Research on radar main lobe false target jamming feature extraction based on time-frequency domain and fluctuation characteristics

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Abstract. Aiming at radar main lobe false target jamming, the forms of target echo and jamming signal are analyzed, and its modeling and simulation are carried out. By extracting the 11 dimensional features of time domain, frequency domain and amplitude fluctuation characteristics, it is proved that it is distinguishable for real target echo and false target jamming signal through simulation experiment, and a feature model is established; aiming at the shortcomings of traditional classification model, bagging algorithm is applied to deal with the over fitting phenomenon. Simulation results show that the feature model established in this paper has good performance in bagging algorithm.

1. Introduction
Active deception jamming uses the wrong target or information to act on the radar target detection system and tracking system, which makes the radar unable to accurately detect the real target, or can not correctly measure the parameter information of the real target, so as to mislead and disturb the radar to detect and track the real target. Since DRFM can produce jamming signal which is highly coherent with radar waveform and can effectively realize deceptive jamming of false target, DRFM technology is mainly used in radar main lobe false target jamming[1].

The main lobe false target jamming can be divided into range false target jamming, velocity false target jamming and angle false target jamming. The three kinds of jamming are used to modulate and transmit the received radar signal by jammer, so that most of its parameters are approximate or close to the target, so as to achieve the purpose of radar deception. The existing radar target recognition methods include support vector machine, Naive Bayes method, convolution neural network, etc. Due to the small feature space dimension (less than 50) and the small scale of training set, common classification algorithms such as support vector machine and Naive Bayes are easy to cause over results of over-fitting. Various machine learning algorithms are used to identify the interference in literature [2-4], although the test results are good, according to the feature dimension and algorithm design analysis, the classification model has the problem of over fitting, and the author didn’t analyze the test results.

In order to solve the above problems, this paper applies bagging algorithm to deal with the over fitting phenomenon caused by low feature dimension, and extracts relevant features from time domain, frequency domain and amplitude fluctuation characteristics respectively, and establishes feature model. The simulation results show that the feature model established in this paper has good performance in bagging algorithm.
2. Jamming model of target echo and false target
This paper mainly discusses the most common pulse system radar in Shipborne radar. At the same
time, because signal with large time-bandwidth products can obtain high resolution, and the linear
frequency modulation (LFM) signal is widely used in those signals, so the radar signal in this paper is
mainly LFM signal.
Because the angle measurement time is very short when angle deception jamming is carried out on
pulse radar through DRFM system, the angle information of target can be extracted through single
pulse echo signal, which is not affected by amplitude fluctuation characteristics of target. While in this
paper, jamming recognition is mainly carried out by analyzing time domain, frequency domain and
amplitude fluctuation characteristics of target and jamming signal, so only range false target jamming
and velocity are considered.
A classical representation method of radar target information parameter set is as follows:
\[ T = \{ R, \alpha, \beta, f_d, S_e \} \]
\( R \) is the distance, \( \alpha \) is the azimuth, \( \beta \) is the angle of pitch, and \( f_d \) is Doppler frequency, \( S_e \) is the
power of the received signal.
The information parameter set of single false target formed by active deception jamming can be
expressed as follows:
\[ T_f = \{ R_f, \alpha_f, \beta_f, f_{d_f}, S_f \} \]
The target resolution of radar is expressed as follows:
\[ \Delta V = \{ \Delta R, \Delta \alpha, \Delta \beta, \Delta f_d, [S_{smin}, S_{smax}] \} \]
In the formula, \( \Delta R \)、\( \Delta \alpha \)、\( \Delta \beta \)、\( \Delta f_d \) represents the resolution of radar in range, azimuth, pitch angle
and velocity respectively, \( S_{smin} \) is the minimum detectable signal power of radar receiver (i.e.
sensitivity of radar receiver), \( S_{smax} \) is the saturation input signal power.
For range/velocity deception jamming, the parameter set satisfies the following conditions:
\[ \| T - T_f \| > \Delta V \]
That is to say, the difference between radar target information parameter set and false target
information parameter set is greater than radar target resolution, which leads to radar to judge it as two
or more targets, resulting in false alarm of radar system, so as to achieve the purpose of deceptive
jamming of false target.
The radar transmitting signal is expressed as follows:
\[ s(t) = A \exp \left[ j2\pi \left( f_c t + \frac{\mu t^2}{2} \right) \right] \]
Where \( A \) is the amplitude of the signal, \( f_c \) is the center frequency and \( \mu \) is the frequency
modulation slope. The target echo received by radar is as follows:
\[ s_R(t) = A_R \exp \left[ j2\pi \left( (f_c + f_d) \left( t - \frac{2R(t)}{c} \right) + \frac{\mu}{2} \left( t - \frac{2R(t)}{c} \right)^2 \right) \right] \]
Where \( R(t) \) is the distance of the target, \( f_d \) is Doppler frequency. \( A_R \) is the target echo amplitude.
When the jammer on the target carries out range false target jamming, the range jamming signal
received by the radar is as follows:
\[ s_j(t) = A_j \exp \left[ j2\pi \left( (f_c + f_d) \left( t - \frac{2R(t)}{c} - \Delta t \right) + \frac{\mu}{2} \left( t - \frac{2R(t)}{c} - \Delta t \right)^2 \right) \right] \]
Where \( A_j \) is the amplitude of jamming signal, and \( \Delta t \) is the time delay of jamming signal relative to
echo signal.
The jamming signal of velocity false target received by radar is as follows:
\[ S_R(t) = A_R \exp \left[ j2\pi (f_c + f_d + \Delta f) \left( t - \frac{2R(t)}{c} \right) \right] \]
Where \( \Delta f \) is the false Doppler frequency modulated by jammer.
The range false target and velocity false target are modeled and simulated respectively. The time
domain and pulse compression results of the received signal are shown in Figure 1 and Figure 2.

