Target detection method based on optical fiber fence

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Abstract. The intrusion alarm system of fiber optic fence perimeter realizes the early warning of intrusion by sensing the vibration of the defense area. How to detect the intrusion correctly, improve the system alarm accuracy and reduce the false alarm rate is the key problem to be explored. In view of the large amplitude of the jump of the intrusion signal and the discontinuous action process, and the disturbance generated by the environment is generally random and disorderly. In this paper, the method based on mean filtering and contrast detection is adopted to detect the intrusion signal. Through the actual data verification, this method can accurately realize the alarm of the intrusion signal and has strong robustness.

1. Introduction
Optical fiber sensing technology is based on optical wave as carrier and optical fiber as transmission medium. Compared with previous sensing technologies, optical fiber sensing technology has shown a series of unique advantages, which are difficult to be compared with other carriers and media. Such advantages enable optical fiber sensors to realize long term monitoring of environmental information in some harsh environments. These advantages mainly include corrosion resistance, high temperature resistance, radiation resistance, electromagnetic interference resistance, high sensitivity, light weight, small size, large transmission information, low loss[1]. At present, in many fields, optical fiber sensing technology has been widely applied and promoted, including national security, medical, aerospace, energy, electric power, military and other fields. At the same time, it has also shown a good development trend. Fiber optic sensing technology will have great development prospects in the industrial and defense fields.

Perimeter security perimeter of fiber optic fence refers to the prevention of illegal intrusion and sabotage activities in important areas, the formation of security precautions along the perimeter of the area, and the timely and accurate warning of intrusion and destruction acts acting on the arming area. By detecting and analyzing the vibration waves acting on the fiber optic vibration sensor, the intrusion alarm system of fiber optic fence perimeter can judge whether the intrusion event occurs in the area[2]. Compared with the traditional electrical sensing technology, it has the advantages of passive explosion protection, weather resistance, lightning protection, flexible layout, long service life, high sensitivity, and can be sensitive to detect vibration, so it is very suitable for the field of perimeter security. Fiber optic fence perimeter intrusion alarm system is based on vibration detection to realize the perception of the environment. Under the influence of various external factors, how to correctly identify and distinguish the invasion and damage behavior and environmental interference, improve the alarm accuracy of perimeter security system and reduce the false alarm rate of the system, is a key issue to be explored.
2. Target detection algorithm for optical fiber signals
Fiber optic fence perimeter intrusion alarm system is a high sensitivity vibration detection fiber optic sensor connected in series, it can be arbitrarily deployed in the perimeter area. In addition, all kinds of disturbance signals directly or indirectly transmitted are collected, and the back-end signal processor and system software realize the analysis and recognition of disturbance signals, and locate the invasion site.[3]

2.1 Signal analysis
By observing the time domain waveform, we can know that when the cable is subjected to human invasion in the external environment, the amplitude of the system signal will suddenly increase, and the completion of the amplitude jump process is a relatively rapid process. When there is a force acting on the cable, the signal amplitude will be higher, and this higher amplitude will last for a certain time.

![Figure 1. Signal status under normal environment](image1)

Figure 1 shows the situation of noise signals, a state in which there is no external interference in silence, when the signal is relatively low and will last for a long period of time. When the external environment of the target invasion of the signal, such as periodic interference signal, artificial invasion signal, simulation of invasion behavior, by flapping, stepping on the distribution of cable equipment, at this time the cable is intermittent force. As can be seen in Figure 2, in the process of slapping, the sensor channel in the corresponding region can generate obvious vibration signals with clear and clean waveforms. The waveforms of adjacent channels are consistent, while the signal waveforms at other time and other positions are in a state of calm. For the intrusion signal, there is still a significant difference, and the flapping signal has a relatively obvious consistency in the waveform of the adjacent channel, while the waveform consistency of the channel without target interference is not obvious in the adjacent channel.

![Figure 2. Signal status under normal environment](image2)
The optical fiber perimeter system captures the external information by sensing fiber. When the sensing fiber is not affected by external forces, the phase of its light wave will not change, and the detector will receive stable signals. When the sensing fiber is subjected to mechanical deformation due to external force, the phase of the transmitted light wave in the sensing fiber will change. Two light waves with different phase will interfere at the coupler, and the interference signal received by the detector will carry the information that leads to the vibration of the sensing light. The vibration signal caused by the intruder climbing the fence is a typical invasion vibration signal. Because the intruder climbing the fence will cause strong vibration of the sensing fiber, which will last for a long time, the amplitude of the vibration signal is large and the frequency is high[4]. For an effective human intrusion signal, the amplitude of the signal will jump, and the amplitude of the jump will be large, so the average amplitude of the calculated force will be large. At the same time, since the artificial force is intermittent, there will be a certain number of peaks in the signal that can be detected. When an invading signal occurs, because the reaction is a relatively fast process, therefore the signal jump speed is faster, the signal from low level to the peak of this process is very fast, amplitude jump of the signal is larger, and this process is a continuous process. At this point, the ratio is also a very large value. Therefore, by detecting the signal contrast of the system and calculating the ratio, the human intrusion signal can be extracted effectively.

