costs of access networks.

II. DESCRIPTION OF THE WORK

In this paper, for identifying the cracked signal decomposition is required for accurate and detection of type of damage occurred in the fibre optic signal. Wavelets are most properly used for analyzing the signal both in time and frequency domain. After decomposing the signal, signature extraction is required for comparing with original signal. Here the AR parameter models are used for signal compression and then signature is extracted by calculating kurtosis of the above filter coefficients.The flow chart is shown below figure1.

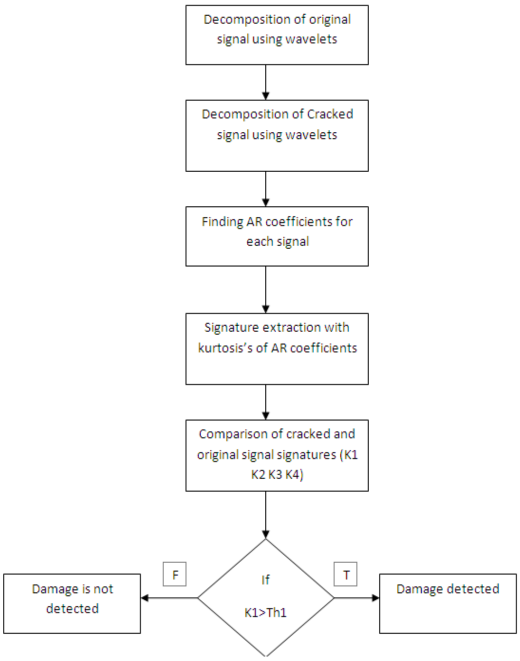

Fig.1. Flow chart of damage identification using AR models

Wavelets transform

The basic analytical expressions for the DWT will be presented here; however the transform is easier to understand, and easier to implement using filter banks, as described in the next section. The DWT is often introduced in terms of its recovery transform as shown in equation 1:

$$x(t)=\sum_{k=-\infty}^{\infty} \sum_{l=-\infty}^{\infty} d(k,l)\, 2^{-k/2}\Psi(2^{-k}t-l) \text{ …….(1)}$$

Here k is related to a as: $a=2^k$; b is related to l as: $b=2^k l$; and d(k,l) is a sampling of W(a,b) at discrete points k and l.

Filter banks

For most signal and image processing applications, DWT-based analysis is best described in terms of filter banks. The use of a group of filters to divide up a signal in to various spectral components is termed sub band coding. The waveform under analysis is divided in to two components, $y_{lp}(n)$ and $y_{hp}(n)$, by the digital filters $H_0(\omega)$ and $H_1(\omega)$ as shown in figure 2. The spectral characteristics of the two filters must be carefully chosen with $H_0(\omega)$ having a low pass spectral characteristic and $H_1(\omega)$ a high pass spectral characteristic. The high pass filter is analogous to the application of the wavelet to the original signal, while the low pass filter is analogous to the application of the scaling or smoothing function.

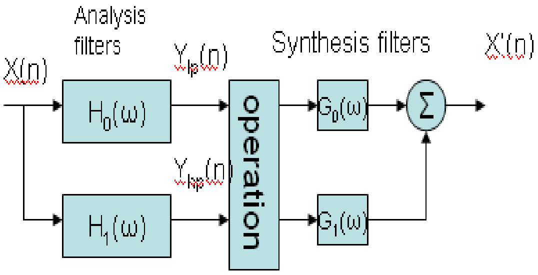

Fig.2. Sub – band decomposition using wavelets.

Designing the filters in a wavelet filter bank can be quite challenging because the filters must meet a number of criteria. A prime concern is the ability to recover the original signal after passing through the analysis and synthesis filter banks. Accurate recovery is complicated by the down sampling process. Note that down sampling, removing every other point, is equivalent to sampling the original signal at half the sampling frequency.

A typical wavelet application using three filters, the down sampling and up sampling process are shown in below figure 3 & figure 4.

