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A computerized system for Monitoring and informing about any unauthorized drilling operations near the cables.

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Abstract: The biggest challenge is to protect the cables in cities and villages from random excavations, as the protection of these cables by traditional methods such as concrete and some cement stones is not sufficient. It has become necessary to search for effective and alternative protection techniques that can protect the cables. In this paper, a novel method is proposed to design a drill monitoring system for early warning using fiber optic distributed acoustic sensing systems (DAS) based on phase OTDR. The proposed method has three stages. The first stage is to use buried fiber optic cable as a sensing system to detect any activity such as drilling or digging near the cable. The second stage is the processing system; in this stage, the sensed signal is de-noised using a wavelet transform, and then the difference is used for high pass filtering. This phase includes the autocorrelation to improve the interferometric visibility of the movements or threats near the goal area via a fiber optic cable. Moreover, the correlated signal power is computed and sent to the test and comparison stages. In the last stage, all signals are compared with a predefined threshold; if the average exceeds the threshold, the discrete signal is considered to be high, and there is drilling near cables; otherwise, the signals are considered to be undesired signals. Different types of activities were used at different SNR levels to assess the effects of the proposed method on detection performance. The results show the effectiveness of the used system for early drilling detection to protect the cables.

Keywords: (Acoustic sensing, DAS systems, sensing, monitoring system)

Introduction

The usage of fiber optic distributed acoustic sensing (DAS) in recent years has attracted extreme attention in the discipline of acoustic and vibration detection in current years. essentially, it's miles based on the measurement of Rayleigh scattered light, which happens while the light traveling in fiber optic cables scatters again alongside the sensor cable path because of imperfections (referred to as "scattering centers") measured at the sender end [1]. According to a theory, mechanical vibrations take place because of threat movements or physical activities, which happen around the buried fiber cable because they create fluctuations in the form of backscattered light. Researchers have investigated such fluctuations and classified them. For this purpose, a phase-sensitive technique called “optical time-domain reflectometry (Phase-OTDR) was developed over the last 25 years to conduct distributed acoustic sensing [2, 3]. Contrary to the traditional OTDRs, Phase-OTDR pulses have coherent lights, which are transmitted through fiber optic cables; so, sensing is done through the relative phases of reflected fields of the scattering centers. For monitoring multi-point acoustic vibrations throughout a fiber cable, it gives an efficient method. For DAS, phase-sensitive OTDR is not only the used method in DAS system. Many other methods are used, which apply optical frequency domain reflectometry (OFDR). Both these major approaches differ based on the used detection method; some of them use direct detection while the other uses coherent (heterodyne) detection. The former is easier-to-implement because it uses a low-constraint optical signal as compared to the later. The coherent detection method assures a longer dynamic range and higher SNR [3]. The effectiveness of the DAS system can also be assessed by its different applications, for example, it is used in structural crack detection [4], railroad and safety monitoring [5, 6], Long Perimeter Monitoring [7], location information of intruder [8], structural health monitoring [2], intrusion detection and security mentoring [9, 14], detection performance improvement in complicated noisy environments [10, 11]. A backscattered signal, which is sensed in a phase-OTDR DAS system, has significantly lower signal-to-noise ratio (SNR) that influences the systems vibration detection [12], monitoring multiple dynamic events in real time [15], Networking of underwater acoustic sensors is the technology behind a wide range of applications including coastal surveillance, oil platform monitoring, earthquake and tsunami early warning [16].

Background (Literature Survey)

The method is a combination of correlation matching and Short Time Fourier Transform (STFT) to detect and analyze events using OTDR. This method achieves high accuracy and efficiency .

Continuous Wavelet Transform (CWT) has been proposed as another used method for detecting non-stationary signals using a distributed phase OTDR based vibration sensor. The time-frequency information regarding a event can be obtained through continuous wavelet transform methods. The wavelet ridge detection method gives information about the frequency evolution with the help of the CWT scalogram. This reported time-frequency analysis is a powerful tool for stationary/non stationary vibration signals in the system.

