A multi-source signals separation algorithm for identifying the threatening signals applied in Fiber-Optic Distributed Acoustic Sensor

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Abstract: A multi-source signals separation algorithm is proposed to identify the potential threatening signals submerged in the strong background noises. Finally, the recognition rate of the mixed signals is improved from 62.83% to 92.36%. © 2022 The Author(s)

1. Introduction

Fiber optic distributed acoustic sensing system (DAS) has been extensively applied in many fields such as oil and gas pipelines security [1], communication or power cables security [2] and so on. In recent years, a lot of pattern recognition technologies based on DAS system has been successfully applied [3, 4]. However, in practical applications, the overlapping interferences of multi-source noises are unavoidable. Some threatening signals such as manual digging are usually submerged by the strong background noises, and the failing identification of the potential threatening signals causes an enormous security risk in applications. Thus, an intelligent recognition of the potential threatening signals submerged in the strong background noises is still a challenging problem and waiting to be solved. In 2021, Wu et al. [5] proposed a blind multi-source separation based on fast independent component analysis. By means of the independency and non-Gaussianity of different sources, the simulation separation experiments of two-, three- and four-sources mixing cases are carried out. In the experiment, two types of the mixed multi-source signals can be effectively separated. But it does not prove the effectiveness of the potentially threatening signals detection and identification, which are completely submerged in various heavy interferences.

In this paper, a multi-source signals separation algorithm for the potential threatening signals identification based on the fiber optic DAS system is proposed and demonstrated. The multi-source signals separation algorithm is composed of wavelet packet analysis, mean filter denoising and effective signal window function denoising, which can effectively extract the potential threatening signals submerged in the strong background noises. Finally, the field test results show that the recognition rate of the mixed signals is improved from 62.83% to 92.36%.

2. Principle and Methodology

The multi-source signals separation algorithm for the potential threatening signals identification with fiber optic DAS system is shown in Fig. 1. The multi-source signals separation algorithm includes three stages: wavelet packet analysis, mean filter denoising and effective signal window function denoising. As shown in Fig. 1(b), in the first stage, the wavelet packet analysis is performed on the mixed multi-source signals to reduce the interferences of fabrication plant noises and some background noises. After that, the signal *A* can be obtained and mainly includes pedestrian, traffic interferences and potential threatening signals. In the second stage, the traffic interferences signal can be obtained by the sliding mean filter with an appropriate parameter of the sliding window length. Then the signal *B* is calculated by subtracting the signal *A* from the traffic interferences. In the last stage, the effective signal window function denoising method is designed to improve the SNR of the potential threatening signals. The short-time energy feature of the signal *B* is calculated by the accumulation of energy value in the sliding window. By means of the voice endpoint detection based on double threshold of short-time energy [6], the effective signal window function of the signal *B* can be obtained. Finally, the signal *C* is obtained by the multiplication of the signal *B* and its corresponding effective signal window function. The separated signal is transmitted to the next part for the feature extraction and the potential threatening events identification.

