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# Labview-Based System for Fiber Links Events Detection

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***Abstract*—With the rapid development of modern communication, diagnosing the fiber-optic quality and faults in real-time is widely focused. In this paper, a Labview-based system is proposed for fiber-optic faults detection. The wavelet threshold denoising method combined with Empirical Mode Decomposition (EMD) is applied to denoise the optical time domain reflectometer(OTDR) signal. Then the method based on Gabor representation is used to detect events. Experimental measurements show that signal to noise ratio (SNR) of the OTDR signal is improved by 1.34dB on average, compared with using the wavelet threshold denosing method. The proposed system has a high score in event detection capability and accuracy. The maximum detectable fiber length of the proposed Labview-based system can be 65km.

***Keywords*—Empirical mode decomposition (EMD), events detection, Gabor transform, optical time domain reflectometer (OTDR), wavelet threshold denoising.

## I. Introduction

With the rapid development of optical communication, diagnosing and maintenance of the fiber-optic are drawing a lot of attention. Optical time domain reflectometry (OTDR) has been widely used for characterizing losses and locating faults in fiber communication links [1]. Same as radar, OTDR sends short pulses of light into a fiber under test, and then analyzes the reflected and scattered signal for link detection. Any change in the return signal level is due to a defect or an alteration in the properties of the fiber, which is called an “event” [2]. It may be a sudden decrease or peak of the amplitude in the return signal, which is called nonreflective or reflective event, respectively.

The central problem in fiber monitoring is detecting fiber events or small faults [3] which are caused by welding, a fiber’s bend, the titled misalignment of a connector and so on. The author in [4] analyzed the various causes of the optical links faults and the consequent OTDR waveforms.

A traditional technology to analyze the OTDR data is the two-point method [5], combined with least square method, but its accuracy is not high when noise exists. Ensemble averaging is the most common denoising method for OTDR signal, which improves the signal to noise ratio (SNR) by the square root of the number of signals in the ensemble [6]. However, averaging is limited and it is a time consuming process technology, a large number of ensemble averaging causes the analysis time to increase. To solve this problem, the gabor series representation method (GSR) combined with minimum description length (MDL) [7] was proposed, but it only gave a coarse estimate of event location. Therefore, the authors further improved it using the rank-1 matched subspace detection and estimation algorithm (R1MSDE) [8].

There are some other fiber event detection methods. In 2008, Kalman filter [9] was introduced to detect events and then it was further improved by combining the match filtering method [10]. In 2013, the method using numerical difference operation combined with vector index matching was proposed [11]. However, these event detection methods require a high SNR for the OTDR trace.

In 1994, the method applying wavelet analysis to OTDR data was proposed for the first time [2] and then the method based on wavelet analysis was widely studied [12], [13]. In [14] the method based on biorthogonal wavelet transform and template matching was proposed to detect and localize nonreflective events. A Gabor Transform (GT) method with binary signal detection theory [15] was also introduced. In [16] an algorithm combining correlation matching with STFT was proposed. The author in [17] proposed the wavelet denoise method to decrease the number of averages and in [18] the approximate entropy was proposed to evaluate wavelet denoising degree. In 2016, an adaptive filter was proposed for identification of faults in a noisy OTDR data [19].

In 2015, EMD was applied to denoise the OTDR signal [20]. It is known that High-frequency IMFs contain useful information of the original signal, which can be lost if removed directly. Scholars have proposed the use of wavelet transform and EMD to jointly denoise and integrate the advantages of them [21].

The event detection methods for optical links are studied widely, but there are few studies focusing on integrating them into a system with optical fiber online real-time monitoring and visualization of events.

In this paper, a Labview-based system is presented, purposely for fiber-optic faults detection. The proposed system integrates the wavelet threshold denoising method combined with EMD and the event detection method based on gabor representation. The experimental results show that the system achieves a higher accuracy and efficiency for events detection and location.

