Identification of Frequency Hopping Radiation Sources Based on the Feature of Ambiguity Function

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Abstract. Aiming at the problem that the traditional feature parameters are difficult to meet the fastness and effectiveness of frequency hopping radiation sources identification, a feature extraction method based on radar ambiguity function theory is proposed. The algorithm applies the radar ambiguity function theory to the identification of frequency hopping radiation sources. Firstly, the single pulse ambiguity function of each hop signal is calculated. Then the particle swarm optimization algorithm is used to extract the main ridge slice of ambiguity function of the signal (MRSAF). Based on the noise reduction processing of MRSAF and the stability of MRSAF envelope, the difference sum, difference maximum value and difference distribution entropy characteristics of MRSAF are extracted. The experimental results of fuzzy cluster mean (FCM) show that the extracted feature parameters can be used to identify signals with high accuracy under dynamic SNR conditions.

1. Introduction

Frequency hopping technology refers to a method of using frequency-shift keying using a pseudo-random code to make the carrier frequency continuously hop and to spread the spectrum. The frequency hopping technology is mainly used in military communication. It can effectively avoid interference, has good confidentiality, and has strong networking capability.

The biggest difference between frequency hopping communication and conventional fixed frequency communication is that the frequency has pseudo-random hopping with time. In the detection and reception of frequency hopping signals, most researches at home and abroad focus on the detection of frequency hopping signals and the estimation of related parameters. There are relatively few studies on feature extraction and classification recognition of frequency hopping signals. The existing algorithms mainly use the duration, orientation information, power and signal time correlation of the frequency hopping signal to realize the classification and recognition of the frequency hopping signals. Literature [1-3] studied the method of sorting using signal characteristics of frequency hopping network stations. The available features include amplitude, frequency, DOA, and networking information. In the case where the estimation of various characteristic parameters is correct, frequency hopping network station sorting can be implemented. However, the acquisition of effective feature parameters is also difficult. In particular, the networking information can be obtained after a series of processing such as frequency hopping signal detection, parameter estimation, solution hopping, and decryption, which is more difficult than the frequency hopping network station sorting problem. Based on the actual environment of the battlefield, the literature [4] proposes a time-correlation algorithm based on the frequency domain information, dwell time information, signal amplitude and other fingerprint features of the frequency hopping network to realize the sorting of the frequency hopping
network signal. However, in practical applications, the extraction accuracy of the fingerprint characteristics of the frequency hopping signal parameters is difficult to meet the application requirements.

However, with the diversification of frequency hopping and the increase in the number of configurations, the classification and recognition of frequency hopping signals by the above features have become stretched. To meet current battlefield environment for sorting speed and accuracy requirements hopping radiation signal, and extracting a new feature parameter is added a feasible approach. [5] noted that the ambiguity function can reflect the internal structural information of the signal more completely, it can dig out the effective features that are different from other signals. In [6], MRSAF was taken as the research object, and the characteristic parameters with better sorting effect were extracted. In [7], the MRSAF is preprocessed by derivative constrained smoothing, which further enhances the anti-noise performance of MRSAF features.

At present, the MRSAF is the research object, which has achieved certain results in radar radiation source identification. In this paper, the radar ambiguity function theory is applied to the identification of frequency hopping radiation sources.

2. signal model and preprocessing

2.1. frequency hopping signal model

The mathematical expression of the frequency hopping signal \( s_n(t) \) can be described as:

\[
s_n(t) = v_n(t) \sum_{k=0}^{K-1} \exp[j(f_{nk}t + \varphi_{nk})] \text{rect}(\frac{t'}{T_n})
\]

Where \( T_n \) is the hop period of the frequency hopping signal \( s_n(t) \), \( K \) is the total hop count in the observation time \( \Delta t \), \( f_{nk} \) is the carrier frequency of the \( k \)th hop, \( \varphi_{nk} \) is the initial phase, and the duration of the initial non-complete hop in the observation time is \( \Delta t_{0u} \), \( v_n(t) \) is the baseband complex envelope of the frequency hopping signal \( s_n(t) \); \( t' = t - (k - 1)T_n - \Delta t_{0u} \) is the instantaneous engraving; \( \text{rect} \) is the unit rectangular window function. Conventional communication systems typically use a fixed frequency signal as the carrier, ie, the transmitter local oscillator signal is a fixed frequency signal. The frequency hopping communication system mainly uses a pseudo-random code sequence generated based on a certain rule to control the carrier generation system, and obtains a carrier signal of a frequency pseudo-random hopping to implement communication. The time domain waveform and spectrum of the frequency hopping signal are shown in Figure 1.

