Research on modulation recognition of Communication Radar Based on spread spectrum technology

Dujiya Bao¹,a, Hua Guo¹, Wenxia Zhang¹, Xinxin Bao²

¹Department of Information Engineering, Ordos Institute Of Technology, Ordos, China
²School of Foreign language Studies, Inner Mongolia Medical University, Hohhot, China

E-mail: guohua716@csu.edu.cn
E-mail: baodujia1983@163.com

Abstract: Aiming at the problem that the traditional radar signal recognition method needs to be completed under the noiseless condition, which leads to the low recognition accuracy of low SNR signal, the modulation recognition method of communication radar signal based on spread spectrum technology is studied. The phase difference and instantaneous frequency characteristics of communication radar signal are extracted after the spread spectrum processing of communication radar signal with direct sequence spread spectrum. The training sample is used to train PNN neural network, and the modulation recognition of communication radar signal is completed. Simulation experiments under different parameters show that the recognition method based on spread spectrum technology has an effective recognition rate higher than 90% for low SNR signal, which is superior to the traditional method and can be applied in practice.

1. Introduction

Communication radar is an important technical means to ensure communication in the modern electronic warfare environment. Identifying communication radar signals can help to mine the favorable information in the signals and reverse jam the enemy. However, the current electromagnetic environment is very complex, which brings great difficulty to the modulation and recognition of radar signal. Modulation recognition of communication radar signal is an important part of signal processing, which is very important for the subsequent estimation of radar parameters, inference and analysis of radar performance, and judgment of radar threat degree. When based on statistical pattern recognition radar signals, it is necessary to assume that the acquired signals are noise-free. When identifying low-SNR signals, the correct recognition rate will be reduced due to fuzzy signal features [1]. Although the recognition method based on sorting statistical histogram improves the recognition rate, it has a large computational burden and complex computation, which reduces the efficiency of signal modulation recognition [2].

Spread spectrum technology uses spread spectrum code to spread the signal and makes full use of the relevant characteristics between different spread spectrum codes to reduce the noise in the signal and improve the efficiency of subsequent signal processing [3]. At the same time, the signal features processed by spread spectrum technology are no longer significantly affected by SNR, effectively improving the accuracy of signal feature extraction. According to the above analysis, this paper will
study the modulation recognition method of communication radar signal based on spread spectrum technology.

2. Research on modulation recognition method of Communication Radar Based on spread spectrum technology

2.1 Spread spectrum processing of communication radar

Spread spectrum technology can be divided into direct sequence spread spectrum and frequency hopping. In this paper, direct sequence spread spectrum with stronger jamming capability is used to process communication radar signals. At the signal transmitting end of communication radar, the transmitted signal is modulated to convert the signal into digital signal. The spread spectrum sequence generated by the PN code generator extends the spectrum of the digital signal, and the broadened signal is then transmitted through the carrier for processing. After the communication signal of communication radar is processed by direct sequence spread spectrum technology, the interference signal can be effectively filtered and the complexity of subsequent identification and processing can be reduced.

If the original communication signal of the communication radar is \( a(t) \), the signal is a digital signal with polarity, and its expression is as follows [4]:

\[
a(t) = \sum_{n=0}^{\infty} a_n g_a(t - nT_a)
\]  

(1)

In formula (1), \( a_n \) is the information code of whether the generator generates spread spectrum sequence, and its value is +1 or -1; \( T_a \) is the spectrum width of information code generated by the generator.

If the spread spectrum sequence produced by the spread spectrum sequence code generator is \( b(t) \) and the spectrum bandwidth is \( n \), the expression of spread spectrum sequence is as follows:

\[
b(t) = \sum_{n=0}^{n-1} b_n g_b(t - nT_b)
\]  

(2)

In formula (2), \( g_b(t) \) is a gate function, its amplitude is 1. \( b_n \) is the symbol signal generated by the generator. The spread spectrum processing of the radar communication signal is made by multiplying the original communication signal produced by the communication radar and the spread spectrum sequence produced by the spread spectrum sequence generator.

After spread spectrum processing of the original communication signal of the communication radar, the proportion of noise signal in the signal is reduced. After the signal is further denoised by the filter, the characteristics of radar communication signal are extracted.

2.2 Radar signal feature extraction

In this paper, the correlation function is selected to extract the signal features of communication radar, so as to reduce the computational complexity of feature extraction process and improve the efficiency of feature extraction. The correlation function is used to extract the signal feature to obtain the phase difference by using the principle that the value of the autocorrelation function at time zero is proportional to the cosine of the phase difference of two sinusoids of the same frequency, and a phase difference feature can be used to characterize the unique communication signal. In other words, the signals with the same modulation mode and the same signal carrier have the characteristics of correlation function, and the correlation function can be used to separate the radar signals at different frequencies.

