Modeling and Simulation of Three Distributed Cooperative Suppressive Jamming Modes

Guang Chen, Ziyue Tang and Chang Zhou

Early-warning technology Department, Air-force Early-warning College, Wuhan, 430019, China.
Email: cg99551@163.com

Abstract: The distributed cooperative jamming based on joint modes is an effective means to counter the multi-function radar or netted radar, different joint modes will bring different jamming effects. This paper, analyzed two common suppressive jamming patterns, including noise convolution jamming and dense false target jamming, and presented the simulation suppressive effect aiming at LFM radar; illustrated the conception of cooperative jamming and cooperative mode, put forward three new cooperative modes and carried out theoretic analyses and simulation, the simulated results validated the cooperative jamming’ effectiveness.

Keywords: distributed cooperative jamming; suppressive jamming; cooperative mode

1. Introduction

In modern radar EW field, the distributed jamming is regarded as an effective means to counter multi-function radar or netted radar[1], and different cooperative modes will bring different jamming effect. So, the research of cooperative mode of distributed jamming is very important to optimize the jamming resources and improve the jamming effect. Common jamming modes can be divided into oppression jamming and deception jamming[2], and cooperative jamming can also divided into oppressive cooperative jamming and deceptive cooperative jamming. This paper mainly talks about the oppressive cooperative jamming.

The currently researches on jamming’s cooperative mode are mostly the noise oppressive jamming, which make the use of noise jamming’s spatial power combining to produce a large-powered oppressive jamming[3-5], the effect of this mode is badly decreased for the radars with pulse compression and coherent processing techniques. For this reason, this paper put forward three new cooperative modes and develops modeling and simulation of them.

2. Single jamming pattern

2.1 Smart noise convolution jamming

Suppose radar transmit signal \( s(t) \), the noise \( n(t) \) is a narrow-band gauss white noise, the noise convolution jamming is expressed as[6]:

\[
J(t) = s(t) \otimes n(t)
\]  

(1)

In the equation (1), \( \otimes \) means convolution. The interference signal after matched filter is:

\[
J(t) \otimes s^*(t) = n(t) \otimes s^*(t) \otimes s(t) \otimes s^*(t)
\]  

(2)

Make Fourier Transformation of (2), it is:

\[
N(\omega)S(\omega)S^*(\omega) = N(\omega)\|S(\omega)\|^2
\]  

(3)
Then make inverse Fourier Transformation of (3), it is:

\[
J_r(t) = F^{-1}\left[|S(\omega)|^2 \right] \otimes n(t) \tag{4}
\]

It can be seen that, the smart noise has the same processing gain with radar signal, while the common noise interference doesn’t, so it has more advantages in frequency coincidence and jamming power, compared with traditional pure noise suppressive jamming.

The simulation results are shown as fig.1, among them, noise \( n(t) \) is a narrow-band gauss white noise, time width is 10us, radar signal is LMF signal, time width is 20us, band width is 10MHz, the sample frequency is 50MHz.

\[\text{Figure 1. Simulation results (a) with no jamming; (b) with noise convolution jamming}\]

According to fig.1, the interference signal has got a big pulse compression gain, the matched filter’s output is equal to the pulse compression of a series of altitude-random and time-delayed radar transmitting signal, and so it can mix the radar’s real target and has a better jamming effect.

2.2 Dense false target jamming

Suppose \( n(t) \) is a pulse string made of several different time-delayed pulses, and then the pulse convolution interference is produced, if this signal is received and processed, the dense false target will be formed around the real target \([6]\). The pulse response of matched filter \( h(t) = s*(t) \), and then the interference signal’s output of matched filter is:

\[
y_n(t) = J_r(t) \otimes h(t) = A s(t-t_0-t_i) \otimes s*(-t) \tag{5}
\]

The real target echo’s output of matched filter is:

\[
y_o(t) = s(t-t_0) \otimes h(t) = s(t-t_0) \otimes s*(-t) \tag{6}
\]

\[\text{Figure 2. Simulation results (a) with single pulse; (b) with 10 pusles}\]

As is known that \( y_n(t) = A y_o(t-t_i) \), i.e. the pulse compression results of interference and real target echo are only different on altitude and time-delay, the altitude is relevant with pulse’s altitude, and when \( t_i > 0 \), the false target is lagged, when \( t_i < 0 \), the false target is ahead.
The simulation parameters are: the interference time delay 5us, altitude gain is 10, and others are the same as above, the results are shown as fig.2. According to fig.2, when use pulse convolution interference with a bigger gain than target signal, the jamming effect is better, the radar target signal is covered by interference signal, and making many false target signals, even pulse compression cannot eliminate the interference, the radar’s normal working is badly disturbed.

3. Cooperative jamming mode

3.1 Noise convolution joint jamming

Noise convolution joint jamming is many jammers transmit noise signal jointly to realize power cooperation or time cooperation. Power cooperation is to add suppressive power in the same area; time cooperation is to add suppressive scope for the adjacent areas. Here mainly discuss the former. According to radar equation, the SNR of target echo after pulse compression and coherent accumulation is:

$$X_0 = \frac{P_i G_i G_j \lambda^2 \sigma}{(4\pi)^2 R_i^2 kT_B F L}$$

(7)

According to jamming equation, the INR for a single jammer’s noise entering radar main lobe and after receiver’s processing is:

$$X_j = \frac{D_j}{I_j} \frac{P_i G_i G_j (\theta, \phi) G_j (\theta, \phi) \lambda^2 \sigma}{(4\pi)^2 R_i^2 kT_B F \gamma_j L_j}$$

(8)

$$D_j$$ is the pulse compression gain for noise, and $$I_j$$ is coherent accumulation gain for noise. Cited from reference [7], there are:

1) for stochastic noise, $$D_j = 0$$dB, $$I_j = 0$$dB.