A technique called “curvelet de-noising” has been proposed for noise removal in the time domain, and also for improving the system’s detection performance using phase-sensitive optical time-domain reflectometry. In this context, gray image means raw data traces while curvelet transformation means removed noise. The vibration detection in a sensing path has been shown. In this method, the SNR has increased to 7.8dB.

A new technique to remove the effect of fading noise has been discovered, which his now used in distributed acoustic sensing systems [11]. This method has used the temporal adaptive f-OTDR signal processing method. In this context, the fundamental theory suggests SNR maximization, and the results have demonstrated that it is possible to achieve above 10dB SNR values without system bandwidth reduction and it does not need any optical amplifier.

A novel empirical mode separation method has been used in the detection system of wireless communication signal transceivers. The empirical mode method is used in the detection system to separate signal modes and then component analysis is applied to extract certain properties. This system is successful for low SNR transient signals and is certainly superior to other techniques. The system is successful in classifying specific transmitters and they can also be used for wireless communication for security purposes.

Distributed acoustic sensing system

In distributed acoustic sensing system the whole fiber acts like a multi-sensor, so it is very sensitive to environmental noise and all vibrations that happen near the cable path. The main idea of this system is to process and locate the backscattered light in an optical fiber to detect and extract changes, which happened at a specific point along the sensing path in DAS. Typically, one of the backscattered lights that occurred in the optical fiber is called Rayleigh scattering [3], which is a form of elastic scattering, in which, the scattered light frequency is similar to the incident light. Distributed acoustic sensing (DAS) is a technology that uses Rayleigh backscattering in a buried fiber-optic cable to detect vibration signals around the sensing path by sending laser pulses along the buried fiber cable. Small imperfections within the fiber cause light backscatter. Many activities cause vibration around the sensing path such as moving vehicles, hitting, or digging by different tools besides many other vibrations with distinct acoustic characteristics. Threat vibration along the fiber path causes this backscattering light then, Rayleigh backscattering measured and processed to localize and extract the threats [1, 3].

Proposed Method

The proposed method as shown in the block diagram as shown in Fig. 1.

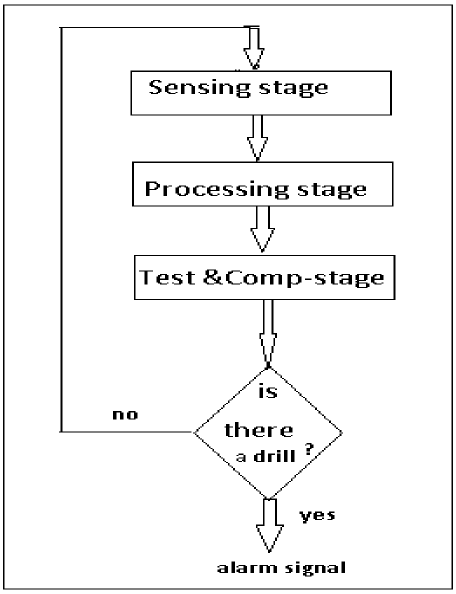

Fig. 1: The proposed method.

- Sensing stage

The main idea of sensing stage is to sense any activity or drilling near the cable by locating the backscattered light using phase OTDR. Phase OTDR measures the Rayleigh backscatter for each transmitted pulse. The characteristics change due to any mechanical vibrations that interact with the buried fiber optic cable and any changes that happened at a specific point along the sensing path are send to the processing stage.

- Processing stage

The goal in this stage is to identify and extract the event y (t) that was sensed near the cable from the whole signal x (t) by removing the noise g (t), as illustrated in equation (1).

$$x(t)=y(t)+g(t) \qquad (1)$$

where x(t) is the backscattered signal, y(t) is the event signal (drill signal), and g(t) is the noise. The goal is to extract the event signal y(t) from the backscattered signal while suppressing the noise g(t). The technique starts with noise reduction g(t) from x (t) to find the goal signal y(t) using wavelet de-noising method [3, 16]. On different scales, wavelets can localize the signal features; so, during the noise removal, preserving important signal features is possible, using Symlets at level 5, sym5 wavelets are used to decompose the DAS data for each channel [13]. Effectively remove the noise of the system and other environmental interferences. Then the difference is used for high pass filtering and extracting the changes as shown in Fig. 2.