The rest of this paper is organized as follows. Section II presents the theoretical analysis including the model

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of OTDR signal, the wavelet threshold denoising method combined with EMD and the event detection method based on gabor representation. Section III introduces the proposed Labview-based system and in Section IV the experimental results are provided and analyzed. Finally Section V concludes the paper.

## II. Theoretical Analysis

### A. Modeling of Signal

In an OTDR system, short pulses are injected into the fiber under test and there are the reflected and backscattered optical signal along the fiber. The signal model received by the detector can be written in the general form $(t \geq 0)$

$$x(t) = f(t) + h(t) \tag{1}$$

where $f(t) = Ae^{-2\alpha L}$, the result of Rayleigh scattering of light along the fiber. $L$ is the distance of laser transmission, $\alpha$ is the attenuation constant and $A$ is a constant, determined by the pulse width, laser power, fiber scattering coefficient, etc. $h(t)$ includes the term of fiber events and the measurement noise. In order to obtain a large dynamic range, OTDR data is usually converted to a linear model in a logarithmic manner. An OTDR trace is shown in Fig. 1, which includes nonreflective event and reflective event.

### B. Wavelet Threshold Denoising Method Combined With EMD

EMD is an effective signal-adaptive analysis method [22], which decomposes the signal into several Intrinsic Mode Functions(IMFs) containing different time scales. The signal $x(t)$ can be decomposed into the sum of several IMFs and residual signal.

$$x(t) = \sum_{i=1}^{n} imf_i(t) + r_n(t) \tag{2}$$

where $r_n(t)$ is the residual signal.

Wavelet threshold denoising method is a denoising technique based on the idea of thresholding wavelet coefficients of the noisy signal [23]. In practice, the discrete-time wavelet transform (DWT) is usually used, which is obtained by sampling the continuous-time wavelet transform (CWT) with a dilation factor as powers of 2. The form of the mother wavelet and the DWT are defined as

$$\psi_{j,k}(t) = 2^{(-j/2)}\psi(\frac{t - 2^j k}{2^j})(j,k) \in Z^2 \tag{3}$$

$$X_{DWT}(j,k) = \sum_{j,k} x_{j,k} 2^{-j/2}\psi(\frac{t - 2^j k}{2^j}) \tag{4}$$

where $j$ and $k$ are dilation and translation parameters, respectively.

EMD decomposes the signal into several IMFs from high frequency to low frequency. It is known that the lower frequency IMFs are mainly composed of original signal and noise is contained in high frequency IMFs. Based on this idea, the noise can be suppressed by appling wavelet threshold denoising method on the high frequency IMFs. (IMFs selection is detailed in Section III).

### C. Gabor Representation Theory

Gabor transform, a windowed Fourier transform, has been widely used in signal processing and image representation [24]. Suppose that $x(t) \in L^2(R)$ is a continuous-time real-valued signal, $g(t) \in L^2(R)$ is a nonnegative function with unit norm, called the window function. The gabor representation of $x(t)$ using the window function $g(t)$ is

$$x(t) = \sum_{m,n=-\infty}^{\infty} C_{m,n} g(t - n\alpha) exp[j2\pi m\beta(t - n\alpha)] \tag{5}$$

where $\alpha > 0, \beta > 0$ and $\alpha\beta \leq 1$. The condition $\alpha\beta \leq 1$ is necessary to guarantee the existence of the gabor representation. It is common to choose $\alpha\beta = 1$, in this case there is no loss of generality and formula (5) can be written as

$$x(t) = \sum_{m,n=-\infty}^{\infty} C_{m,n} g(t - n) exp(j2\pi mt) \tag{6}$$

The gabor representation with one-sided exponential window function is particularly suitable for modeling transients [5]. So the window function selected is the one-side exponential window

$$g(t) = \sqrt{2\lambda} exp(-\lambda t)u(t) \tag{7}$$

where $u(t)$ is unite step function and $\lambda$ is the window parameter controlling the width of the window and deciding the time domain resolution. According to the framework theory, the results of the gabor coefficient can be derived (A detailed derivation process is given in [5] and [25]). The gabor coefficient $C_{m,n}$ can be expressed as:

$$C_{m,n} = D_{m,n} - exp(-\lambda)D_{m,n-1} \tag{8}$$

The coefficient $C_{m,n}$ in (8) is called gabor coefficient, m represents the frequency of each point and n represents the position of each point.

