Compound Jamming Signal Recognition Based on Neural Networks

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***Abstract*—An algorithm of recognizing radar compound jamming signals including additive, multiplicative and convolution signals of typical blanket jamming and deception jamming based on neural networks is proposed in this article. Firstly, all signals of echo, jamming and noise received in one pulse repetition interval are acquired as signal sources. Then the features of the signal sources are extracted in time domain, frequency domain and fractal dimensions. Finally, classifier based on neural networks is established, by which compound signals are recognized. Results of the experiment indicate that the algorithm has the ability to recognize not only compound modes but also signal types, which enhances the accuracy of recognition .**

Keywords—compound jamming; feature extraction; neural network; signal recognition

I. INTRODUCTION

In the modern electronic warfare environment, signals received by radar are not only echoes and noise, but also a variety of jamming signals in most cases. Jamming signal recognition is the premise of jamming suppression and also an important guarantee for the effective performance of radar.

Compound jamming is using more than two kinds of jamming means or patterns at the same time or in turn when resisting at least one threat target [1]. Compound jamming signal recognition is an urgent problem to be solved in radar anti-jamming: On the one hand, compound jamming performs better against modern radar countermeasure systems than conventional single jamming signals [2]. On the other hand, advanced radar jammers generally have the ability to produce blanket jamming, deception jamming and their compound forms in the meantime [3]. At present, there have been domestic and foreign scholars researching compound jamming signal recognition. However, few articles are published due to military and technical reasons. Literature [2] recognized compound jamming combination mode of additive, multiplicative and convolution signals of range gate pulling off(RGPO) jamming and radio frequency(RF) noise jamming, noise amplitude modulation(AM) jamming, noise frequency modulation(FM) jamming, as well as RGPO combined with velocity gate pulling off(VGPO) jamming, by neural network and fuzzy clustering with time domain and fractal features. Literature [3] recognized compound jamming of RF noise jamming and range deception jamming in additive, multiplicative and convolution ways by learning vector quantization(LVQ) neural network with box dimension and L-Z complexity features. Aiming at RF noise jamming, false target jamming and their additive combination, Literature [4] recognized these signals by Wigner-Viller time frequency analysis and Kohonen network feature extraction. In Literature [5], additive compound jamming of false target and noise FM, noise AM jamming are simulated, suppression method of which is also discussed. However, from literature above, the signal source is selected of signal fragments with pulse width, which is difficult in practical situation; types of jamming signals are not enough; recognition algorithms can only obtain the compound modes, instead of specific types of the compound signals.

In this paper, compound jamming signals are modeled with all received signals in one pulse repetition interval(PRI), which is approximate to actual situation. Features of compound jamming signals in time domain, frequency domain, and fractal dimensions are extracted. Recognition classifier based on neural network is established to recognize modes and types of compound jamming signals.

II. COMPOUND JAMMING RECOGNITION ALGORITHM

A. Modeling of compound jamming

Compound jamming signals are usually comprised of blanket jamming and deception jamming. Blanket jamming has the ability to cover the target echo, as a result reducing detection rate and detection accuracy of radar. Deception jamming manufactures fake target or information similar to the echo, which interferes radar obtaining correct information of the target [6,7]. Currently, RF noise jamming, noise AM jamming, noise FM jamming and noise phase modulation(PM) jamming are most commonly used blanket jamming, while RGPO commonly used deception jamming.

RF noise jamming is white noise passing through the filter and then direct noise amplifier(DINA). RF noise jamming has the optimal probability distribution and good covering performance [7]. Expression of RF noise is

978-1-5090-1195-7/16 $31.00 © 2016 IEEE
DOI 10.1109/IMCCC.2016.163

$$J_{RF}(t) = U_n(t)\cos[\omega_j t + \phi(t)] \quad (1)$$

where $U_{\mathrm{n}}(t)$ is the envelope of noise, ω_j is the carrier frequency, and $\phi(t)$ is the phase.