3. Feature extraction of time-frequency domain and amplitude fluctuation

3.1. Standard deviation of normalized instantaneous frequency absolute value

In the process of calculating the maximum normalized instantaneous amplitude of radar received
signal, the instantaneous phase of the signal can be obtained as \( \varphi(n) = \arctan \left( \frac{x(n)}{\dot{x}(n)} \right) \). The phase
sequence of the signal can be obtained as \( \varphi_{NL}(n) \) by phase convolution and then linear phase
operation. When the carrier of the signal is completely synchronized, it meets the requirement of
\( \varphi_{NL}(n) = \varphi_{NL}(n) - \varphi_0 \). The latter is the mean value of \( \varphi(n) \).

Thus, the instantaneous frequency of radar signal \( x(t) \) can be expressed as

\[
 f(n) = \frac{f_s}{2\pi \left( \varphi_{NL}(n+1) - \varphi_{NL}(n) \right)}
\]

As mentioned earlier, \( \varphi_{NL}(n) \) is the phase sequence of \( x(t) \), and the instantaneous frequency can be
normalized.

\[
 f_1(n) = \frac{f(n)}{\max_{i=1}^N \{ \text{abs}[f(i)] \}}
\]

Finally, the standard deviation of normalized instantaneous frequency absolute value of radar
received signal can be expressed as

\[
 a_{sf} = \left( \frac{1}{c} \sum_{a_n(i) > a_t} f_n^2(i) - \left[ \frac{1}{c} \sum_{a_n(i) > a_t} |f_n(i)| \right]^2 \right)^{1/2}
\]
Among them, $a_t$ is the threshold value of weak signal amplitude, $f_n$ is the normalized instantaneous frequency of radar received signal, $c$ is the number of sample points (satisfying $a_n(i) > a_t$) [5].

The simulation results are shown in Figure. 3-a.

3.2. Correlation ratio parameter
Similarly, if the received signal is $x(t)$ and its autocorrelation function is $B(t, \tau) = x(t) \ast x(t - \tau)$, then the correlation ratio parameter (parameter $s$) of signal $x(t)$ can be expressed as

$$S = \frac{\min(N, P)}{\max(N, P)}$$

Where $N$ is the number of positive sampling points of the instantaneous autocorrelation function, and $P$ is the number of negative sampling points. The simulation results are shown in Figure. 3-b.

3.3. Moment skewness coefficient
The moment skewness coefficient can be understood as a parameter reflecting the degree of signal asymmetry. Generally, it is calculated by the third power of the first standard deviation of the third central moment

$$Ske = \frac{E(X - \mu)^3}{\sigma^3}$$

Where $\mu$ is the mean value of signal and $\sigma$ is its standard deviation.

