A Novel Algorithm for Jamming Recognition in Wireless Communication

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***Abstract*—The jamming is one of the most important factors in modern wireless communication. More and more attention has been paid to the analysis of jamming signals. In this paper, a novel algorithm for the recognition of jamming signals in wireless communication is proposed. This algorithm is based on the singular value decomposition of the signals' cyclic spectrum density. The cyclic spectrum density is insensitive to Gauss white noise and put up many important signal features. The singular value decomposition method is conducive to decrease the dimensions of cyclic spectrum density function. Simulation results show that the proposed algorithm has a higher recognition rate than the traditional method, especially when the jamming to signal ratio is lower.**

***Index Terms*—jamming recognition; wireless communication;cyclic spectrum density; singular value decomposition;**

I. INTRODUCTION

With the wide application of wireless communication technology, wireless communication system has to confront complex jamming environment composed with multiple jamming sources or multiple jamming patterns. The jamming environment is an important factor to the real-time performance and effectiveness in wireless communication [1]. Therefore, how to identify the jamming signal accurately and rapidly has become an essential problem. Most traditional jamming identification researches are based on feature parameters extracted from the time domain or frequency domain. Besides, one parameter only can distinguish one or several types jamming signals. If we want to recognize all jamming signals, many different features must be needed, which leads to a higher computation complexity. Therefore, we adopt the cyclic spectrum density feature to distinguish the jamming signal and lower computation complexity. Much information of the jamming signal can be obtained from the signals' cyclic spectrum density [2]. Many differences can be discovered among the cyclic spectrum density of different jamming signals [3].

Cyclic spectrum analysis is one of the most popular methods in signal processing recent years [4,5]. Cyclic spectrum density is the promotion of the power spectrum density function, but better for signal processing . Cyclic spectrum density is used to describe the signal's cyclostationary features and its insensitive to noise makes it possible to extract the features when signal to noise ratio is lower. Singular Value Decomposition (SVD) is one of the most important tools for matrix decomposition in linear algebra [6]. It is the generalization of regular unitary matrix diagonalization. SVD is essential for a wide range of signal processing and makes it possible for any matrix to spectrum analysis.

Cyclic spectrum is insensitive to the noise and can be used to suppress the noise in signal processing. Besides, SVD can extract the features of data and simple them which is important for classifier [7,8]. According to above features of cyclic spectrum density and SVD, this paper proposed a jamming recognition algorithm based on the singular vectors of cyclic spectrum density.

Our work is closely related to general signal recognition in wireless communication. However, the focus of jamming recognition is on the recognition of jamming signals, rather than general signals. Jamming recognition in wireless is a well-researched and complex problem. The general jamming recognition problem in wireless communication is a pattern recognition problem. There are two important steps in pattern recognition, feature parameters and pattern classifier. The latter has many mature algorithms in signal processing field. Therefore, the extraction of feature parameters will be the heart of this paper.

The paper is organized as follows. In section II we discuss the jamming signal model in the paper. In section III the proposed algorithm is described in detail. Section IV shows the simulation results. In Section V concluding remarks are given.

II. SIGNAL MODEL

The proposed algorithm is tailored specifically for jamming signals recognition system in wireless communication. The following are four common jamming signals in modern wireless communication system:

Single-tone jamming signal:

$$J(t) = \sqrt{2P_J}\cos(2\pi f_J t + \varphi) \tag{1}$$

P_J is the power of jamming signal,f_J is the frequency of jamming signal, φ is the initial phase of signal, $\varphi \in (0, 2\pi)$ and φ follows the standard normal distribution.

Multi-tone jamming signal:

$$J(t) = \sum_{i=1}^{N} \sqrt{2P_J/N}\cos(2\pi f_{J,i} t + \varphi) \tag{2}$$

$f_{J,i}$ is the i^{th} frequency components of the multi-tone jamming signal,N is the tones' number of multi-tone jamming signal, and φ is the initial phase.

Scan frequency jamming Signal:

$$J(t)=\left\{\begin{array}{cc} A\exp(j\beta_i t^2/2+j\omega_i t+j\varphi) & |t|\le T/2 \\ 0 & else \end{array}\right. \quad (3)$$

β_i is the speed of scan frequency ,ω_i is the initial angular frequency, φ is the initial phase, T is the duration of scan frequency.