## III. The Proposed System

In this section, the proposed labview-based system for fiber links events detection is introduced. Fig. 2 illustrates the system structure.

### A. System Setup

The proposed system is developed under the control of Labview integrated virtual instrument environment, which makes use of its powerful graphical programming ability and flexible and diverse data processing functions. It can realize optical signal acquisition, processing and optical fiber online real-time monitoring and allow visualization of events occurring along the fiber.

In the system, the parameters of the pulsed laser are controlled by the labview program through the serial port. Then short pulses are injected into the fiber under test through the coupler. The photodetectors are used to collect the reflected and scattered signal throughout the fiber link. Ni-scope module combined with data acquisition card is used for data visualization and storage. The collected data

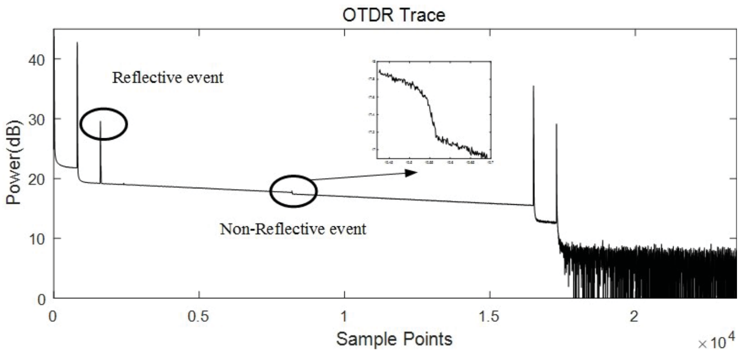


Fig. 1 OTDR trace

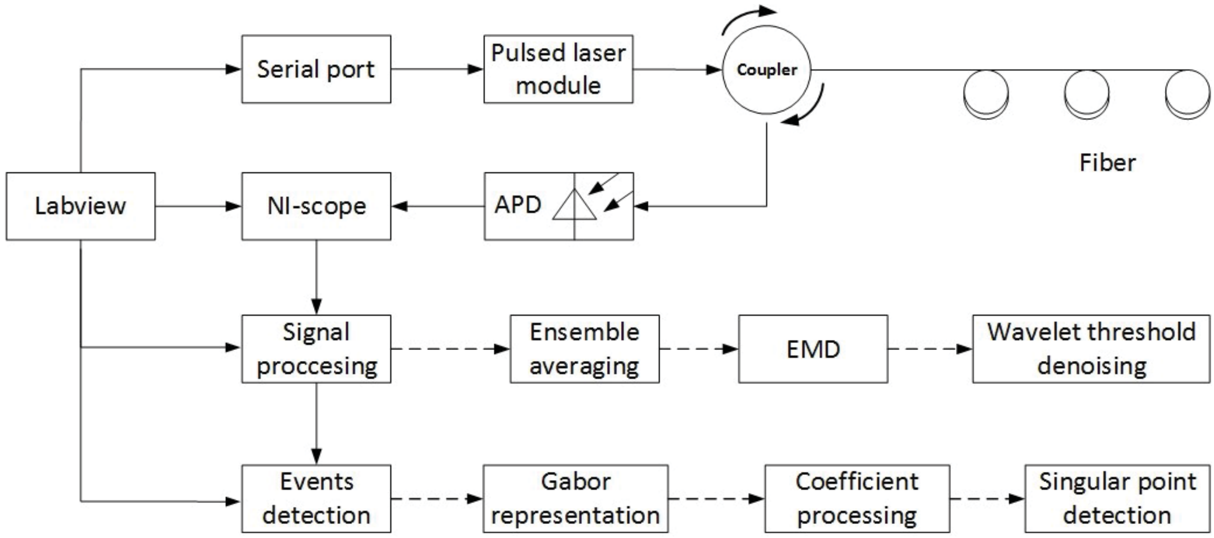


Fig. 2 The Labview-based system for fiber links events detection



are transmitted to the signal processing module and event detection module.