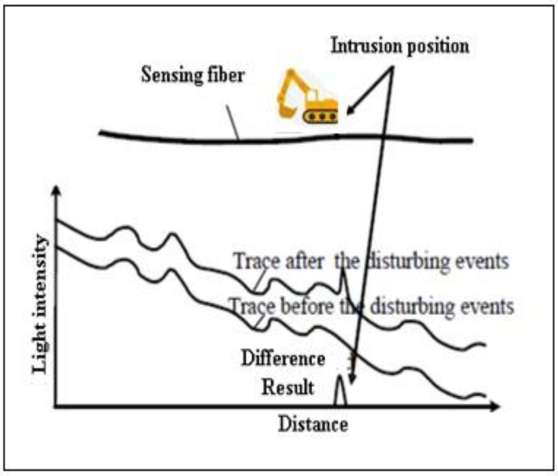

Fig. 2: Difference in time domain.

This phase includes autocorrelation to improve the interferometric visibility of the digging near the cable in all areas over a fiber optic cable. Moreover, the correlated signal power is computed and then sent to the next stage.

Test and comparison stage

In the third stage, all signals are compared with a predefined threshold, if the average of these signals exceeds the threshold, the discrete signal is considered to be high, and there is drilling near the cables, then an alarm signal sent from the system to the main system to show the position of the threat and alarm messages sent to all units. If the signals do not exceed the threshold, they are deemed undesirable and ignored. The drill detection architecture system is depicted in Fig. 3.

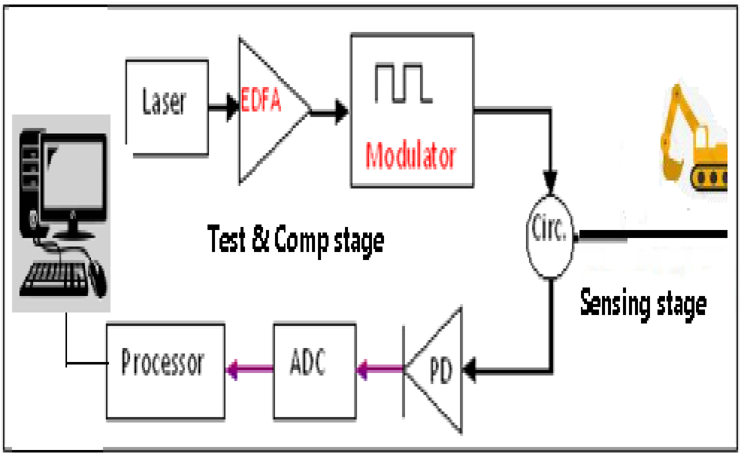

Fig.3: Drill Detection architecture system

Experimental results

The proposed method tested with different captured data called this called raw data as shown in Fig. 4.

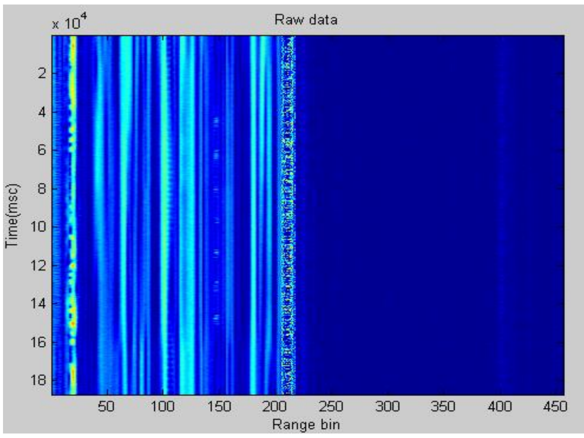

Fig. 4: The waterfall graph of raw data.

As an illustration, the activity near the cable that have been tested in this study and de-noised by applying Wavelet method as shown in Fig. 5.