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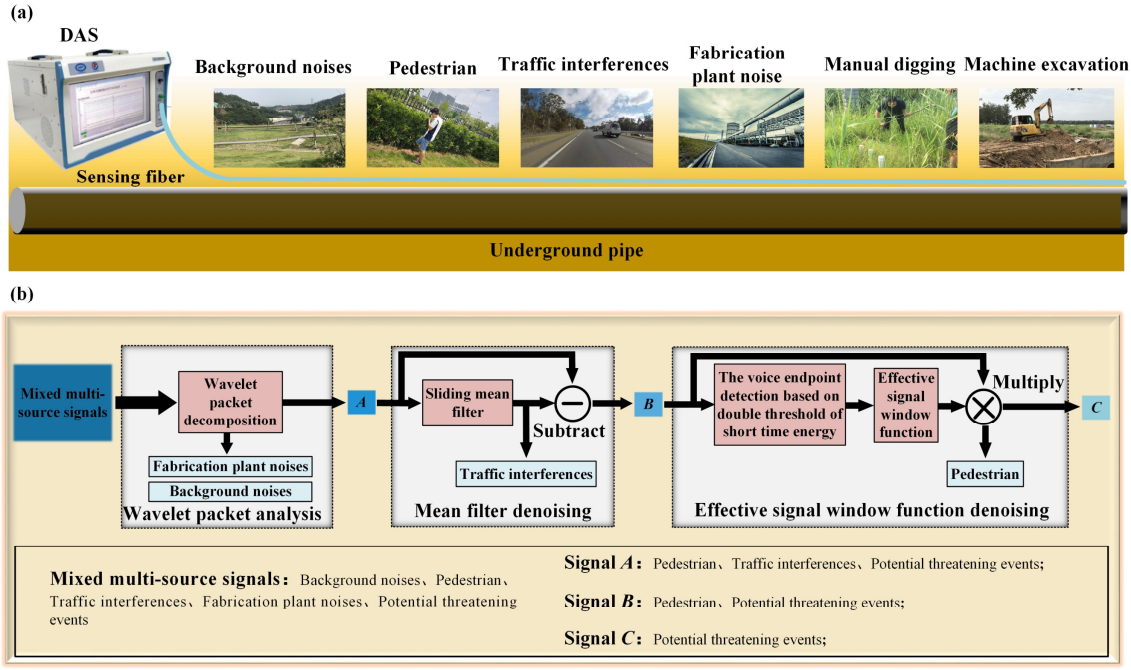

Fig. 1. (a) The system configuration of threatening signals detection based on DAS; (b) The process of the multi-source signals separation algorithm.

3. Field Test Results

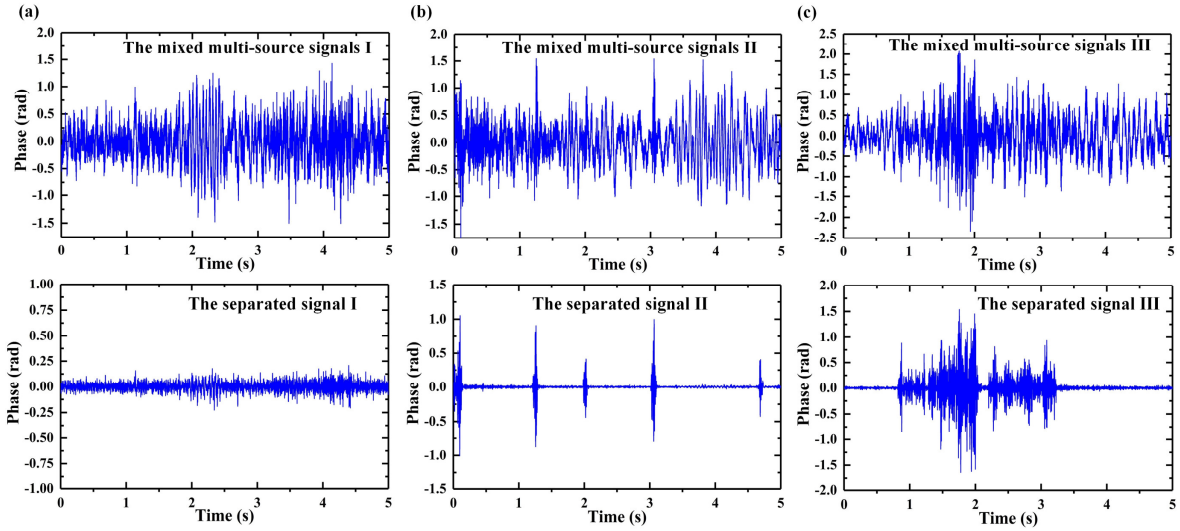

Fig. 2. The temporal waveforms of the three types of the mixed multi-source signals and their corresponding separated signal.

