Intrusion Signal Recognition and Classification Algorithm based on Fiber Signal

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***Abstract*—Optical fiber sensor, because of its immunity to electromagnetic interferences and corrosion resistance, now is widely used in the perimeter security alarm system. The classification between the intrusion and nuisance events without compromising system sensitivity plays a key role in distributed fiber optical perimeter intrusion detection system. This paper proposed an intrusion signal recognition and classification algorithm. Extract intrusion fiber optical signal by using signal envelope extraction based on Hilbert Transformation, which is combined with erosion and expansion operation in mathematical morphology. Denise signal by using wavelet shrinkage and translation-invariant algorithm. Extract features of intrusion signal based on "wavelet packet-energy" signal feature extraction strategy. Classify the intrusion signal by using ANN based on BP and RBF separately. The experiment results show that the system is reliable and of good accuracy.**

***Index Terms*—Distributed Fiber Optical Perimeter Intrusion Detection System; Wavelet shrinkage; Translation-invariant Algorithm; ANN.**

I. INTRODUCTION

The security systems based on fiber optic sensors have many characteristics, such as they are passive, transmission distance, intrinsically safe, anti-electromagnetic interference and they can bear harsh environments such as high temperature and high pressure[1-2]. They are very suitable for the theft loss prevention detection of long-distance oil and gas pipelines and other abnormal scenes such as hillsides, dams, and airports. So in recent years, the development and research of Distributed Intrusion Detection System based on fiber has become a global hotspot of many companies and research institutions. This kind of system can distinguish invade and normal events without affecting the sensitivity is a key performance indicator. Whereas the invasion and normal events are very similar in the signal indicates, so we need to distinguish the two kinds of signals.

II. BACKGROUND

Nowadays, Europe and America, Australia and other developed countries began early in this domain, they have developed a series of intrusion signal recognition algorithm based on the fiber optic sensing. Vires raised value feature extraction algorithm [3] based on frequency domain signal, combined with artificial neural network to classify the signal, in order to achieve perimeter intrusion warning system. However, we just extract eigenvalues from the frequency domain to classify the signals is not convincing. Min and some other people used the method of nonlinear scale filter bank, cepstrum mean elimination and classifier combined with Gaussian mixture model and multilayer perceptron to extract eigenvalues of the signal in the frequency domain [4], in order to achieve real-time monitoring system based on gasoline pipeline buried intrusion events. Seedahmed and some other people put forward a set of fiber optic intrusion signal recognition method which is high robustness in the literature [5]. This method extracted from the time domain a portion of characteristics that can identify signal uniquely as the eigenvectors of the signal, and the input these eigenvectors into artificial neural networks for training and discrimination. Seedahmed and some other people proposed a method which can distinguish large rainfall events and other invasions in the literature [6].

In China, the related research has just began. Jiang and some other people proposed a signal recognition algorithm of the fiber optic sensor based on Mach-Zehnder interferometer technology in the literature [7]. Where it use wavelet packet transform to remove noise of the signal and extract eigenvalues, and it use neural network as classifier of invasions. In the literature [8] it proposed a method using wavelet analysis to remove and cut up signals. In the literature [9] it proposed a method to analysis eigenvectors of the signal. In the literature [10] it proposed a feature extraction algorithm based on wavelet packet transform - energy spectrum, and it has achieved good results.

This paper use digital signal processing theory including signal detection and wavelet analysis as its basic theory, through analyzing the characteristics of the intrusion vibration signal, identifying the real intrusion vibration signal, removing the interference signal through wavelet de-noising, in order to enhance the output SNR.

III. BASIC THEORY

A. Wavelet threshold shrinkage

Wavelet threshold shrinkage was first raised by Johnstone and Donoho in 1992. Under the meaning of Minimum Mean Square Error(MMSE), wavelet shrinkage denoising to Gauss noise is progressively almost optimal, and thus has a further reseach and extensive application. The main theory basis for this

approach is that the wavelet transform can concentrate the energy of signals on a few wavelet coefficients and the noise of wavelet coefficient for white Gaussian noise is expanded evenly on the signals of wavelet coefficient. Through the wavelet decomposition, the amplitude of wavelet coefficient of the noise is smaller than that of the signals, and then reduce the wavelet coefficients of most of the noise to zero by using the method of threshold setting as well as keep the wavelet coefficients of signals. The method can achieve the effect of de-noising. It mainly use the statistical characteristics of wavelet coefficients, and in theory it is a kind of method for the estimation of the risk of the maximum and minimum risk with

$$R(\hat{f}, f) = \mathrm{n}^{-1} E \| \hat{f} - f \|^2 \quad (1)$$

Wavelet thresholding method is not only used for signal de-nosing, but for the density function estimation spectrum estimation and so on. Compared to the traditional de-noising methods(such as linear low-pass filter ,spatial mean and nonlinear median), this method can effectively eliminate or reduce the noise and preserve the catastrophe characters of signals as well, when selecting appropriate threshold parameter or threshold method.

