Advances in Computer, Signals and Systems (2023)
Clausius Scientific Press, Canada

DOI: 10.23977/acss.2023.070911
ISSN 2371-8838 Vol. 7 Num. 9

A Novel Recognition Method for Direct Sequence Spread Spectrum (DSSS) Signals Based on Secondary Power Spectrum

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Keywords: Spread Spectrum Communication, Secondary Power Spectrum, BPSK Modulation, DSSS

Abstract: DSSS signal is a technical means used for spread spectrum communication. Due to its unique frequency characteristics, it has great anti-interference and multipath resistance capabilities, and has many advantages such as a wide spectrum, making it an important enabling technology for spread spectrum communication. However, the relevant characteristics of spread spectrum signals pose challenges in detecting spread spectrum signals from conventional signals. Based on this, this article selects a feature value based on quadratic power spectrum to distinguish between conventional signals and spread spectrum signals after binary phase shift keying (BPSK) modulation, and selects decision boundaries through a large number of training sets, and tests the model. The results show that the spread spectrum signal detection method based on the secondary power spectrum has good detection accuracy and performance, with a discrimination accuracy of 99.44% and 99.6% for the training and testing sets, respectively, verifying the feasibility of this detection method.

1. Introduction

In the field of modern wireless communication, reliable signal detection, differentiation, and recovery have always been an important research direction. Spread spectrum technology, as a powerful post-modulation transmission method, has become an important enabling technology in the field of signal processing and has been widely applied in many communication systems. By multiplying the original signal with a direct spread spectrum sequence, spread spectrum technology can effectively improve the anti-interference performance of the signal, improve transmission security, and have better transmission efficiency. In spread spectrum technology, BPSK modulation is a commonly used modulation method, and its simplicity and efficiency make it the preferred choice for many spread spectrum communication systems. However, although spread spectrum technology has many theoretical advantages, in practical environments, signals are often subject to various interferences and influences, such as conventional or some noisy signals, which can affect the detection and recovery performance of signals. So detecting and distinguishing unknown DSSS signals in complex signal backgrounds is an urgent problem to be solved.

In recent years, a large number of scholars have done relevant work on the detection and modulation of spread spectrum signals. A.W. Azim proposed dual-mode linear frequency modulation spread spectrum modulation for low-power wide area networks, and achieved higher spectral efficiency [1]. J. Xu proposed and designed a direct sequence spread spectrum communication method based on FPGA, which implemented simple spread spectrum communication in applications [2]. Spread spectrum methods can also be used to optimize the transmission of specific signals. V. Hordiichuk proposed a spread spectrum method to improve the security of timer signal transmission and implemented some noise protection functions [3]. Spread spectrum communication also has great application potential in anti-interference, anti-attack, and anti-multipath effects. The new spread spectrum communication theory proposed and implemented by W. Huang has been applied to the problems encountered in signal transmission processes such as anti-interference [4]. A. Kumar has promoted the DSSS method and applied it to alleviate autocorrelation-based attacks, with good anti attack performance [5]. However, due to the advantages of spread spectrum signals, their detection is extremely difficult. Therefore, scholars have also proposed many methods based on the detection of spread spectrum signals [6]-[9].

The secondary power spectrum is a tool used for signal frequency domain characteristics in the field of signal processing [10]. In the secondary power spectrum, this article focuses on the energy distribution of signals at different frequencies, so as to display frequency and phase information and distinguish the characteristics of the signal. Therefore, signal analysis methods based on the secondary power spectrum have important significance in fields such as signal processing and communication system analysis, which can effectively demonstrate the characteristics of signals and improve the effectiveness and performance of signal processing. This paper aims to study a BPSK modulated spread spectrum signal detection method based on a secondary power spectrum. This paper compares the secondary power spectrum of the spread spectrum signal modulated by BPSK with the secondary power spectrum of the conventional signal to achieve signal detection and differentiation in the signal background discussed in this paper. The proposed conclusion is verified through digital simulation.