(a) The time domain waveform
(b) The spectrum

Figure 1. The time domain waveform and spectrum of the frequency hopping signal.
2.2. Pretreatment:
To calculate the single-pulse ambiguity function of each hop signal, extraction the single-hop signal and estimation of the moment of the transition are required.

There are many types of existing frequency hopping parameter estimation methods, in the literature [8-9], domestic and foreign scholars have studied the use of Gabor spectrum, wavelet transform, S transform and The Hilbert-Huang transform estimates the frequency hopping parameters. Ren Xu, Zhu Weigang combined the theory of compressed sensing with the parameter estimation algorithm of frequency hopping signals in [10]. Reasonably avoiding the problem of large amount of data in the frequency hopping signal due to the high sampling rate, but the algorithm complexity is slightly higher. In this paper, the time-frequency variation method is used to estimate the frequency hopping transition time, and the single-hop signal is extracted to calculate the single-pulse ambiguity function of the single-hop signal.

The processed frequency hopping signal is shown in Figure 2.

![Figure 2. The processed frequency hopping signal time domain waveform](image)

3. Algorithm and process based on ambiguity function feature extraction
Firstly, a single-pulse ambiguity function for each hop signal after processing is calculated. Then, using the PSO algorithm to search the slice of the radar source signal, the extraction speed of the signal slice feature can be greatly improved, and the feasibility of the slice feature as an alternative parameter for the sorting feature of the frequency hopping source of the complex system can be enhanced. Three characteristic parameters, namely the difference sum, the difference maximum value and the difference distribution entropy, are extracted from the obtained main ridge plane to form a feature vector. Finally, it is sent to the classifier for training, identification, and classification.

3.1. Calculation of ambiguity function
For any narrowband radar signal $s(t)$, its AF is defined as:

$$ |\chi(\tau, f_d)|^2 = \left| \int_{-\infty}^{\infty} s(t) s^*(t) e^{j2\pi f_d t} dt \right|^2 $$ (2)

In equation (2), $s^*(t)$ is the conjugate of $s(t)$, $\tau$ is the delay, and $f_d$ is the frequency shift. It can be seen that the AF of the signal is the joint two-dimensional of the signal on the time delay $\tau$ and the frequency shift $f_d$ plane. AF is a joint two-dimensional time-frequency representation of the signal on the time delay and frequency shift plane, which can display the waveform characteristics and structural information of the signal.

For the ambiguity function, the highest point of the ambiguity energy is at the origin of the time-frequency plane, so there will generally be at least one main distribution band of the ambiguity energy, that is, the main ridge of the ambiguity function. As long as their signal forms are different, their distribution of ambiguity energy will show a certain difference, and the main ridge of the ambiguity
function will generally show different characteristics. Therefore, extracting and describing the characteristic distribution information of the signal blur main ridge will help to sort and identify the hopping source signal.

3.2. Feature Extraction

The flow chart of the local difference method for MRSAF feature extraction is shown in the Figure 3.

![Flow chart of the local difference method for MRSAF feature extraction](Figure 3)

The flow chart of the local difference method for MRSAF feature extraction is shown in the Figure 3.