B. Threshold estimation and processing

Using the threshold de-noising method, there are several key factors: the first is the selection of threshold parameters, the second is the selection of threshold function, the third is the selection of wavelet transform method and wavelet base. Commonly used threshold values are as follows:

1) VisuShrink threshold: it was referred to as universal-threshold, first proposed by Donoho and Johnstone.

$$T = \sigma\sqrt{21nN} \quad (2)$$

Among them, N is signal length, σ is standard deviation of noise. Generally we use the first layer of the wavelet decomposition coefficient to estimate the standard deviation of noise. $\sigma = Median(|Y_{ij}|)/0.6745$, where Y_{ij} is the wavelet decomposition coefficients.

2) SureShrink threshold: SureShrink threshold is a kind of adaptive threshold based on the principle of Stein Unbiased Likelihood Estimating rule, also refer to Unbiased Risk Estimation. The basic step is as follows: apply a given threshold r to likelihood estimation, and then get the selected threshold.

We set $x_i N(\mu,1), i = 1,2,\cdots,k$, the Stein unbiased likelihood estimating is:

$$SURE(\lambda, x) = k - 2\sum_{i=1}^{k}(|x_i| \le \lambda) + \sum_{i=1}^{k}(|x_i| \wedge \lambda)^2 \quad (1)$$

Among them, x_i is wavelet coefficient, and $\sigma = 1$, otherwise it should be standardized. $\wedge$ means we choose the smaller one of the two numbers.

SURE threshold is :

$$\lambda^{SURE} = \arg\min_{\lambda \ge 0} SURE(\lambda, x) \quad (2)$$

3) Minimax threshold: On the basis of Minimax Criterion, the selected threshold value is fixation, which is not error free, but produce a extreme value of minimum mean square error. This kind of extremum principle is commonly used to design estimator in statistics. In a given function, this extremum estimator can minimize the maximum mean square error. Specific selection rules of illustrates value is:

$$T = \begin{cases} \sigma(0.3936 + 0.1829\log_2 \mathrm{n}); \mathrm{n} > 32 \\ 0; \mathrm{n} < 32 \end{cases} \quad (3)$$

among them, $\sigma = Median(|Y_{ij}|)/0.6745$ is the estimated value of noise standard deviation by wavelet transform.

The selection rules of SureShrink threshold and Minimax threshold is more convinent only when a small amount of signal high frequency coefficients are located within the noise bandwidth. By setting part of the coefficients to zero, the real signal compontents are not easily lost and weak signals can be extracted.To sum up, this paper chooses VisuShrink threshold.

IV. FIBER OPTIC INTRUSION SIGNAL EXTRACTION AND RECOGNITION ALGORITHMS

A. Algorithm flow

This part concerns with a set of algorithms of intrusion signal extraction and recognition in accordance with the characteristics of the optical signal. The algorithm process is shown in Fig. 1. As can be seen from Fig. 1, according to the sequential process, the algorithms can be divided into four parts: intrusion signal division, de-noising, feature extraction, classification. Algorithms corresponding to the practical flow chart are shown in Fig. 2. Extraction algorithms of fiber optic intrusion signal based on Hilbert transform of the extraction of signal envelope method, combined with morphological dilate and erode, get accurate segmented vibration fragments of intrusion signal. Apply soft threshold shrinkage de-noising based on stationary wavelet analysis, combined with invariant transform algorithm, to the intrusion signal de-noising. Fiber optic intrusion signal recognition algorithms use feature extraction algorithm based on wavelet packet energy, choose signal feature space through wavelet packet energy strategy, and apply BP and RBF Neural Network to classify intrusion signals in the end.

B. Recognizing intrusion vibrated signal based on wavelet multi-resolution analysis

The principle of multi-resolution analysis shows that the signal is mapped to a series of subspaces formed of mutually orthogonal wavelet functions and is stretched out at different scales, thus extract the characteristics of signals in different frequency band, and at the same time preserve every signal characteristic timescale [11-13]. In wavelet decomposition, if the highest signal frequency component is regarded as 1 [14-15], that is Nyquist frequency (half of sampling frequency), wavelet decomposition of the layers is a low-pass filter or band-pass filter [16].