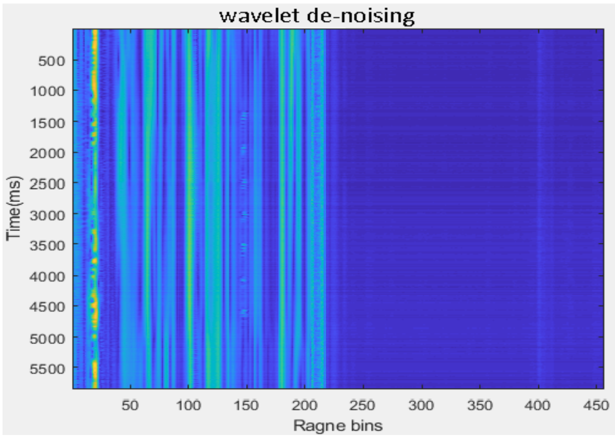

Fig. 5:De-noising data using wavelet.

Then difference in the time domain approach is used to find the abrupt changes in the signal Then the power of each signal is estimated. It is based on relation of Parseval that can be expressed as in equation (2).

$$\sum_{m=0}^{N-1} |y_{dtf}[c, m]|^2 \quad (2)$$

Where m is the digital time index, and c is the measurement point on the cable and ydif is the drill signal and N is the number of samples used for signal power estimation as shown in Fig. 6.

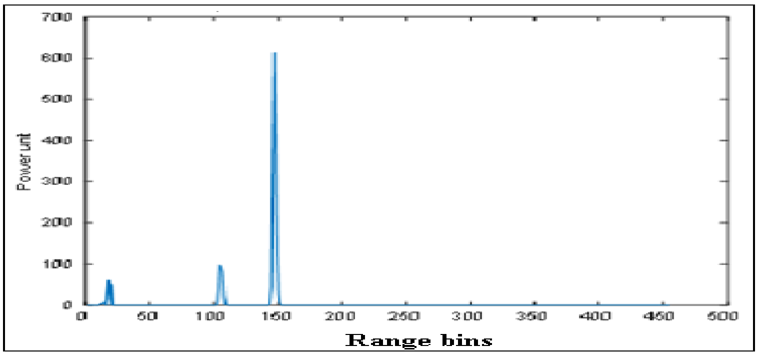

Fig. 6: The power of signals at each bin.

Finally, the data is sorted, and we found the maximum- valued bins, which correspond to the drilling events as illustrated in Fig. 7.

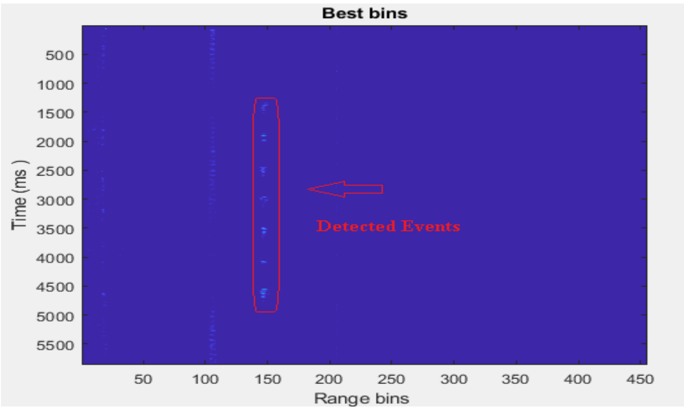

Fig. 7:The best events detected in the range bins(7 drilling hits).