The local difference feature of the signal slice is extracted by the local difference method. Using the method of the literature [11], the local difference is defined as:

\[ ld = f(i + m) - f(i), i = 1, 2, \ldots, 512 - m \]  

(3)

Where \( ld \) represents the difference between the ambiguity energy values of two points separated by a certain step on the MRSAF of the signal, and \( m \) is the difference step size, the number of differences that can be obtained by the above formula is \( 512 - m \). After a large amount of simulation, the difference step \( m \) in the [65-70] interval can get the difference of the MRSAF with greater difference. Three characteristic parameters are extracted by the local difference method: difference sum, difference maximum value, and difference distribution entropy. (The \( 512 - m \) difference is equally divided into \( t \) equal parts, and the number of difference points \( x \) falling in each interval is counted, and then the probability that the difference falls in each interval is calculated, and the difference distribution entropy is calculated.)

\[ \text{sum}_{ld} = \sum ld \]  

(4)

\[ \text{max}_{ld} = \max (ld) \]  

(5)

\[ \text{entr}_{ld} = -p \sum \log p \]  

(6)

\[ p = \frac{x}{512 - m} \]  

(7)

The sum of the local MRSAF differences is described by the difference sum. The maximum value of the difference describes the maximization of the local difference in the main energy of the ambiguity energy. The difference distribution entropy describes the distribution of local differences in the main energy of the ambiguity energy from the global perspective.

4. experiment and analysis

In this paper, four typical frequency hopping radiation source signals CW, BPSK, QPSK and MSEQ are selected for experiments. The specific parameters are set as follows: the single-hop duration is set...
to 10 μs; the sampling frequency is set to 100MHz; the signal carrier frequency is 3 to 30MHz, with 3M steps: 10 hopping points randomly hopping; MSEQ encoding is \{1 0 1 1 1 0 0\};

4.1. MRSAF extraction
The maximum energy slice of four typical modulation pattern signals is extracted by the method described in the literature [11], and the directly extracted main ridge slice is smoothed to obtain a waveform that is less affected by noise.

![Figure 4. The main ridge slice of ambiguity function](image)

The waveform extraction results from the method of this paper are shown in Figure 4. The waveform is greatly weakened by the influence of noise, and the discrimination between the modulations is very high, which satisfies the cluster identification requirements.

4.2. Clustering and Identification
Under the condition of signal-to-noise ratio SNR={2,4,6,8,10,12,14,16,18,20}, each SNR, each hopping point generates 20 hop signals, according to the method The feature vector of the frequency hopping signal is extracted, and the result is shown in the Figure 5. The FCM algorithm is used to identify the recognition accuracy as shown in the Table 1.

It can be seen from Figure 5 that the characteristic distribution of the four types of signals under dynamic SNR still has relatively satisfactory intra-class convergence and inter-class separation ability, and there is a small overlap between the categories. It can be seen from Table 1 that the clustering accuracy of BPSK signals in the four types of signals is the lowest, which is 80.5%. The other types of signals have relatively satisfactory clustering accuracy, and the average clustering accuracy of the four types of signals is 88%. The above clustering results further confirm the robustness of the extracted features to SNR changes. It can be seen that the local difference feature extracted in this paper can adapt to the large dynamic SNR.

![Figure 5. FCM clustering map of 4 types of signals](image)
Table 1. FCM clustering results for four types of signals

| signal type | CW  | BPSK | QPSK | MSEQ | correct rate |
|-------------|-----|------|------|------|--------------|
| CW          | 197 | \    | 3    | \    | 98.5%        |
| BPSK        | \   | 161  | 16   | 23   | 80.5%        |
| QPSK        | 1   | 18   | 177  | 4    | 88.5%        |
| MSEQ        | \   | 26   | 5    | 169  | 84.5%        |

5. Conclusion
In this paper, a method of frequency hopping radiation source identification based on ambiguity function features is proposed. The algorithm applies the radar ambiguity function theory to the identification of frequency hopping radiation sources. Firstly, the single pulse ambiguity function of each hop signal is calculated. Then the particle swarm algorithm is used to extract the MRSAF of the signal, and the moving average is used to reduce the noise of MRSAF to improve the MRSAF. On the basis of improving the stability of MRSAF envelope, the difference sum, difference maximum value and difference distribution entropy characteristics of MRSAF are extracted. The FCM experimental results show that the extracted characteristic parameters can be used to identify the frequency hopping signals with high accuracy under dynamic SNR.

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