The simulation results of moment skewness coefficient are shown in Figure. 3-c.

3.4. Moment kurtosis coefficient
Kurtosis is a parameter used to reflect the smoothness of data frequency distribution curve, and kurtosis coefficient is a parameter used to measure the degree of data aggregation in the center [6]. The ratio of the fourth-order central moment to the fourth power of standard deviation is generally used to measure the kurtosis of moments, which is called moment kurtosis coefficient, and is mainly used to describe the steepness of the signal at the top.

Let the echo signal be $x(t)$ and obtain its sampling sequence $x(n), (n = 1, 2, 3 ..., N)$, if $\mu$ is the mean value of the signal and $\sigma$ is its standard deviation, then its kurtosis coefficient can be expressed as

$$Kur = \frac{E(X - \mu)^4}{\sigma^4}$$

The simulation results of kurtosis coefficient are shown in Figure. 3-d.
3.5. Signal information dimension

The information dimension can reflect the distribution of signals and reflect the partial information of signals.

Let the echo signal be $x(t)$ and obtain its sampling sequence $x(n), (n = 1, 2, 3, ..., N)$ in the frequency domain, and isomorphic it in the frequency domain. Set $s(n)$ as:

$$s(n) = x(n + 1) - x(n), n = 1, 2, 3, ..., N - 1$$

The information dimension of the sequence is calculated, set $L$ and $P_i$ as:

$$L = \sum s(n)$$

$$P_i = \frac{S(n)}{L}.$$ 

Then, the information dimension of the reconstructed sequence is

$$D_i = \sum -P_i \log P_i.$$ 

The simulation results of information dimension are shown in Figure. 4-a.

3.6. Signal box dimension

Box dimension is a concept in fractal theory. Its idea is to study and describe things with mathematical methods from the perspective of fractal dimension. Radar echo is a kind of time series. After sampling, it can still show the trend and density in frequency, and fractal can describe it. Box dimension mainly describes the geometric scale of fractal theory. In this paper, box dimension can reflect the amount of information of signal.

The box dimension of radar echo signal is calculated by the method provided by the literature [7]. Firstly, the echo signal $x(t)$ is serialized to obtain $x(n), (n = 1, 2, 3, ..., N).$ If the sequence is placed in a unit square and suppose that its minimum interval is $q = 1/N$, then

$$N(q) = N + \left\{ \sum_{i=1}^{N-1} \max\{x(n), x(n + 1)\} \ast q - \sum_{i=1}^{N-1} \min\{x(n), x(n - 1)\} \ast q \right\}/q^2.$$ 

According to the above formula, the box dimension of radar echo signal can be expressed as

$$D_b = -\frac{\ln N(q)}{\ln q}.$$ 

The box dimension simulation results are shown in Figure. 4-b.
3.7. **Maximum normalized instantaneous amplitude**

Let the signal be \( x(t) \) and obtain its sampling sequence \( x(n), (n = 1, 2, 3 ..., N) \). The instantaneous phase and amplitude can be obtained by Hilbert transform. The expression of Hilbert transform can be expressed as follows:

\[
z(n) = x(n) + j\hat{x}(n) = a(n)e^{j\varphi(n)}
\]

Where \( \hat{x}(n) \) is the Hilbert transform of signal \( x(t) \), and \( a(n) \) is its instantaneous amplitude, which can be expressed as \( a(n) = \sqrt{x(n)^2 + \hat{x}(n)^2} \), \( \varphi(n) \) is its instantaneous phase. The maximum value of normalized instantaneous amplitude can be obtained by normalization and Fourier transform. The feature can reflect the fluctuation information in the signal, which can be expressed as follows:

\[
\text{norm_ins_max_amp} = \frac{\max_{i=1}^{N}|DFT(A(i))|^2}{N}
\]

Where \( N \) is the signal length, \( A(i) = ((a(i) - \mu))/\mu \) is the normalization of amplitude[4].

Due to the randomness of echo amplitude distribution, the simulation error of normalized instantaneous amplitude maximum value is large. The feature is introduced mainly for adding irrelevant factors.