Noise AM jamming is the signal of which amplitude changes with modulated noise. Expression of noise AM is

$$J_{AM}(t) = [U_0 + u_n(t)]\cos[\omega_j + \phi] \quad (2)$$

where U_0 is the carrier amplitude, $u_n(t)$ is the modulated noise, ω_j is the carrier frequency, and ϕ is the phase.

Noise FM jamming is the signal of which frequency changes with modulated noise. Expression of noise FM is

$$J_{FM}(t) = U_j \cos[\omega_j t + 2\pi K_{FM}\int_0^t u_n(t')dt' + \phi] \quad (3)$$

where U_j is the jamming amplitude, ω_j is the carrier frequency, K_{FM} is the FM rate, $u_n(t')$ is the modulated noise, and ϕ is the phase.

Noise PM jamming is the signal of which phase changes with modulated noise. Expression of noise PM is

$$J_{PM}(t) = U_j \cos[\omega_j t + K_{PM}u_n(t) + \phi] \quad (4)$$

where U_j , ω_j , $u_n(t)$, ϕ are as they are in formula (3), and K_{PM} is PM rate.

This paper adopts RGPO as deception jamming. First, the jammer stores the received radar signal and then transmits an interfering pulse as soon as possible, which has a larger amplitude than echo that can be caught by radar range gate; then in the pulling phase, the jammer gradually increases the delay time of the transmitted pulse after every received radar pulse, dragging radar range gate away from the echo; the jammer is closed when the maximum delay time is reached, as a result radar loses the target. Suppose the expression of radar transmit signal is as formula (5).

$$s_t(t) = u(t)e^{j(2\pi f_0 t)} \quad (5)$$

where $u(t)$ is the envelope of radar transmit signal, and f_0 is the carrier frequency.

Expression of echo of the real target is as formula (6).

$$s_r(t) = A * s_t(t-\tau)e^{j[2\pi f_d(t-\tau)]} \quad (6)$$

where A is the amplitude of the echo, τ is the time delay of the echo, and f_d is the Doppler frequency of the target.

Expression of RGPO is as formula (7).

$$J(t) = A_J * s_t(t - \tau - \Delta t_j(t))e^{j[2\pi f_d(t-\tau-\Delta t_j(t))]} \quad (7)$$

where A_J is the amplitude of the RGPO jamming, 1.3~1.5 times of echo amplitude in general [7]. $\Delta t_j(t)$ is the transmitting time delay that changes with time. τ and f_d are as they are in formula (6).

Twelve kinds of compound jamming signals can be obtained by using the four kinds of blanket jamming and one kind of deception jamming by the addition, multiplication and convolution ways.

In modeling of compound jamming, the signal source in this paper is significantly different from that in existing literature of active jamming recognition. In those literature, signal source is selected as the signal fragment of the pulse width, which means truncating the signal after the target echo location is acquired. It is very difficult to separate the signal fragment from radar received signals under active jamming. In cases of blanket jamming, the echo is covered by jamming noise, making it difficult to confirm the specific location of the echo and obtain the signal fragment at the low signal to noise ratio(SNR). In cases of deception jamming, the signal fragment can be selected more likely the jamming instead of the echo because the radar range gate follows RGPO signal of which amplitude is higher. Therefore, signal source in this paper is selected as all radar signals received in one PRI, avoiding problems above effectively.

B. Feature extraction of compound jamming

Obtaining multidimensional information of jamming signals by extracting the feature parameters in multiple transform domains is a necessary requirement of compound jamming recognition. Features that used in this paper are as follows, including most commonly used ones at present.

1) $\gamma_{\max}$ *:* The maximum value of the power spectral density of the normalized centered instantaneous amplitude[8].

$$\gamma_{\max} = \frac{\max|DFT(a_{cn}(i))|^2}{N} \quad (8)$$

where $a_{cn}(i)$ is the value of the normalized centered instantaneous amplitude, $a_{cn}(i) = a(i)/E[a(i)] - 1$, $a(i)$ is the instantaneous amplitude of the signal, and N is number of signal points.