If the general communication signal model of communication radar is shown as follows [7]:

\[
\text{General Communication Signal Model}
\]
\begin{equation}
    s(t) = \exp\left[j\left(2\pi f(t)t + \varphi(t)\right)\right]
\end{equation}

In formula (5), $f(t)$ is the frequency function of modulation of radar communication signal; $\varphi(t)$ is a phase modulation function that modulates the radar communication signal. Frame processing is carried out for the communication signal of radar. After frame processing, the phase difference between adjacent frame signals is obtained according to the above steps. According to the relevant data, the phase difference of LFM signal after frame processing is positively correlated; The phase difference of MPSK signal appears hopping phenomenon at its phase mutation[5]. The phase difference of MFSK signal after framing processing shows step change. After the signal type of radar communication signal is determined by the above steps, the instantaneous frequency characteristics of the signal are extracted. Several short time series can be obtained from the signal processed by framing, then the instantaneous frequency of the segment sequence of the communication signal after framing is as follows [6]:

\begin{equation}
    f(i) = \frac{(k + \delta(i)) * f_s}{N}
\end{equation}

In formula (4), $k$ is the time window serial number corresponding to the maximum value of the time-domain spectral line after the Fourier transform of the signal segment $i$th sequence; $f_s$ is the sampling frequency of signal sequence; $N$ is the number of points in the Fourier transform of the sequence; $\delta(i)$ is the frequency correction factor. After extracting the features of radar signal, the modulation recognition of radar signal is realized by using neural network.

2.3 Modulation identification of radar signals

In this paper, modulation recognition of communication radar signals is realized by using PNN neural network. The number of neurons in the hidden layer of PNN is the same as that in the input neural network. The number of neurons in the input layer is the same as the number of signal sequences to be recognized in the input network. The training sample set is used to determine the radial basis function center of the hidden layer neuron. If the sample input matrix of the neural network is an $R \times Q$ matrix, the output matrix is a $Q$-dimension row vector, in the following form [7].

\begin{equation}
    P = \begin{bmatrix}
    p_{11} & p_{12} & \cdots & p_{1Q} \\
    p_{21} & p_{22} & \cdots & p_{2Q} \\
    \vdots & \vdots & \ddots & \vdots \\
    p_{R1} & p_{R2} & \cdots & p_{RQ}
    \end{bmatrix}
\end{equation}

\begin{equation}
    T = \begin{bmatrix}
    t_1 \\
    t_2 \\
    \vdots \\
    t_Q
    \end{bmatrix}
\end{equation}

In formula (5), $Q$ is the number of neurons in the hidden layer of the neural network; $P_{ij}$ is the $i$th input variable of the $j$th training sample; $t_i$ is the output variable of the $i$th training samples. The Euclidean distance between the input sequence and the sample sequence is calculated, and the input vector matrix is transformed into the Euclidean distance [8]. Under the action of neural network transfer function, the output vector of hidden layer is obtained. When the output vector value of the hidden layer contains 1, the similarity between the input signal sequence and the sample sequence is the highest, and the corresponding recognition result is output to complete the recognition of the radar communication signal[9]. At this point, the modulation recognition method of communication radar based on spread spectrum technology is completed.
3. Simulation experiment and analysis
The modulation identification method of communication radar signal based on spread spectrum technology is studied above. This section will select different types of communication radar signals to verify the feasibility of this identification method.

3.1 Simulation condition setting
In this experiment, four kinds of modulation signals were selected for simulation experiment, namely conventional pulse (NS) signal, linear frequency modulation (LFM) signal, two-phase coded signal (BPSK) and binary frequency coded signal (BFSK) signal. BPSK signal adopts 7-bit Barker code. BFSK signal adopts 13-bit Barker code.

Under the condition of different SNR, the four modulated signals generate 600 signal samples respectively, and 100 signal samples are randomly selected from each signal as training sample signals. Four modulation signals are used to carry out simulation experiments, and the experimental parameters are measured. The corresponding conclusions are obtained by analyzing the experimental data.

3.2 Content of simulation experiment
In order to enhance the scientific and effective results of the simulation experiment and verify whether the recognition method designed in this paper has practical application value, the traditional recognition method of communication frequency modulation based on statistical mode is added as a comparison in this simulation experiment. Four modulated signals were set as the recognition objects of the two signal recognition methods, and the two signal recognition methods were used to experiment each type of modulated signal in the form of Monto Carlo respectively at different sampling frequencies and sampling points. By comparing the effective recognition rate of the two recognition methods under different experimental conditions, the performance of the two signal recognition methods is compared. The simulation experiment was carried out on the same virtual simulation experiment platform. Other experimental conditions were kept unchanged during the experiment to ensure the authenticity and effectiveness of the experimental results. After processing and analyzing the experimental data recorded in the experimental platform, the final conclusion of this experiment is obtained, and the performance verification of the modulation recognition method for communication signals is completed.