Here the pulsed laser module is a 1625 nm laser source. The detector is selected InGaAs APD photodetector. The data acquisition card signal is PCI-5114 produced by National Instruments.

### *B. Signal Processing*

As shown in Fig. 1, since the SNR level decreases when propagation time of optical signal along the fiber increases, some events may be masked by the detector noise, especially the nonreflective events. It leads to the difficulty for improving the performance of event detection and the accuracy of event localization for OTDR [26]. The processing of signal denoising is very necessary.

It is known that OTDR signal contains the non-stationary noise and the event can be approximately regarded as a sharp transition on the linear data. The wavelet threshold denoising method combined with EMD is applied on the OTDR data, which avoids the bad noise reduction effect caused by improper selection of wavelet basis function. It also retains some useful signals contained in the high frequency IMF component [21].

The key of using the wavelet threshold denoising method combined with EMD is selecting the IMFs, which will be applied the wavelet threshold denoising method. In this paper, the IMFs are selected according to the correlations coefficient between the IMF and the noise signal. The correlations coefficient is defined as

$$R(x,imf)=\frac{\sum_{i=1}^{N}[x(t)-\overline{x}][imf(t)-\overline{imf}]}{\sqrt{\sum_{i=1}^{N}[x(t)-\overline{x}]^2}\sqrt{\sum_{i=1}^{N}[imf(t)-\overline{imf}]^2}} \quad (9)$$

$$\overline{x}=\frac{1}{N}\sum_{i=1}^{N}x(t) \quad (10)$$

$$\overline{imf}=\frac{1}{N}\sum_{i=1}^{N}imf_i(t) \quad (11)$$

where $N$ is the number of sampling points. $x(t)$ is the noisy signal. $imf_i(t)$ is the i-th IMF.

The selected IMFs are determined by the minimal value $R(k)$ among $R(i)$. Then $imf(i)$ will be identified as high frequency IMFs containing the noise $(i \leq k)$.

The wavelet threshold denoising method combined with EMD for OTDR data can be summarized as follows and the flowchart is shown in Fig. 3.

1) perform EMD decomposition on the signal x(t) to obtain IMFs;
2) calculate the correlation coefficient $R(i)$ between each IMF and the noise signal;
3) find the minimal value $R(k)$ among $R(i)$;
4) apply the wavelet threshold denoising method to the $imf(i)$, $i = 1, 2...k$.
5) reconstruct the denoised signal according to the following formula;

$$x^{'}(t) = \sum_{i=1}^{k} imf_i^{'}(t) + \sum_{i=k+1}^{n} imf_i(t) + r_n(t) \qquad (12)$$

where $imf_i^{'}(t)$ is the denosied result of $imf_i(t)$.

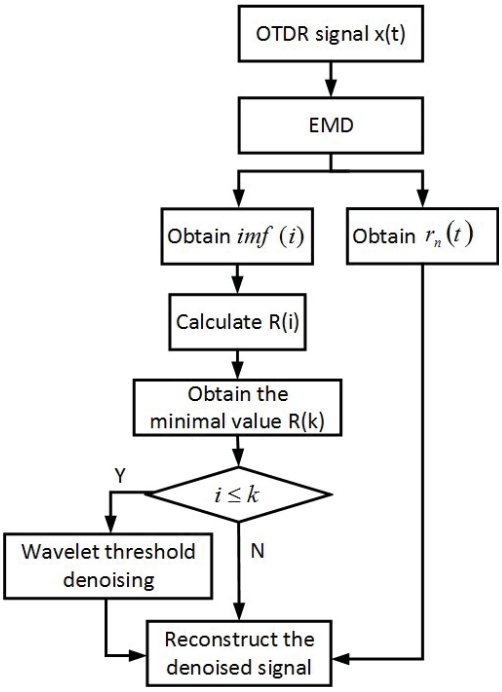


Fig. 3 Flowchart of the wavelet threshold denoising method combined with EMD process