2.2 Detection algorithm

Most of the time, the fiber perimeter security system is working under normal conditions. Therefore, it will greatly improve the work efficiency of the system to judge whether the fiber signal is vibration signal or not, that is, whether the system is working under normal conditions. When the system is not affected by external factors, the amplitude and fluctuation of the optical fiber signal are very small, so the short-term energy and short term zero crossing rate are relatively small[5]. When external factors cause small vibration of optical fiber, the vibration signal amplitude does not change much, but the vibration frequency will increase significantly. When external factors cause strong vibration of the fiber, the amplitude and vibration frequency of the fiber signal will increase, and the short-term energy and value will increase. Therefore, the short term energy objectively reflects whether the system has vibration. The short-term energy of the optical fiber signal under normal conditions is selected as the reference. By comparing the short term energy of the optical fiber signal, it is preliminarily determined whether the current optical fiber signal is a vibration signal[6]. Most of the time the optical fiber perimeter security system is working in normal condition, so it will greatly improve the working efficiency of the system to judge whether the optical fiber signal is vibration signal at first, that is, whether the system is working in normal condition. In the case that the system is not affected by external factors, the amplitude and fluctuation of the optical fiber signal are very small, so the short term energy is relatively small. When external factors cause small vibration of optical fiber, the vibration signal amplitude does not change much, but the vibration frequency will increase significantly. When external factors cause strong vibration of the fiber, the amplitude and vibration frequency of the fiber signal will increase, and the short term energy will increase. Therefore, the short term energy objectively reflects whether the system has vibration or not. The short term energy of the optical fiber signal under normal conditions is selected as the reference. By comparing the short-term energy of the optical fiber signal, the current optical fiber signal is preliminarily judged to be a vibration signal. The specific steps are shown in Figure 3.
Figure 3. Flow chart of detection algorithm

1. Input raw optical fiber data \( x(t,k) \), where \( t \) is time-dimensional sampling and \( k \) is channel number;

2. Removing direct current. The data of each channel is subtracted from its mean value to obtain the data \( s(t,k) \) after direct current removal;

3. Mean filtering processing. Set a two-dimensional sliding window with the size of \( WT \times WK \).

4. Calculate the contrast value. Set the two-dimensional sliding window, whose size is \( MT \times MK \). Calculate the mean value and standard deviation of the window according to the following formula:

\[
\begin{align*}
\text{means} &= \frac{1}{MT \times MK} \sum_{tt=0}^{t0+MT/2} \sum_{kk=0}^{k0+MK/2} s(tt,kk) \\
\text{stds} &= \frac{1}{MT \times MK} \sqrt{\sum_{tt=0}^{t0+MT/2} \sum_{kk=0}^{k0+MK/2} [s(tt,kk) - \text{means}]^2}
\end{align*}
\]

Then the contrast of each target in the window is:

\[ D_{bd}(t,k) = \frac{s_{\text{mean}}(t,k) - \text{means}}{\text{stds}} \]

Finally, slide the two-dimensional window from top to bottom and left to right to get the contrast value of all target points.

5. Target detection. Set the contrast threshold \( \text{thr}_{\text{bd}} \), then the target detection result is:

\[ s_{\text{out}}(t,k) = \begin{cases} 1, & D_{bd}(t,k) > \text{thr}_{\text{bd}} \\ 0, & D_{bd}(t,k) \leq \text{thr}_{\text{bd}} \end{cases} \]

6. Extract alarm information such as channel number and time according to target detection results.
3. Experimental data verification

The total length of a monitoring perimeter is about 1.25km, each channel is 2.5m long, and the signal sampling rate is 1000Hz. Artificial climbing disturbance and knocking disturbance are used to simulate the invasion behavior. Set the threshold value and test the perimeter alarm performance. The specific experimental results are shown in Figure 4.

Due to the position limitation of the actual fiber deployment, 164 channels to 464 channels are taken as effective channels, for a total of 300 channels. Figure 4(a) shows the original intrusion signal, because the intrusion signal has discontinuity and it can be seen that there is intrusion behavior near the 93 channel, (b) is the result after the mean filtering, (c) is the contrast result, and (d) is the alarm result processed by the above detection algorithm. As can be seen from (d), the detection algorithm of this paper can accurately detect the intrusion target and verify the reliability of the detection algorithm.

In order to verify the robustness of the algorithm, five experiments were carried out on the system with different invasion targets. Each target experiment was invaded 100 times in total, and each time the system was invaded randomly in 300 channels. The specific detection rate results are shown in Table 1. It can be seen that the algorithm proposed in this paper can effectively detect the intrusion of different targets and verify the robustness of the algorithm.

| target type | 1  | 2  | 3  | 4  | 5  |
|-------------|----|----|----|----|----|
| alarm rate  (%) | 98 | 96 | 97 | 100| 99 |

Table 1. Detection rate statistics results

Based on the above test results, the system uses mean filtering and contrast detection, and adjusts the signal analysis mode of the system to provide a high-sensitivity method for perimeter security system in different environments. Under different environments, the system can alarm intrusion effectively and has good environmental adaptability.
4. Conclusion
With the rapid development of optical fiber sensing technology, optical fiber sensing technology will play an irreplaceable role in different measurement applications. The alarm monitoring system designed by using optical fiber sensing technology can stable and accurate detection data, and the high-efficiency characteristic of optical fiber transmission enhances the real-time performance of the system, which can meet the real-time needs of the practical application environment. The characteristics of fiber transmission bandwidth is large and can be reused, which improves the reliability of data and provides great help for data collection and processing. Optical fiber fence alarm system based on optical fiber sensing technology as a new security platform has become a new focus in the development of optical fiber sensing technology in recent years. In order to quickly and accurately detect the intrusion signals in the optical fiber perimeter system, this paper applies the contrast method to the optical fiber perimeter system, uses the characteristics of the short-term energy of the intrusion signals to judge the vibration signals, reduces the calculation of the system, improves the efficiency of the system, reduces the false alarm rate, and makes the alarm results more accurate. Experimental results show that the proposed contrast based detection algorithm can effectively detect the intrusion targets in the optical fiber system.

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