2) σ_{aa} *:* Standard deviation of the absolute value of normalized instantaneous amplitude.

$$\sigma_{aa} = \left(\frac{1}{N}\sum_{i=1}^{N} a^2{}_{cn}(i) - \left[\frac{1}{N}\sum_{i=1}^{N}|a_{cn}(i)| \right]^2 \right)^{\frac{1}{2}} \quad (9)$$

where N and $a_{cn}(i)$ are as they are in formula (8).

3) FD_{width} *:* The width beyond the average value of the distribution of normalized instantaneous frequency.

4) *R:* The envelope fluctuation parameter, reflecting the degree of signal envelope variation.

$$R = \sigma^2 / \mu^2 \tag{10}$$

where μ is the average and σ^2 the variance of the square of instantaneous envelope of the signal.

5) a_3 *:* Moment of skewness in time domain, reflecting asymmetry of the signal distribution.

$$a_3 = \frac{E(x(n)-\mu)^3}{\sigma^3} \tag{11}$$

where *x(n)* is the sequence of the signal. μ is the average of *x(n)* and σ^2 the variance of *x(n)*.

6) a_4 *:* Moment of kurtosis in time domain, reflecting the steepness of the signal distribution

$$a_4 = \frac{E(x(n)-\mu)^4}{\sigma^4} \tag{12}$$

x(n), μ and σ^2 are as they are in formula (11).

7) fa_3 *:* Moment of skewness in frequency domain.

$$fa_3 = \frac{E(X(\omega)-\mu)^3}{\sigma^3} \tag{13}$$

where *X(w)* is the power spectral density of the signal. μ is the average of *X(w)* and σ^2 the variance of *X(w)*.

8) fa_4 *:* Moment of kurtosis in frequency domain.

$$fa_4 = \frac{E(X(\omega)-\mu)^4}{\sigma^4} \tag{14}$$

where *X(w)*, μ and σ^2 are as they are in formula (13).

9) R_{cw} : Ratio of the maximum and the second high amplitude of the frequency spectrum of the signal.

10) D_b *:* Box dimension, a description of fractal complexity. Set the fractal curve *x(t)*, the measurement scale *r*, and *N(r)* is the length that measured with the ruler along the curve. *N(r)* is calculated by

$$N(r) = N + \frac{\sum_{i=1}^{N-1} \max\{x(i), x(i+1)\} r - \sum_{i=1}^{N-1} \min\{x(i), x(i+1)\} r}{r^2} \tag{15}$$

and box dimension is

$$D_b = -\frac{\ln N(r)}{\ln r} \tag{16}$$

III. SIMULATION EXPERIMENTS

Radar received signals contain three parts, namely the true target echo, jamming signals and background noise. In this experiment, linear frequency modulation(LFM) signal is used as radar transmitting signal with carrier frequency of 20MHz, bandwidth of 20MHz, pulse width of 2.5μs and sampling frequency of 80MHz. A point target is moving towards the radar in a straight line with a distance of 112.5km and a relative speed of 400m/s. Modulated noise of blanket jamming is white Gaussian noise mean 0 and variance 1, with carrier frequency of 20MHz and bandwidth of 6MHz. The effective modulation factor of noise AM is $m_{Ae} = 1$. The FM rate is $K_{FM} = 1\times 10^6$. The PM rate is $K_{PM} = 0.1$. RGPO is selected as the deception jamming with a pulling accelerate speed of $30 m/s^2$. White Gaussian noise is selected as background noise. The expression of radar received signal is as formula (17)

$$x_i(t) = s_r(t) + J_i(t) + n(t), i = 1,2,...,12 \tag{17}$$

where $s_r(t)$ is the echo, $J_i(t)$ the number i jamming signal, and $n(t)$ the noise.

Neural network is used as the classifier in this experiment. Back Propagation(BP) network is a kind of artificial neural network model commonly used in pattern recognition, classification and clustering [9,10]. The network is a BP network with one hidden layer. There are 10 neurons in input layer, 15 neurons in hidden layer and 12 neurons in output layer. The activation function of all neurons is sigmoid function.

In training stage, twelve kinds of compound jamming signals are generated, 20 groups with the jamming to signal ratio(JSR) range in 0~15dB for the extensive representation. Fifty percents of the mixed signals of the echo, jamming signals and noise are chosen randomly as training samples to train the BP network after random sorting and feature extraction. Each kind of the jamming has a type number as the output.