Part band jamming Signal:

$$J(t)=U_n(t)\cos(f_J+\varphi) \quad (4)$$

$U_n(t)$ is base band noise with a zero mean and an variance σ_n^2 ,f_J is the center frequency of the signal,$\varphi\in(0,2\pi)$ have an uniform distribution and independent with the base band noise $U_n(t)$.

The jamming signals sample library is created by adding jamming signals with AWGN channel noise and communication signals. Here we use MATLAB software to simulate the four types jamming signals, QPSK modulated signal is adopted as the normal communication signal in the simulation. The QPSK signal's time domain expression is as follows:

$$\mathrm{S}(t)=\sum_n g(t-nT_d)\cos(\omega_c t+\varphi_n) \quad (5)$$

$g(t)$ is the code element to be transmitted with an amplitude 1, T_d is the time interval of code element, ω_c is the carrier angular frequency, φ_n is the n^{th} code element's phase. After normalization, the QPSK modulated signal is added to Gaussian white noise $n(t)$. The communication signals containing jamming signal can be shown as follows:

$$E(t)=S(t)+J(t)+n(t) \quad (6)$$

III. Algorithm

A. Cyclic autocorrelation function and cycle spectrum density function

For one generalized cyclostationary signalif it has a period-T . Its means function $m_x(t)$ and autocorrelation function $R_x(t,\tau)$ also meet the cyclical nature with the period T . The (7) is the definition of the signal autocorrelation function:

$$R_x(t,\tau)=E[x(t)\cdot x^*(t-\tau)] \quad (7)$$

For (7) also has a period T here we use the sample average value to replace the time average value, (7) can be rewritten as the (8):

$$R_x(t,\tau)=\lim_{N\to\infty}\frac{1}{2N+1}\sum_{n=-N}^{N}x(t+nT)\cdot x^*(t-\tau+nT) \quad (8)$$

Therefore we can deal $R_x(t,\tau)$ with Fourier series expansion

$$R_x(t,\tau)=\sum_{m=-\infty}^{\infty}R_x^\alpha(\tau)e^{jmt\frac{2\pi}{T}} \quad (9)$$

Here we let $\alpha=m/T$ and call it as cycle frequency of the signal.

We can get (10) after reshape (8) and(9)

$$R_x^\alpha(\tau)=\lim_{N\to\infty}\frac{1}{T}\int_{-T/2}^{T/2}x(t+\tau/2)x^*(t-\tau/2)e^{-j2\pi\alpha t}dt \quad (10)$$

$R_x^\alpha(\tau)$ means the cyclic autocorrelation function on the frequency α . The cycle frequency of a stationary signal contains two parts information: Zero cycle frequency and the non-zero cyclic frequency. Among them, the zero cycle frequency corresponds to the smooth part of signal, and non-zero cyclic frequency is used to describe the cyclostationary feature of signal.

The following is the Fourier transform of the correlation function

$$S_x^\alpha(f)=\int_{-\infty}^{\infty}R_x^\alpha(\tau)e^{-j2\pi f\tau}d\tau \quad (11)$$

$S_x^\alpha(f)$is called as the period spectrum density function or cyclic spectrum density function of the signal $x(t)$.

The cyclic spectrum analyzing is one popular tool in cyclostationary analyzing. The differences of cyclic spectrum can be used to recognize and identify different signal parameters. Besides, the stationary noise does not have cyclostationary, cyclic spectrum can be a very perfect feature parameter to distinguish between signal and noise [6]. In this paper, we adopt the cyclic spectrum features in the analysis of signal differences to achieve the jamming signals recognition purposes. Fig.1 shows the cyclic spectrum figures of four typical

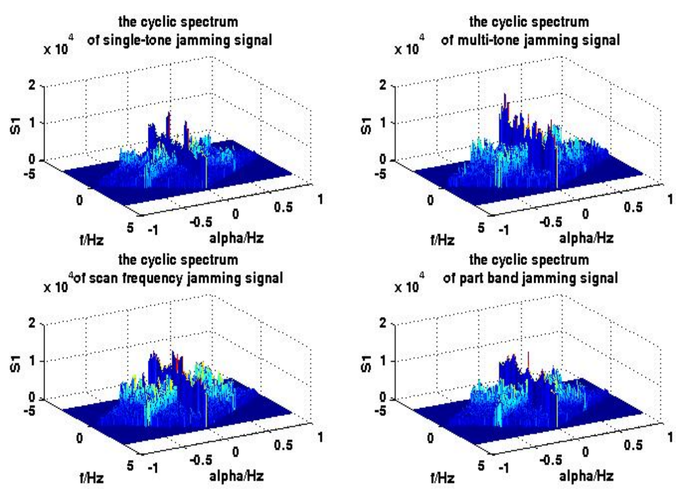

Figure. 1. the cyclic spectrum of four classic jamming signals with Gauss white noise