### C. Events Detection

In OTDR data, the event can be approximately regarded as a sharp transition on the linear data. As discussed in Section II, the gabor coefficient of the signal are calculated according to formula (8). These coefficients are associated with transient event position (in time) and frequency. If an event is present at a particular time and a particular frequency then the corresponding gabor coefficient will be nonzero, otherwise it is zero. Fig. 4 shows the flow chart of event detection based on gabor representation.

The signal at the event point location in the OTDR data is a non-oscillating low frequency signal. In the process the processing of the gabor coefficients, the frequency index $m$ can be set to 0; for shift index $n = 0, 1, 2, 3...$, then the gabor coefficient is

$$C_{0,n} = D_{0,n} - exp(\lambda)D_{0,n-1} \qquad (13)$$

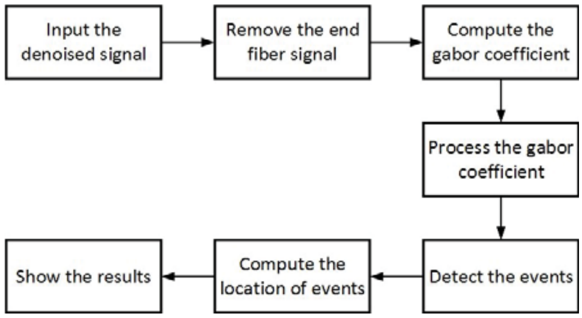


Fig. 4 Flowchart of the event detection-based gabor representation

$$D_{0,n} = \frac{1}{L\sqrt{2\lambda}} \sum_{k=0}^{L-1} exp[\frac{\lambda}{2L} + \frac{\lambda k}{L}]x(\frac{2Ln + 2k + 1}{2L}) \qquad (14)$$

Focusing on the influence of the gabor coefficients of measurement noise on event location, the gabor coefficients of signal $C_{0,n}$ are processed as follows

$$C_{0,n}^{'} = \mid C_{0,n} \mid \qquad (15)$$

$$C_{0,n}^{''} = C_{0,n}^{'} - C_{0,n+1}^{'} \qquad (16)$$

After processing the gabor coefficients, the events can be detected by recognizing the nonzero gabor coefficients. Finally, the position of the event is calculated according to the identified gabor coefficients and the detection results are obtained.

## IV. Experiment and Result

The experiment setup is shown in Fig. 5. Some fibers are connected and event points are set among them including welding points and connectors. With wavelength of 1625nm, measurement time of 120s and the sample rate of 125M, The OTDR signals are received.

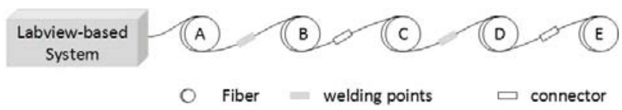


Fig. 5 Experiment setup

After collecting the OTDR signal, the data are processed by the wavelet threshold denoising method combined with EMD. In this paper, the OTDR signal is decomposed into 11 IMFs and $k = 6$. The result of $R(i)$ is shown in Table I.

TABLE I
The Correlations Coefficient between the IMF and the Noise Signal

| | $imf_1$ | $imf_2$ | $imf_3$ | $imf_4$ | $imf_5$ | $imf_6$ |
|---|---|---|---|---|---|---|
| R | 0.0429 | 0.0477 | 0.0239 | 0.0195 | 0.0353 | 0.0121 |
| | $imf_7$ | $imf_8$ | $imf_9$ | $imf_{10}$ | $imf_{11}$ | |
| R | 0.0187 | 0.0146 | 0.0281 | 0.0482 | 0.1809 | |

Fig. 6 shows an original OTDR signal and the denoising result is shown in Fig. 7. Comparing the amplified signal parts, it is clear that the noise is effectively suppressed.