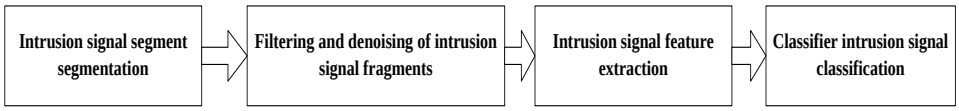

Fig. 1. Flow chart of the algorithm for the extraction and recognition of optical fiber intrusion signals

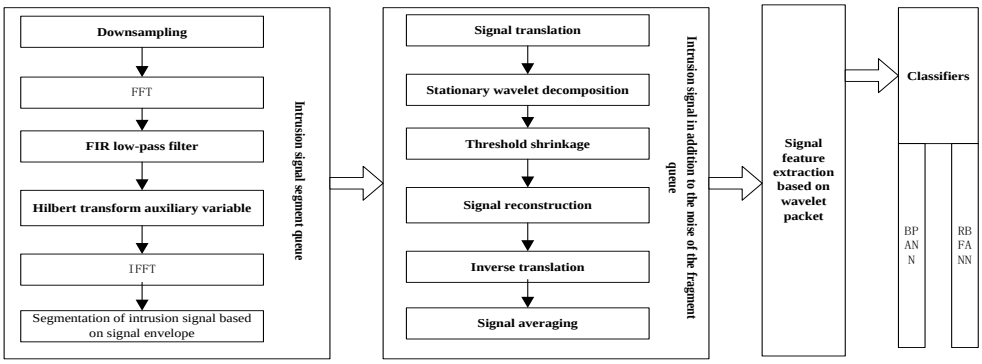

Fig. 2. Extraction and recognition algorithm of optical fiber intrusion signals

Suppose the energy of d^j layer is E_j, analyze the signal frequency band through time domain analysis method, and obtain the energy of each frequency band signals. Then

$$E_j = \frac{1}{n}\sum_{k=1}^{n} | d^j(k) |^2 \quad (4)$$

Among them, $d^j(k)(k = 1, 2, \ldots\ldots, n)$ represents the value of discrete points of j layer by wavelet analysis method.Therefore, through signal energy feature vector on each scale, the vibration signal and its changes by different causes will be reflected on each frequency band energy, resulting in different feature vectors.

Suppose that the signal is decomposed into J layer through wavelet decomposition method, E_j represents energy feature vector. Then

$$T = [E_1, E_2, \ldots, E_j, ?\ ](j = 1, 2, \ldots, J) \quad (5)$$

To determine the nature of the events through vibration signal measured, we should be determined that the feature value of feature vectors is regarded as standard value in each event state. Feature value can be determined by using the experimental statistics method. Suppose e_1 is the feature value of the first element of vector, e_2 is the second, in the same way, $e_j(j = 1, 2, \ldots, J)$,i.e.

$$e_j = \frac{1}{n}\sum_{k=1}^{n} e_{jk}(k = 1, 2, \ldots, n) \quad (6)$$

Among them, n is the experiment times, and if the experimental data reproducibility is high, the value of n takes smaller; if not, n takes bigger. The real detection signal is AC components because detector output signals pass by the pre-filter. As e_j layer and d_j layer also contain no DC components, to obtain the energy of every scale can be transformed for the solution of variance of every scale layer.

V. EXPERIMENT AND PERFORMANCE

In actual field experiments, when carried out the frequency analysis, extract feature vectors, using the BP neural network classifier training and testing. When using precision to construct the objective function, the average accuracy of the test system was 93. 2%; when using accuracy to construct the objective function, the system accuracy rate of 92. 3%; when using the recall to construct the objective function, the system recall rate of 95. 6%. In contrast, the use of literature [17] algorithm for training and testing, the results of the accuracy of the system is 87. 7%, and accuracy was 88. 9%, the recall was 89. 5%.

VI. CONCLUSION

According to the distribution characteristics of the intrusion signal and noise in different bands, we can use wavelet multiscale analysis theory to decompose the received signal into seven layers, extracting the energy amplitude of wavelet d^7 signal, analyzing the characteristic threshold of intrusion vibration and noise signal, we put forward a signal detection scheme of distributed fiber optic system. We use soft threshold shrinkage method based on stationary wavelet, and combined with translation invariance algorithm to remove noise of the intrusion signal fragment, in order to get cleaner signal fragment. Combining noise segmentation and noise removement of the intrusion signal fragment, we can achieve extraction algorithm of the optical signals eventually.

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