In order to verify the effectiveness of the proposed algorithm, a field test for pipeline security monitoring is arranged in Qingdao, Shandong province in October 2021. The oil pipeline is submerged 1-2 meters deep underground. The one spare core of the communication cable buried along about 20 cm from the pipeline is taken as the sensing fiber, as shown in Fig. 1(a). There are six main events frequently encountered: background noises, pedestrian, traffic interferences, fabrication plant noises, manual digging and machine excavation. Three types of the mixed multi-source signals would be discussed, which are separately labeled as the mixed multi-source signals I, the mixed multi-source signals II and the mixed multi-source signals III respectively. The mixed multi-source signals I is a mixed version of some non-threatening signals, such as background noises, pedestrian, traffic interferences and fabrication plant noises; and the mixed multi-source signals II is generated by mixing the above four types of the non-threatening signals with an additional manual digging signal; and the mixed multi-source signals III is generated

by mixing the above four types of the non-threatening signals with an additional machine excavation signal. The temporal waveforms of the three kinds of the mixed multi-source signals and their corresponding separated signal are shown in Fig. 2. Obviously, some potential threatening signals are completely submerged in various heavy interferences. However, some traditional recognition methods are difficult to recognize these similar mixed multi-source signals [1, 2]. Thus, the multi-source signals separation algorithm is proposed to identify the potential threatening signals. As seen in Fig. 2, the temporal waveforms of the above three mixed multi-source signals corresponding separated signal can be obtained by the proposed multi-source signals separation algorithm. It is remarkable that the potential threatening signals submerged in the mixed multi-source signals II and III are effectively separated from the mixed heavy interferences. Besides, the noises mixed in the mixed multi-source signals I are effectively suppressed. Subsequently, the nine different features of these separated signals are extracted to recognize the threatening events, as shown in Fig. 3(a). The comparison of recognition results for the system without/with the multi-source signals separation algorithm is shown in Fig. 3(b). It is seen that the proposed method has a high recognition accuracy for the potential threatening signals identification. And the average recognition accuracy of the three kinds of the mixed events can be achieved at 92.36%, which is much higher than that of the system without the multi-source signals separation algorithm (62.83%).

(a)

Feature types	Feature names
In time domain	Short time energy
	Average amplitude of signal
	Impulse number
	Average amplitude of impulse
	SNR of impulse
In frequency domain	Bandwidth of main frequency peak
	Frequency band energy
	Flatness of the spectrum
In transform domain	Information entropy of wavelet

(b)

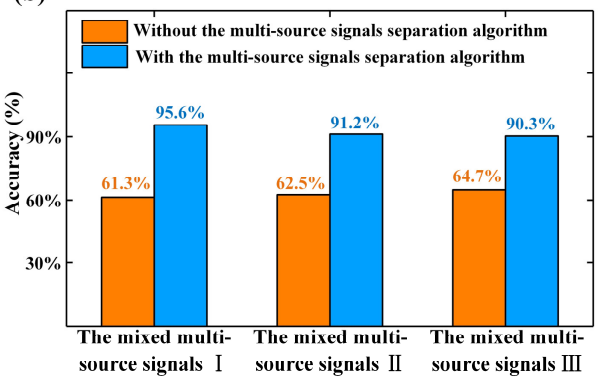

Fig. 3. (a) The nine different features of the target signals. (b) The comparison of recognition results for the system without/with the multi-source signals separation algorithm.

4. Conclusions

In this paper, a multi-source signals separation algorithm for the potential threatening signals identification based on the fiber optic DAS system is proposed. The potential threatening signals submerged in various heavy interferences can be effectively separated by the proposed algorithm. Finally, field test results demonstrate that the proposed method can realize a high recognition accuracy rate of 92.36% for the three types of the mixed events. Obviously, the safe hidden danger from the potential threatening events in some safety monitoring applications can be greatly reduced by the proposed algorithm.

Acknowledgments

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