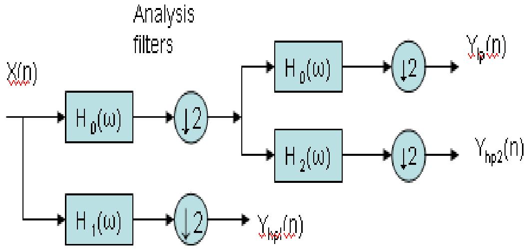

Fig.3. Second level decomposition of wavelets.

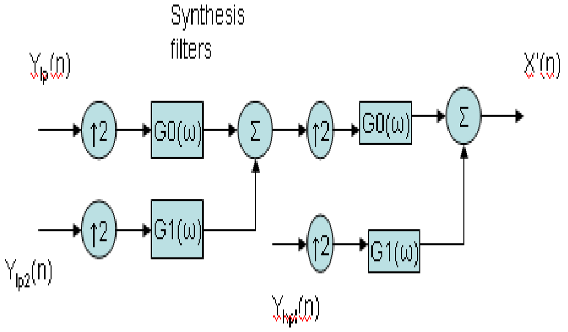

Fig.4. Second level synthesis of wavelet decomposition

Autoregressive Moving Average Models

A wide-sense stationary ARMA(p,q) process may be generated by filtering unit variance white noise v(n) with a causal linear shift-invariant filter having p poles and q zeros whose transfer function is shown in equation (2),

$$H(z)=\frac{B_q(z)}{A_p(z)} = \frac{\sum_{k=0}^{q} b_q(k)\, z^{-k}}{1+\sum_{k=1}^{p} a_p(k) z^{-k}} \qquad (2)$$

Therefore, a random process x(n) may be modelled as an ARMA(p,q) process using the model shown in Figure 5 where v(n) is unit variance white noise. To find the filter coefficients that produce the best approximation $\hat{x}(n)$ to x(n) can be obtained by replacing the least squares error ε_{LS} with a mean square error as shown in equation (3)

$$\xi_{MS} = E\left\{|x(n) - \hat{x}(n)|^2\right\} \qquad (3)$$

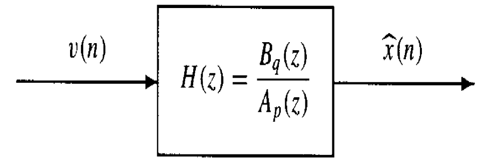

Fig.5. Modelling a random process x(n) as the response of a linear shift-invariant filter to unit variance white noise.

The above filter coefficients can be obtained by the following yule-walker equation

$$r_x(k) + \sum_{l=1}^{p} a_p(l) r_x(k-l) = 0 \text{ ; } k > q \text{……(4)}$$

III. RESULTS AND DISCUSSION

The figure 6 shows the original and cracked fibre optic normalized voltage signal. The cracked signal shown in the figure 6 consists of voltage hype in between 300 to 315 samples. So our objective is to detect this type of crack. The figure 7 and 8show three level decomposition of the original and cracked signals with db wavelets. The next is to compress the decomposed signal in each level, figure 9 and 10 shows the plot of AR parameter coefficients withdb wavelets. Finally the signature is obtained by calculating the kurtosis at each level i.e. k1, k2, k3, k4 respectively. Table 1 shows signatures of original (k) and cracked (k_d). From the table 2, it is clear that there is a large difference between k_1 and k_2 values of k and k_d that shows the presence of crack.