jamming signals with Gauss white noise. From Fig.1 we can see that unique characteristics of jamming signals are reflected on the cyclic spectrum. Significant differences between the four types of jamming signals are exist, which can be used for the classification of the jamming signals.

In order to reduce the computational burden of the later data processing , multiple slices of cyclic spectrum were used.Fig.2 is the schematic diagram of cyclic spectrum slices extraction. In Fig.2, there are two cyclic spectrum in left of the figure and five slices each cyclic spectrum in right. We can understand the extract method well in Fig.2.

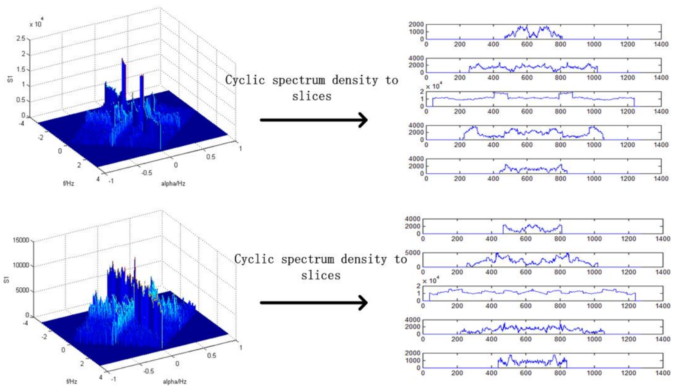

Figure. 2. the schematic diagram of cyclic spectrum density slices extraction

B. Singular vectors extracted

We know that the cyclic spectrum transformation is extended from the spectrum frequency axis. The cyclic spectrum transformation provides a lot of useful information, but the estimated results for the entire two-dimensional plane is a large amount of data matrix and can't be directly used for classification and identification [9]. Here we use the singular value decomposition(SVD) to reduce the dimension of the slices of cyclic spectrum. SVD is one of the most important tools of modern numerical analysis [10]. The SVD of the matrix is reversible [11], the decomposition of singular vectors can preserve the original cyclic spectrum information better. For any matrix A meet $A \in R^{m \times n}$, there is an orthogonal matrix $U \in R^{m \times n}$ and $V \in R^{m \times n}$ meet

$$
\begin{aligned}
A &= U \sum V^T \\
&= [u_1, u_2, u_3, \cdots u_p] \begin{bmatrix} \sigma_1 & & & \\ & \sigma_2 & & \\ & & \ddots & \\ & & & \sigma_p \end{bmatrix} \begin{bmatrix} v_1^T \\ v_2^T \\ \vdots \\ v_p^T \end{bmatrix} \\
&= \sigma_1(u_1 v_1^T) + \sigma_2(u_2 v_2^T) + \cdots \sigma_p(u_p v_p^T)
\end{aligned} \tag{12}
$$

The non-zero diagonal elements $\sigma_1 \geq \sigma_2 \geq \cdots \geq \sigma_p \geq 0$ is called as the non-zero singular values of the matrix A. $u_1, u_2, u_3, \cdots u_p$ and $v_1, v_2, v_3, \cdots v_p$ are referred to the left and right singular vectors of the matrix A. The singular values are stable, scale invariance and rotate invariance. These inherent characteristics proved that the singular value matrix can effectively reflect the features of the matrix. Therefore, the non-zero singular value of matrix is often used as classification features in the traditional pattern recognition problem. Therefore, singular value decomposition is reversible. The original matrix can be reconstructed perfectly with singular values and singular vectors. Singular vectors can also effectively reflect the characteristics of the original matrix and the subtle differences between different signals.