2. Secondary power spectrum correlation theory

There is a non-periodic continuous input signal $f(t)$. In order to facilitate analysis and modeling, this article assumes that it satisfies the Dirichlet condition and first samples $f(t)$ using a periodic impulse sequence $S_{T_s}(t)$ with a period of T_s to obtain sequence $f_s(t)$ as

$$f_s(t) = f(t) \cdot S_{T_s}(t) = f(t) \cdot \sum_{n=-\infty}^{\infty} \delta(t - nT_s) \tag{1}$$

Then discretize the sequence to obtain $f_s(k)$

$$f_s(k) = f_s(t)\Big|_{t=kT_s} \tag{2}$$

At this point, assuming it is a finite length sequence of length M , perform N points discrete Fourier transform on the obtained discrete sequence to obtain $F(k)$ as

$$F(k) = \mathrm{DFT}[f(k)] = \sum_{k=0}^{N-1} f(k) W_N^{kn}, k = 0,1,\ldots, N-1 \tag{3}$$

Where $W_N = e^{-j\frac{2\pi}{N}}$, N is the length of the DFT transformation interval, and satisfies $N \geq M$.

On this basis, get the power spectrum corresponding to $F(k)$ and take the logarithm based on 10 to obtain the power spectrum $P(k)$

$$P(k) = \lg(|F(k)|^2) \tag{4}$$

Then calculate the DFT transformation again based on the obtained primary power spectrum to obtain the secondary power spectrum $H(k)$

$$H(k) = |\text{DFT}[P(k)]|^2 \tag{5}$$

Based on this, it is able to distinguish between conventional signals and DSSS signals.

3. Generation and modulation of conventional signals and DSSS signals

3.1 The generation of DSSS signal

There is a conventional random binary 01 sequence $b(t)$ with a length of N_b, and in this paper, we need to obtain a spread spectrum signal sequence $q(t)$ with a code rate of K times for transmission. Obviously, the length of $q(t)$ is KN_b, which can be represented as

$$q(t) = \begin{cases} \text{NOT}(b(n)) & t = Kn - K + 1 \\ 1 & t \neq Kn - K + 1 \end{cases} \tag{6}$$

Where n takes all integers range in $[1, N_b]$.

3.2 The BPSK modulation of DSSS signals and conventional signals

Firstly, for the conventional random binary signal $b(t)$ in 3.1, it is processed as a rectangular pulse signal composed of 1 and -1 binary codes as

$$b_r(t) = (1 - 2b(t))g(t - nT_n) \quad n = 1, 2, ..., N_b \tag{7}$$

where $g(t)$ is a rectangular pulse signal with an amplitude of 1 and a width of T_n. Then, in this paper, a sine signal with a sampling rate of f_s is used to modulate it with BPSK, resulting in the signal $b_{\text{BPSK}}(t)$ as

$$b_{\text{BPSK}}(t) = b_r(t)\cos(2\pi f_s t) \tag{8}$$

Similarly, a spread spectrum signal sequence $q_{\text{BPSK}}(t)$ modulated by BPSK can also be obtained.

4. Processing of secondary power spectrum after BPSK modulation

By calculating the secondary power spectra of the conventional signal and the spread spectrum signal modulated by BPSK, two sets of sequences $H_b(k)$ and $H_p(k)$ can be obtained, respectively. The overall algorithm flow is shown in Figure 1. By processing the data of these two types of secondary power spectra, it is easy to binary the data and distinguish between conventional signals and spread spectrum signals modulated by BPSK.