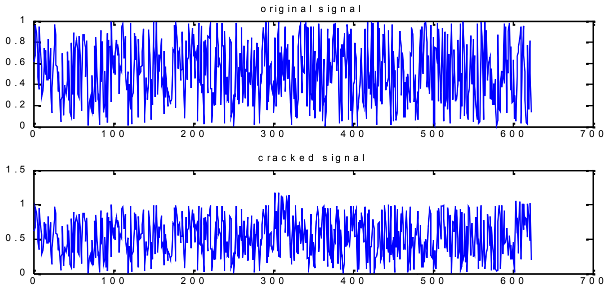

Fig.6. original and cracked signals

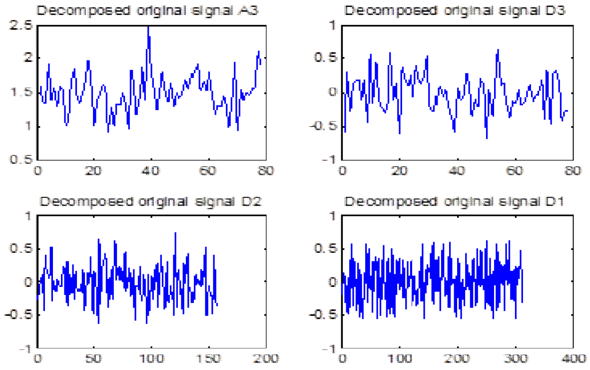

Fig.7. decomposed original signals A3, D3, D2 and D1 with db wavelets

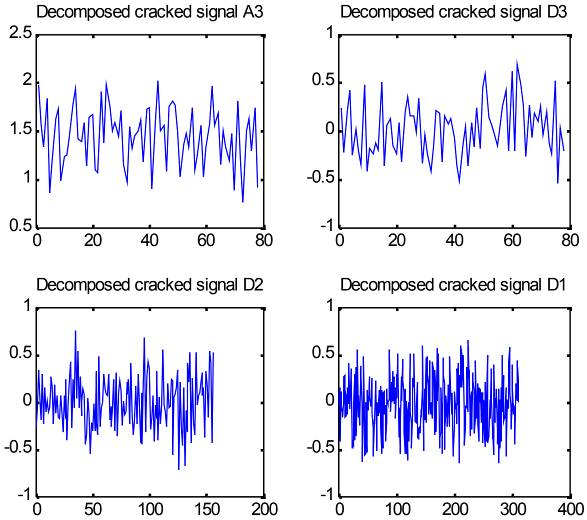

Fig.8. decomposed cracked signals A3, D3, D2 and D1 with db wavelets

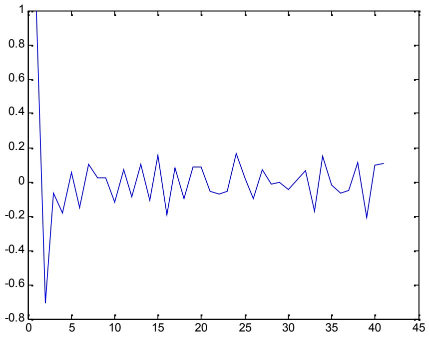

Fig.9. Plot of original AR coefficients of A3 with db

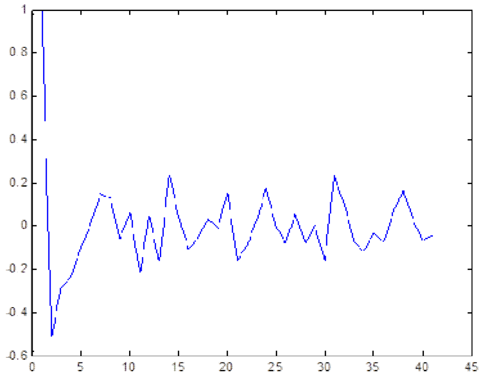

Fig.10. Plot of original AR coefficients D1 with db

Table 1: signature extraction using Db wavelet decomposition and AR parameter models

	K1	K2	K3	K4
K	14.7696	11.7224	15.8067	8.2566
Kd	10.7813	19.5746	16.6000	8.3650

K1 = fourth order cumulant of decomposed signal A3
K2 = fourth order cumulant of decomposed signal D3
K3 = fourth order cumulant of decomposed signal D2
K4 = fourth order cumulant of decomposed signal D1

Table 2: signature extraction using Haar wavelet decomposition and AR parameter models

	K1	K2	K3	K4
K	14.7696	11.7224	15.8067	8.2566
Kd	10.7813	19.5746	16.6000	8.3650

IV. CONCLUSION

From the above analysis it is concluded that the signatures extracted from the proposed algorithm shows an improvement of 18% accuracy over the other algorithms like correlation coefficient, power spectral density analysis etc. And the signature extracted using db wavelet technique has better damage level identification efficiency than the haar wavelet technique

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