To demonstrate the effectiveness of the denoised method, the wavelet threshold denoising method combined with EMD

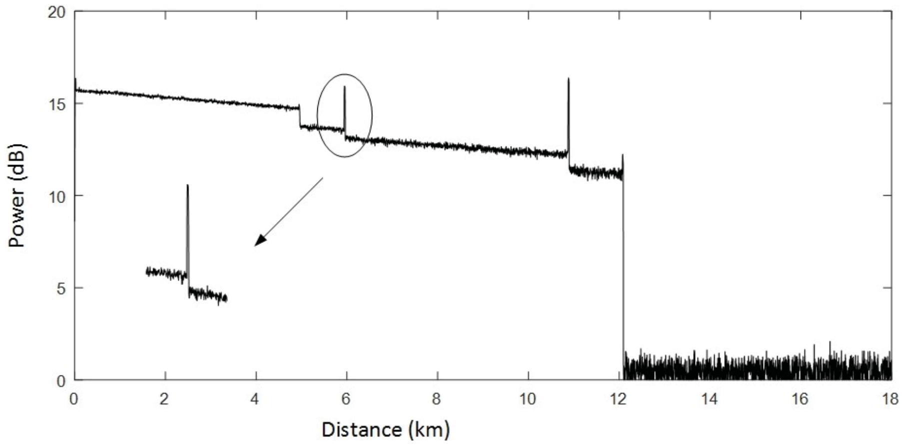


Fig. 6 Original OTDR signal

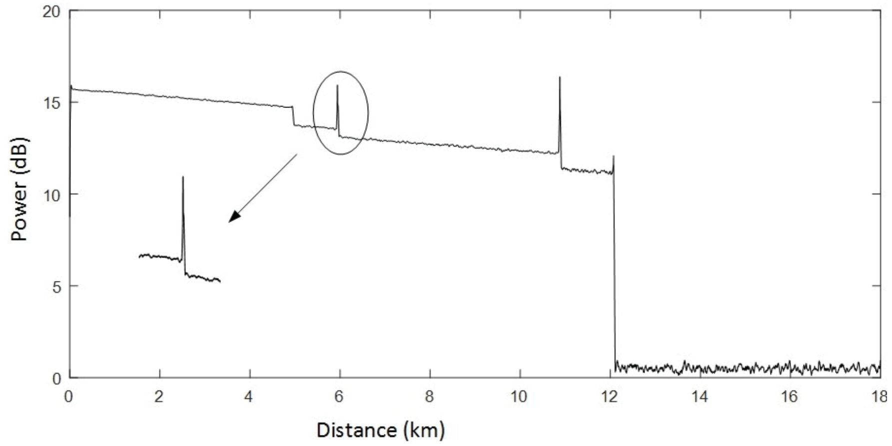


Fig. 7 Denoised OTDR signal



is compared with the wavelet threshold denoising method. The performance is evaluated using SNR and mean square error (MSE). The larger SNR means the better effect of denosing, while the opposite is true for the MSE. SNR and MSE are defined as

$$SNR = 10lg[\frac{\sum x(t)^2}{\sum [x(t) - x'(t)]^2}] \quad (17)$$

$$MSE = \sqrt{\frac{\sum [x(t) - x'(t)]^2}{N}} \quad (18)$$

where $x'(t)$ is the denoised signal and $N$ is the number of sampling points.

The comparison results are listed in Table II. As can be seen from Table II, SNR of the wavelet threshold denoising method combined with EMD are improved by 1.34dB on average, compared with the wavelet threshold denoising method. It is shown that the wavelet threshold denoising method combined with EMD is superior to the wavelet threshold denoising method.