C. Algorithm summary

We divide the algorithm into four steps:

(1)the first step is to preprocess the signal samples and the second step is to calculate the cyclic spectrum of jamming signals. The next step is The end, Firstly, we will adopt measures to achieve the normalization of jamming signal samples. Here, we make it with the maximum minimum value method, one of the linear function methods;

(2)Secondly, the main task is calculating the cyclic spectrum density matrix and extract the slices of cyclic spectrum. Here, we take an improved fast algorithm for cyclic spectrum estimation. This method decreases the requirement of data quantity without reducing the performance;

(3)The third step is singular value decomposition of the cyclic spectrum matrix and extract the left 1,the left 2,the right 1and the right 2 singular value vectors;

(4)The probabilistic neural network will be trained with singular value vectors and checked in the last step.

IV. Simulation Results

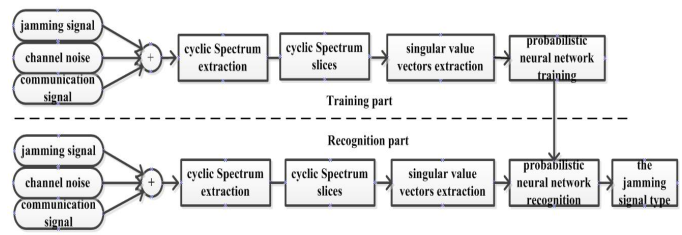

Figure. 3. The proposed jamming signals recognition system

QPSK signal is used as normal communication signal in the simulation. The communication data rate is set as 1kbps and the carrier frequency 15k Hz. 500 samples are generated randomly for each one type of jamming signal and in all 2000 samples for four types jamming signal. 1200 samples are used to train probabilistic neural network classifier, the others to test. The structure of the proposed jamming signal recognition system is shown in Fig.3.

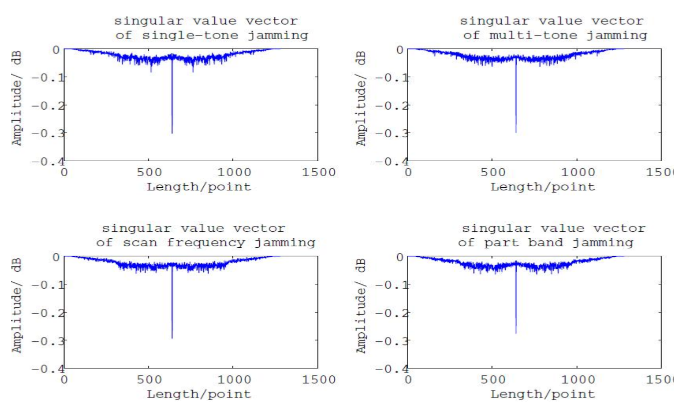

Figure. 4. left 1 singular value vectors of four different type jamming signals

Fig.4, Fig.5, Fig.6and Fig.7 are left 1, left 2, right 1 and right 2 singular value vectors. The singular vectors are obtained by singular value decomposition of four different jamming signal samples. The simulations are processed in different