Conclusion

The current paper has presented a new technique to detect any unauthorized drilling operations near the cables using phase-OTDR-based fiber optic distributed acoustic sensing systems, which combines the difference in the time domain and the wavelet de-noising with autocorrelation, which is conducted during the detection stage. We applied a series of tests for recorded and created data sets collected from different tools, hammer, pickaxe, and shovel. This technique uses a different approach to event detection that combines Wavelet de-noising and difference-in-time-domain methods with the autocorrelation process. Since wavelet de-noising is used for removing noise from measured backscattered signals, we used difference in time domain approach between the consecutive pulses to extract abrupt signal changes and to perform high-pass filtering in the signal, and then, to decide whether the signal should be removed, we used the autocorrelation function in all the ranges throughout the sensing fiber cable, which compares a signal with its own time-delayed version in every bin. Then, each of the calculated values is compared to a predefined threshold. If it exceeds the threshold, the discrete signal is considered as highly correlated while others are considered as undesired (uncorrelated) signals. We calculated the power of the correlated signal in the last phase at each bin and sorted it in a vector form in descending order, which shows that the maximum-valued bins were event signals. These signals are sent to the main system, and the system sends alert signals to all control systems, providing them with all information about the threat and its location to take the necessary action. System performance is evaluated at various SNR levels. The results shows that the method is quite effective in reducing the strong background noise and making it easy to detect any unauthorized drilling operations near the cables. This technique can be easily generalized to identify different types of threats of interest for many security applications.

References

[1] D. Hill, Distributed Acoustic Sensing (DAS): Theory and Applications, pp. 4,5, 2015.

[2] Y. Liu et al., Distributed fiber optic sensors for vibration detection, Sensors, vol. 16, no. 8, 1164, 2016.

[3] Abufana. S. A et al., Variational mode decomposition based threat classification for fiber optic distributed acoustic sensing, IEEE Access,2020.8:100152-100158J.

[4] H. Yue et al., Simultaneous and signal-to-noise ratio enhancement extraction of vibration location and frequency information in phase sensitive optical time domain reflectometry distributed sensing system, Optical Engineering, vol. 54, no. 4, 047101, Apr. 2015

[5] F. Peng et al., Real-time position and speed monitoring of trains using phase-sensitive OTDR, IEEE Photonics Technology Letters, vol. 26, no. 20, pp. 20552057, Oct. 2014.

[6] Z. Wang et al., Novel Railway-Subgrade Vibration Monitoring Technology Using Phase-Sensitive OTDR, in Proc. SPIE 10323,25th International Conference on Optical Fiber Sensors, Jeju, SouthKorea, 2017.

[7] J. C. Juarez, E. W. Maier, and H. F. Taylor, Distributed fiber-optic intrusion sensor system, Journal of Lightwave Technology, vol. 23,no. 6, pp. 20812087, June 2005.

[8] H. Liu et al., Traffic flow detection using distributed fiber optic acoustic sensing, IEEE Access, vol. 7, pp. 6896868980, 2018.

[9] F. Peng et al., Ultra-long high-sensitivity-OTDR for high spatial resolution intrusion detection of pipelines, Optic Express, vol. 22, no.11, pp. 1380413810, Jun. 2014.

[10] H. Wu et al., Separation and determination of the disturbing signals in phase-sensitive optical time domain reflectometry (Φ-OTDR),"Journal of Lightwave Technology, vol. 33, no. 15, pp. 3156–3162,Aug. 2015.

[11] I. Olcer, I. and A. Oncu, "Adaptive temporal matched filtering for noise suppression in fiber optic distributed acoustic sensing, Sensors,vol. 17, no. 6, 1288, 2017.

[12] Z. Qin, L. Chen, and X. Bao, Wavelet de-noising method for improving detection performance of distributed vibration sensor,.IEEE Photonics Technology Letters, vol. 24, no. 7, pp. 542544, Apr.2012.

[13] M. Aktaş et al., "Deep learning based multi-threat classification for phase-OTDR fiber optic distributed acoustic sensing applications," in Proc. SPIE 10208, Fiber Optic Sensors and Applications XIV,Anaheim, California, United States, 2017.

[14] A. Makarenko."Deep learning algorithms for signal recognition in long perimeter monitoring distributed fiber optic sensors" 2016 IEEE 26th International Workshop on Machine Learning for Signal Processing (MLSP). IEEE, 2016.

[15] Y. Muanenda."Recent advances in distributed acoustic sensing based on phase-sensitive optical time domain reflectometry" Journal of Sensors 2018 (2018).

[16] P. Kumar and K. Preetam. "DCT based OFDM for underwater acoustic communication. " 2012 1st International Conference on Recent Advances in Information Technology (RAIT). IEEE, 2012.