Then the denoised signals are processed by the event detection method based on gabor representation. As shown in Fig. 8, it is clear that the gabor coefficients are nonzero only near discontinuities in the data record.

TABLE II
COMPARISON OF DENOISING PERFORMANCE

| OTDR signal No. | Denoising method | SNR (dB) | MSE |
|---|---|---|---|
| 1 | Wavelet threshold | 30.3973 | 0.3402 |
| | **EMD + Wavelet threshold** | **31.6954** | **0.2930** |
| 2 | Wavelet threshold | 30.3999 | 0.1629 |
| | **EMD + Wavelet threshold** | **31.9055** | **0.1370** |
| 3 | Wavelet threshold | 28.7943 | 0.3731 |
| | **EMD + Wavelet threshold** | **30.0191** | **0.3240** |

To further verify the accuracy and the efficiency of the proposed system, the location of the welding points and the fiber connectors are changed and the length of the fiber is also changed.

The calculated location values of events from the proposed system in this paper are compared with the actual values. Table III summarizes the experimental results.

It can be seen that the event locations located by the proposed system are very close to the actual event locations. The experiment sets up 18 event points, including 5 nonreflective event points, 9 reflective event points and 4 fiber ends events. Except for the false detection at 16.327km, all other events are identified. The proposed system achieves a high accuracy and efficiency for events detection and the maximum detectable fiber length of the proposed system can

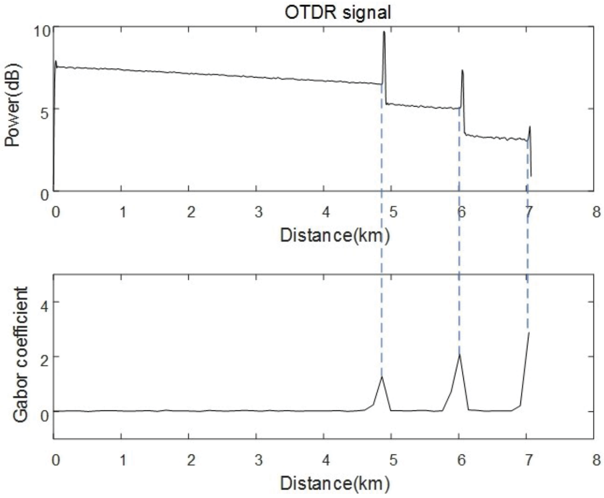


Fig. 8 Result of the gabor representation of OTDR signal

TABLE III
THE RESULTS OF EVENTS DETECTION

| OTDR signal No. | The actual events location /km | The examination events position /km | Event type |
|---|---|---|---|
| 1 | 4.836 | 4.838 | 2 |
| | 6.057 | 6.059 | 2 |
| | 7.078 | 7.075 | 3 |
| 2 | 1.046 | 1.052 | 1 |
| | 6.256 | 6.158 | 2 |
| | 11.295 | 11.29 | 2 |
| | 12.311 | 12.324 | 3 |
| 3 | 5.036 | 5.144 | 2 |
| | 10.072 | 10.084 | 1 |
| | 11.292 | 11.29 | 2 |
| | 16.327 | - | 0 |
| | 38.175 | 38.238 | 3 |
| 4 | 1.046 | 1.050 | 2 |
| | 11.292 | 11.29 | 2 |
| | 21.362 | 21.371 | 1 |
| | 26.398 | 26.410 | 1 |
| | 56.532 | 56.64 | 2 |
| | 65.142 | 65.098 | 3 |

Note: 0: false detection, 1: non-reflection event, 2: reflection event, 3: end of fiber.

be 65km.

## V. CONCLUSION

In this paper, a Labview-based system is proposed for fiber links events detection. The system is implemented in labview platform, which allows visualization of events occurring along the fiber and accurately determines the faulty fiber as well as identified the failure location in the fiber links. The proposed system can suppress the noise effectively and has a high score in event detection capability and accuracy. The performance indicates that the proposed system provides an effective solution for event detection in optical time domain reflectometers.

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