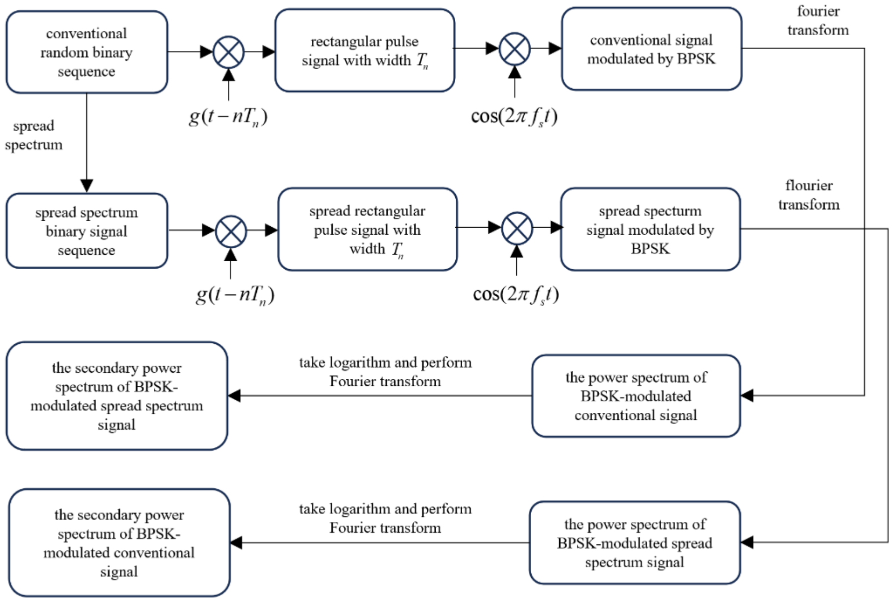


Figure 1: Flowchart of Algorithm for Obtaining Secondary Power Spectrum

Firstly, normalize the secondary power spectrum after and before spreading to obtain the $H'(k)$ as

$$H_b'(k) = \frac{H_b(k)}{\max\{H_b(k), H_q(k)\}\big|_{k=0,1,\ldots,N-1}} \tag{9}$$

After similar treatment, $H_q(k)$ can obtain $H_q'(k)$. Take the standard deviations s_b and s_q of $H_b'(k)$ and $H_q'(k)$ separately as

$$s = \sqrt{\sum_{k=0}^{N-1}(H'(k) - \overline{H'(k)})^2} \tag{10}$$

Where $\overline{H'(k)}$ is the data $H_b'(k)$ or $H_q'(k)$ corresponding average value. As a result, this article obtained the eigenvalues s_b and s_q that distinguish the spread spectrum signal from the conventional signal. In order to perform binary classification of the data, through this article's research, the following methods can be used to classify the eigenvalues of the conventional signal and the spread spectrum signal.

A large number of repeated experiments were conducted m times to obtain m sets of signal eigenvalues as follows

$$(s_b(k), s_q(k)) \quad k = 1, 2, \ldots, m \tag{11}$$

For the two sets of data s_b and s_q, calculate the mean $\overline{s_b}$ and $\overline{s_q}$ respectively, and then calculate the mean s_d for $\overline{s_b}$ and $\overline{s_q}$. This article considers s_d as the decision boundary for distinguishing the eigenvalues of conventional signals and spread spectrum signals.

5. The result of distinguishing between conventional and DSSS signal

To fully validate the proposed method for distinguishing between conventional signals and spread spectrum signals based on the secondary power spectrum, this paper adopts Matlab digital simulation to simulate the process of generating conventional signals, spreading the signals, modulating them with BPSK after spreading, drawing their respective secondary power spectra, and selecting decision boundaries.