3.3 Experimental results and analysis
When the sampling frequency is 150MHz and the number of sampling points is 1024, the correct recognition rates of the two signal recognition methods for the four modulated signals with different SNR are shown in the table below.

| Signal types | Method of this paper | Comparison method |
|--------------|----------------------|-------------------|
|              | 0dB  | 5dB | 10dB | 15dB | 0dB | 5dB | 10dB | 15dB |
| NS           | 92.6 | 93.4 | 94.9 | 95.3 | 85.1 | 85.4 | 86.3 | 86.7 |
| LFM          | 91.7 | 93.8 | 94.9 | 95.4 | 85.0 | 85.5 | 85.9 | 86.4 |
| BPSK         | 90.5 | 90.2 | 91.5 | 92.7 | 87.6 | 87.2 | 86.5 | 86.0 |
| BFSK         | 93.2 | 94.7 | 95.2 | 96.1 | 91.2 | 91.8 | 92.6 | 93.1 |

When the SNR of the signal is 0, the recognition rate of NS signal and LFM signal in this method is higher than 90%, and the recognition rate of the comparison method is higher than 85%. However, when the SNR is increased, the recognition rate of the method in this paper is greatly different from that of other signals. The correct recognition rate of BPSK signal is far lower than that of BFSK signal. The recognition rate of BPSK signal increases with the increase of SNR, but the recognition rate of BFSK signal is lower than that of the method in this paper. The recognition rate of NS signal and LFM signal increases with the increase of SNR, and the maximum recognition rate can reach 87.9%, which is lower than the highest recognition rate of this method.
To sum up, the modulation recognition method of communication radar signal based on spread spectrum technology studied in this paper has a certain tendency when it is used, and the recognition results for different types of signals are different. In comparison, the recognition rate of the signal increases with the increase of the signal-to-noise ratio. In comparison, the effective recognition rate of the proposed method is higher than 90% and better than the comparison method, which has practical application value.

4. Conclusion
The modulation recognition method of communication radar signal based on spread spectrum technology is studied in this paper. The traditional method is improved to solve the problem of low recognition rate of low SNR signal. Simulation experiments show that the recognition rate of the proposed method is higher than 90% for low SNR signals, and it is effective. It can be found from the simulation experiment that the recognition method designed in this paper has a relatively poor recognition effect for a certain type of signal. Therefore, in the future research, it is necessary to optimize the signal recognition method to get a higher correct recognition rate.

REFERENCE
[1] BAI X.W., ZHANG L.J., LIN H. X. (2020) Ultra-Wideband Communication Signal Recognition Simulation Based on Cyclic Frequency Characteristics. Computer Simulation, 37(05): 105-109.
[2] WU P.P., SHI Y.C., ZHANG M.(2019) Performance of Repeater Jamming Against Spread Spectrum Communication Based on Signal Reconstruction. Electronic Warfare Technology,34(05):39-44.
[3] XIONG G, ZHAO E.F.(2019) Spread Spectrum Code Sequence Recognition Method based on Hebb Optimization Criterion. Communications Technology,52(09):2098-2101.
[4] QIAO Y.M., ZOU D.C., LU X.C.(2019) Semi-physical simulation research of spread OFDM signal based on FPGA. Journal of Time and Frequency,42(01):68-76.
[5] ZHENG Y., SHEN Y.J., ZHOU Y.S.(2019) Radar Signal Modulation Identification Based on Multilayer Bidirectional LSTM [J]. Journal of Telemetry, Tracking and Command, 40(01):33-41.
[6] WU X.X., ZHANG K.M, ZHANG H.Z, et al.(2018) Investigation of low-PAPR optical OFDM system based on DFT-Spread technology. Optical Communication Technology, 42(08): 18-21.
[7] CHEN T., LIU L.Z., GUO L.M.(2018) Intra-pulse Modulation Recognition of Radar Signals Based on MWC Compressed Sampling Wideband Receiver. Journal of Electronics & Information Technology,40(04):867-874.
[8] LIU L.T., DAI L.J., CHEN T.(2018) Radar signal modulation recognition based on spectrum complexity. Journal of Harbin Engineering University,39(06):1081-1086.
[9] XU W., YU J.Y., CHEN M.(2018) Intra-pulse modulation recognition of radar signal based on multi-dimensional features. Journal of Terahertz Science and Electronic Information Technology,16(01):81-86.