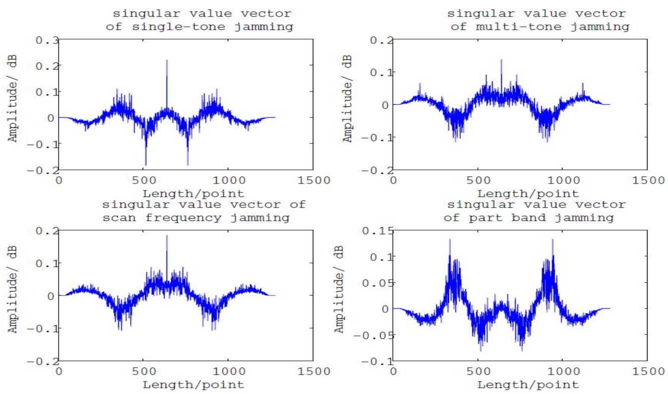

Figure. 5. left 2 singular value vectors of four different type jamming signals

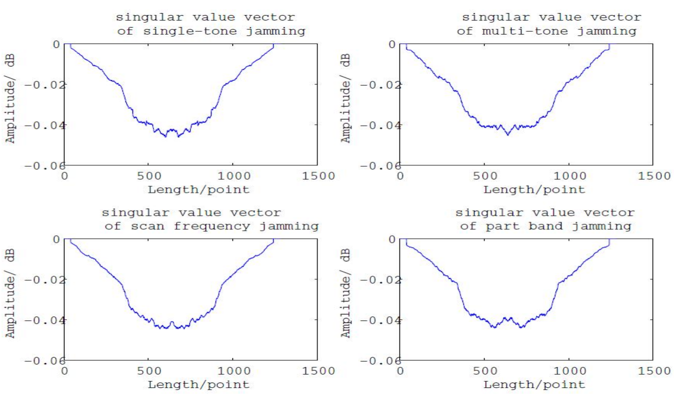

Figure. 6. right 1 singular value vectors of four different type jamming signals

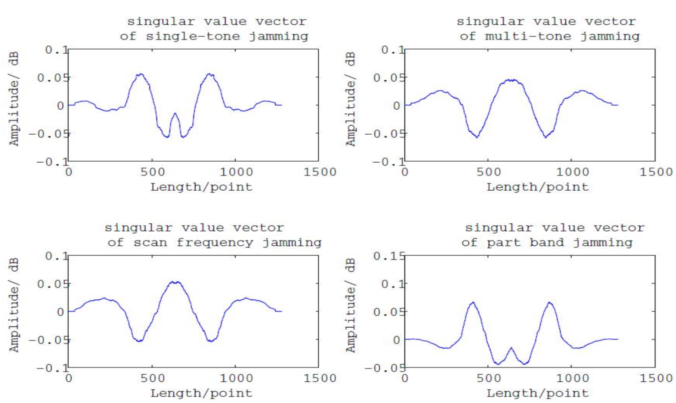

Figure. 7. right 2 singular value vectors of four different type jamming signals

jamming to signal ratio. The recognition effectiveness is shown in Fig.8 and Fig.9. When jamming to signal ratio is -6dB, the simulation of the proposed method has a well correct recognition rate above 75% to single-tone jamming and multi-tone jamming. But for the other two types jamming signals

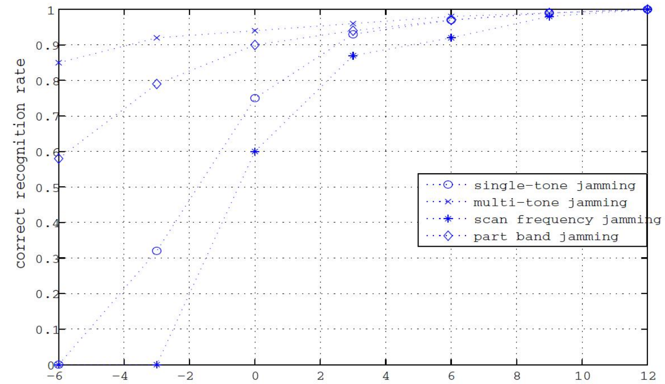

Figure. 8. the performance of recognition with traditional method

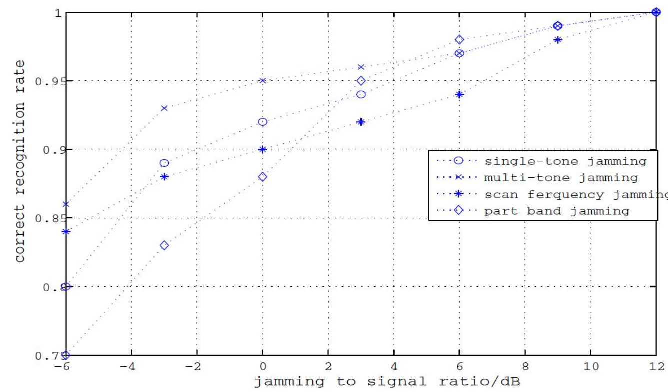

Figure. 9. the performance of recognition with the proposed method

don't have obviously improvement. When jamming to signal ratio above 0dB, the proposed method has a higher correct recognize rate above 86%, better than the traditional method. When the JSR greater than 6dB, two methods both can give a perfect results.

V. Conclusion

In this paper, one jamming recognition algorithm is proposed. It is based on singular value decomposition of the signal cyclic spectrum density. The singular vectors are obtained from the singular value decomposition to the signal cyclic spectrum. Then, probabilistic neural network will come true the identification of jamming signals. The simulation results show that the speed and accurate rate of jamming signal identification can be improved significantly with the proposed algorithm. Moreover, the results show that the proposed algorithm provide a better performance when lower jamming to signal ratio than traditional method.

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