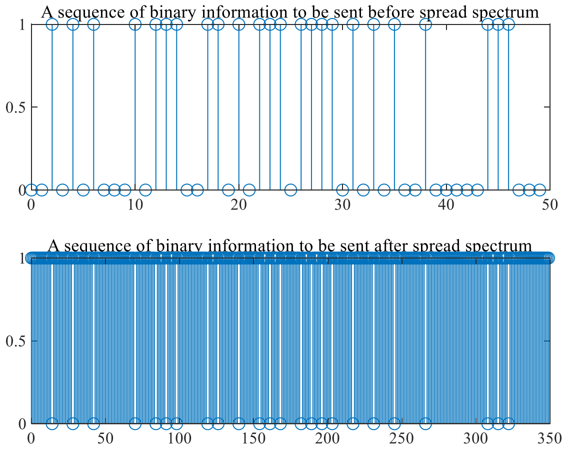
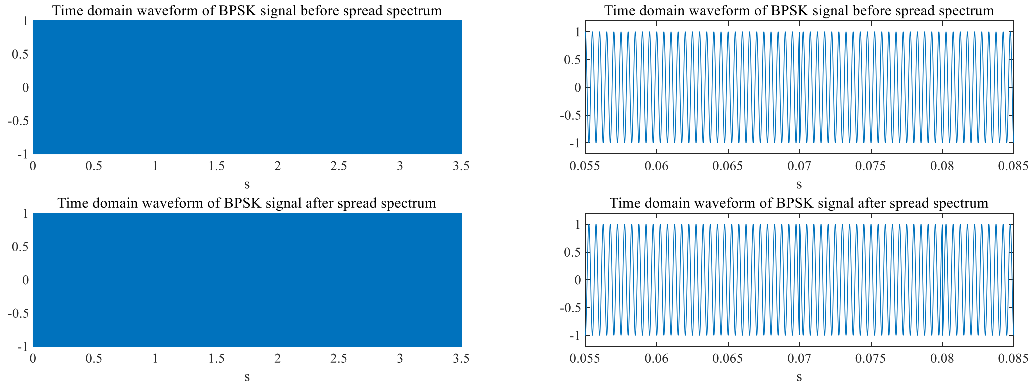


Figure 2: The information sequence of the signal before and after the spreading spectrum

Firstly, in this simulation, a random sequence of 01 with a length of 50 is selected as $b(t)$ and spread to a signal $q(t)$ with a 7-fold code rate. Their sequence diagrams are shown in Figure 2. Then, the complete time-domain waveform of the signal before and after spreading is modulated by BPSK with a sampling rate of 2000Hz, as shown in Figure 3(a).

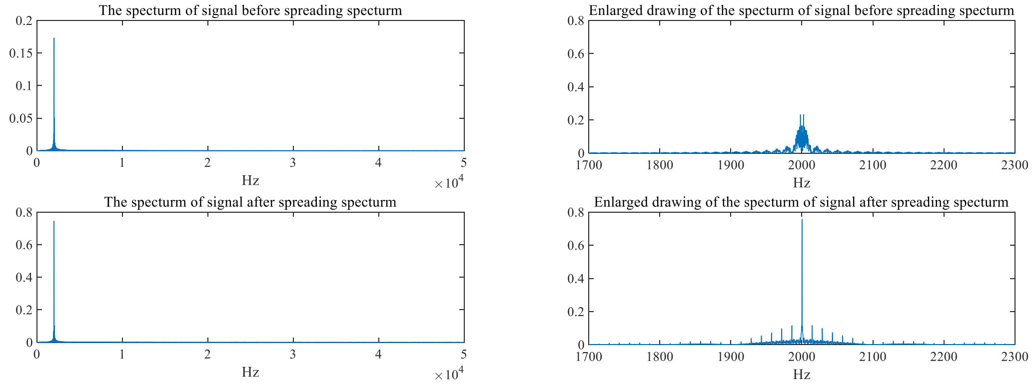


(a) (b)

Figure 3: (a) Time domain waveform of signals after BPSK modulation (b) Enlarge drawing of time domain waveform of signals after BPSK modulation

It can be observed that in the global time domain, due to the high density of the time-domain waveforms of the BPSK modulated spread spectrum signal and the conventional signal, it is difficult to distinguish them. In Figure 3(b), even if the waveform is amplified, the difference between the spread spectrum signal and the conventional signal in the time-domain waveform cannot be easily found. Therefore, it is almost impossible to distinguish between the conventional signal and the spread spectrum signal in the time domain.