3.8. **Normalized instantaneous amplitude mean**

Let the signal be \( x(t) \) and obtain its sampling sequence \( x(n), (n = 1, 2, 3 ..., N) \). After normalization, the average value can be obtained as below:

\[
\text{Mean} = \frac{1}{N} \sum_{n=1}^{N} \frac{x(n)}{\max (x)}
\]

The amplitude average simulation is shown in Figure 5-a.

3.9. **Normalized instantaneous amplitude variance**

In this paper, we consider that the amplitude of echo signal follows the distribution of \( \chi^2 \), so the amplitude variance can be expressed as

\[
\delta = 2\bar{\sigma}
\]

The amplitude variance simulation is shown in Figure 5-b.
3.10. Third order central moment
The third-order central moment can reflect the fluctuation characteristics of amplitude, and its calculation formula is as follows:

\[ M_3 = E(X - \mu)^3 \]

The simulation of the third-order central moment is shown in Figure 5-c.

3.11. Fourth order central moment
The fourth-order central moment is generally used to measure kurtosis, it can be calculated as below:

\[ M_4 = E(X - \mu)^4 \]

The fourth-order central moment simulation is shown in Figure 5-d.

![Figure 5](a) (b) (c) (d)

Figure 5. Simulation results of undulation characteristics

4. Feature modeling
In Section 2, 11 dimensional features are extracted, and the corresponding symbols are shown in Table 1.

| Feature name                              | Symbol |
|-------------------------------------------|--------|
| Standard deviation of normalized frequency absolute value | \( \sigma_{af} \) |
| Correlation ratio parameter               | S      |
| Moment kurtosis coefficient               | Ske    |
| Moment skewness coefficient               | Kur    |
Among them, except for normalized instantaneous frequency absolute value standard deviation and moment skewness coefficient, most features can reflect the difference between target echo and false target jamming, but the discrimination degree of each feature is different. For example, for the information dimension feature, the characteristic curve of three kinds of signals with SNR is shown in Figure 6.

![Figure 6. Information dimension simulation of three kinds of signals](image)

Obviously, the discrimination between target echo and velocity false target is large, but the discrimination between target echo and range false target is quite small.

This phenomenon is common in feature space. In this paper, this situation is reserved to suppress the over fitting phenomenon caused by the low dimension of feature space. The proportion of distinguishable features corresponding to each category is shown in Table 2.

| Class name          | Distinguishable feature scale |
|---------------------|------------------------------|
| Echo signal         | 100%                         |
| Range false target  | 64%                          |
| Speed false target  | 73%                          |

Table 2. The Proportion of Distinguishing Features Corresponding to Each Category.

Obviously, the categories that can be distinguished by each dimension feature are overlapped. All the features extracted in this paper can distinguish the difference between echo and at least one kind of interference.
5. Simulation experiment and result analysis
The performance of the feature model designed in this chapter is tested by using the random forest algorithm attached to Python sklearn library. The test was conducted in jupyter notebook.

The simulation data is output by MATLAB, in which the SNR changes from 0 to 15. For each tag, 300 sample signals are generated under each SNR, and its 11 dimensional features are extracted, and 100 other types of interference signals are generated, and their selected features are extracted as noise input. Therefore, there are $16 \times 3 \times 300$ sample data and 900 samples and 100 noise data for each SNR value. Then, by changing the simulation parameters of MATLAB, 100 new test data are generated when SNR is 15, including 30 target echo signals, 30 velocity and 30 range false target interferences and 30 noise signals.

After the simulation samples are input, the max_features of random forest algorithm are set as auto, and the feature dimension ranges from 11 to 5, which ensures that all tags except noise will be recognized, and the rest parameters are selected by default. The final algorithm accuracy output is shown in Figure 7.

![Figure 7](image.png)

FIGURE 7. Accuracy curve of characteristic model under random forest algorithm

As shown in Figure 7, the accuracy rate of the feature model under the random forest algorithm increases gradually with the increase of SNR and tends to be about 92%, which proves that the feature model can be used for radar false target jamming classification and recognition.

6. Conclusion
In this paper, the main lobe false target jamming is analyzed deeply, and 11 dimensional features of time domain, frequency domain and amplitude fluctuation are extracted for simulation. The simulation results show that most of the features can distinguish the target from the false target jamming. The test data of classification algorithm show that the features extracted in this paper can be used for machine learning algorithm classification. The next step is to design a perfect algorithm on the basis of feature space to improve the accuracy and practicability of target interference recognition.

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