In recognition stage, various types of jamming signals are generated 100 samples for each type as test samples separately in different JSR and different SNR. Features of the test samples are extracted as the input of the network, and the output of the network is the type number of the compound jamming signals. The type number can reflect not only the subtype of blanket jamming but also the combination modes of blanket jamming and deception jamming. Results of one group of the experiments are shown in Fig. 1~4.

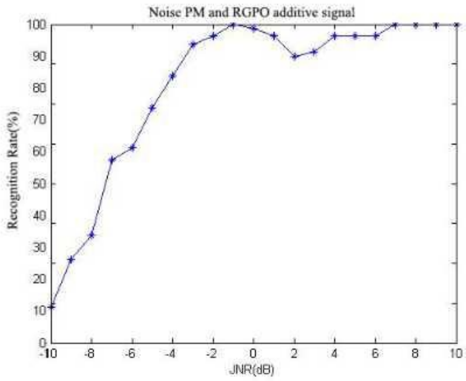

Figure 1. Recognition rate of noise PM and RGPO additive signal

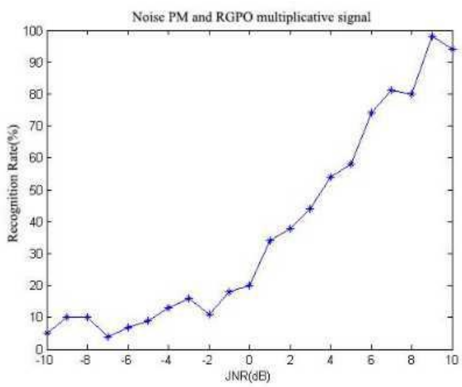

Figure 2. Recognition rate of noise PM and RFPO multiplicative signal

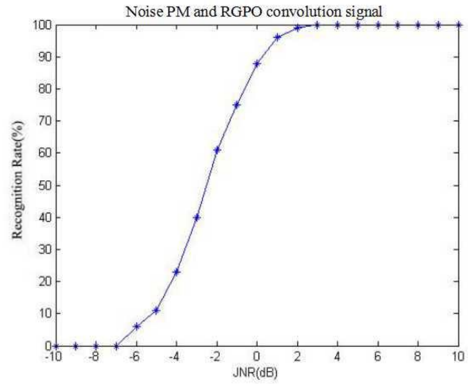

Figure 3. Recognition rate of noise PM and RGPO convolution signal

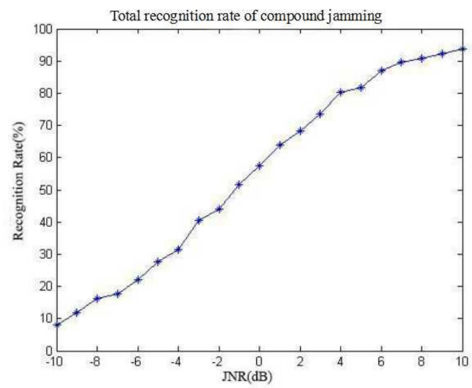

Figure 4. Total recognition rate of compound jamming

Fig. 1, Fig. 2, and Fig. 3 respectively show the recognition rate of compound signals of noise PM jamming and RGPO jamming in additive, multiplicative and convolution mode. Figure 4 shows the total recognition rate of radar active compound jamming signals. It can be seen in these figures that the algorithm of compound jamming recognition based on neural networks performs well with the ability to recognize not only the combination modes but also the specific types of compound jamming. The results show that the recognition rate of each kind of compound jamming signals is increased with the increase of the JNR. When JNR is above 10dB, the correct recognition rate of all kinds of compound jamming signals can reach more than 90%.

IV. CONCLUSIONS

In this paper, compound jamming signals of a reasonable modeling are recognized by BP neural networks with the extracted features in time domain, frequency domain and fractal dimensions as sorting parameters. The results of simulation indicate that the classifier based on BP neural networks can recognize various kinds of jamming signals effectively with a higher recognition rate for all kinds of jamming signals.

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