Based on the fast Fourier transform (FFT) in Matlab, the amplitude spectrum of the signal before and after spreading can be plotted, as shown in Figure 4(a). It can be seen that there is no significant difference in the spectral morphology from the global amplitude spectrum before and after spreading. In Figure 4(b), even if the amplitude spectrum is amplified in the 1700-2300Hz frequency domain, there is no obvious distinguishing feature between the two except for their different amplitudes. Therefore, it is also very difficult to distinguish between conventional signals and spread spectrum signals from the amplitude spectrum in the frequency domain.



(a) (b)

Figure 4: (a) The spectrum of signals before and after the spreading spectrum (b) Enlarged drawing of the spectrum of two kinds of signals

Therefore, this article applies the method of extensive repeated experiments shown earlier to calculate the eigenvalues s of 10,000 sets of random conventional signals and corresponding spread spectrum signals, and visualizes the data as shown in Figure 5.

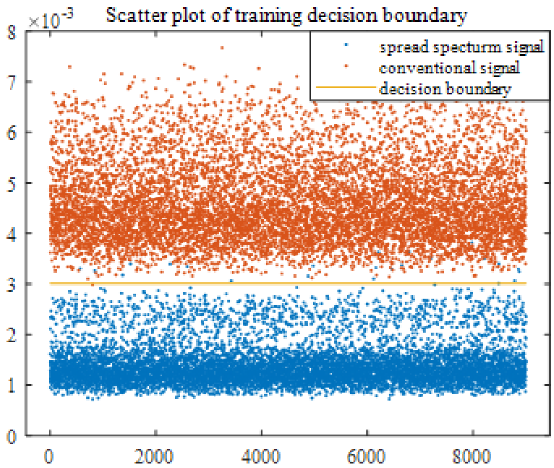


Figure 5: Scatter plot of training decision boundary

This simulation used and calculated 10,000 sets of data, and selected 0.9 as the proportion of the training set. By using this dataset to train the model and calculate the decision boundary s_d, the two types of data were effectively classified. Through calculation, the data showed that the classification accuracy of the training set was 99.44%, which can play a good distinguishing role. Then, this experiment applied a test set with 1000 samples for testing, and the results of the test set are shown in Figure 6.

After visualization of the test results and calculation, the accuracy of distinguishing between conventional signals and spread spectrum signals using this feature value reached 99.6%, and still has a high testing accuracy.

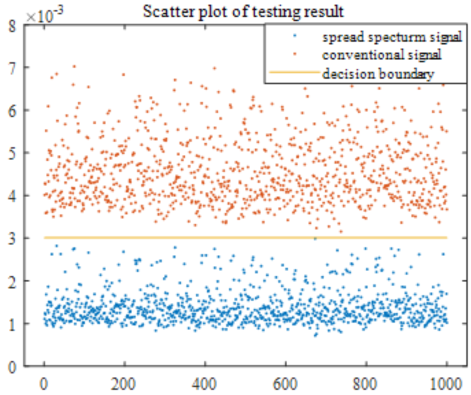


Figure 6: Scatter plot of testing result

6. Conclusion

On the basis of the generalized quadratic power spectrum theory, this article selects the standard deviation of the quadratic power spectrum of the conventional signal and the spread spectrum signal modulated by BPSK as the eigenvalues to distinguish between the conventional signal and the spread spectrum signal. Through a large number of digital experiments in Matlab, the training and testing models are trained and tested. Finally, the training accuracy and testing accuracy of the detection method for spread spectrum signals based on the quadratic power spectrum in this study are verified to be 99.44% and 99.60%, respectively. It has good detection performance, which provides a more reliable and accurate method for the detection of spread spectrum signals. The operation method is also relatively simple and reliable, with good resolution and detection performance.

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