2) for smart noise convolution signal, $$D_j = (T + T_{n}) / (1 / B + T_{n})$$

$$T_n$$ is the noise’s time width before convolution. For single jammer, the SIR is:

$$\chi = \frac{X_0}{X_j} = \frac{D_I}{I_j} \frac{P_i G_i G_j \lambda^2 \sigma}{4\pi R_i^2 P_j (\theta, \phi) G_j (\theta, \phi) \lambda^2 \sigma} \frac{\gamma_j L_j}{L}$$

(9)

For multi jammers, the SIR is:

$$\chi = \frac{X_0}{\sum_{j=1}^{M} X_j}$$

(10)

The detection probability of SO-CFAR in noise environment is proximately[7]:

$$P_d = 2 \sum_{i=0}^{N/2-1} \left( \frac{N}{2 + i - 1} \right) (2 + T / (1 + \chi))^{-(N/2 + i)}$$

(11)

$$T$$ is radar signal’s pulse width, $$N$$ is CFAR unit length, $$K$$ is threshold scaling factor, $$\chi$$ is SIR of target echo.

3.2 Dense false target joint jamming

Dense false target joint jamming is many jammers transmit groups of dense pulse strings to enlarge suppressive zone, realizing time cooperative jamming, its sketch map is fig.3.

For one jammer, suppose the false target’s number is $$M_j$$, the distance is $$L / 2$$, the max suppressive time width $$\Delta t_{\text{max}} = c(M_j - 1)L / 2$$; the optimal suppressive time width $$\Delta t_j = cL / 2$$. As the location error of jammer-to-radar is existed, the deviation between practical position and predetermined position is also existed. When the deviation is max, the number of false target falls in
real target’s reference unit window is marked \( I_j = \text{ceil}(\Delta r / L) \), \( \text{ceil}(\cdot) \) means making integer up, \( \Delta r \) is the largest deviation of false target’s position. When \( M_j \leq I_j \leq -M_j \), the real target falls in the optimal suppressive zone. Cited from reference [7], \( P_d \) is expressed as:

\[
P_d = \frac{2(1+\chi_j)}{K\chi_j + 2(1+\chi_0)}
\]

When \( \Delta r > L / 2 \), \( I_j \neq \pm 1 \), the suppressive power is small, the bigger \( \Delta r \) is, the worse the effect is, therefore, more dense false target interference should be used to conduct time cooperative suppressive jamming. When the number of jammers is \( M \), the optimal suppressive distance is \( \Delta l = (2M-1)l / 2 \), to cover the real target echo, \( \Delta l > \Delta r \) should be required.

![Figure 3. dense false target joint jamming](image)

![Figure 4. Noise-dense false target joint jamming](image)

### 3.3 noise-dense false target joint jamming

Noise-dense false target joint jamming is two or more jammers transmit noise convolution signal and dense false target pulse strings respectively, realizing power cooperative jamming, the sketch map is fig.4.

The noise signal through pulse compression covers a distance \( \Delta l \), overlapped with the radar receiver’s inside noise power, the general noise power is \( \delta^2 = \delta_j^2 + \delta_i^2 \), \( \delta_j^2 \) is the output of inside noise, and \( \delta_i^2 \) is the output of noise convolution signal. Then the SIR of real target is:

\[
\chi_j = \frac{S_0}{\delta^2} = \frac{S_0}{\delta_j^2 + \delta_i^2} = \frac{\chi_0}{\chi_j}
\]

In equation (13), \( \chi_j \) is the INR of general noise. Mark the false target is \( I_j \), whose INR is the minimal in the real target echo CFAR unit, the INR is computed by \( \Delta r \).

(1)when \(-M_j \leq I_j \leq M_j \), the real target falls into the largest covered zone of ordered dense false target jamming, based on \( I_j = \text{ceil}(\Delta r / L) \), \( I_j \) and \( \chi_j \) are got, then \( P_d \) is:

\[
P_d = \frac{2(1+\chi_j)}{K\chi_j + 2(1+\chi_0)}
\]

(2)when \( I_j < -M_j \) or \( M_j < I_j \), the real target falls outside the largest covered zone of ordered dense false target jamming, at this moment, if \( \Delta l > \Delta r \), the noise convolution signal can still exert suppressive jamming for real target, then \( P_d \) is:

\[
P_d = 2 \sum_{i=0}^{N/2+1} \left[ \frac{N}{2} + i - 1 \right] \frac{2}{2 + K / (1 + \chi_i')^{(N/2+i)}}
\]
4. Simulation analyses

4.1 Simulation parameters

Suppose the operation background of distributed jamming is shielding the fighters to penetrate the enemy’s air-defense system, the range of target to radar is 10-100 km, demanding detection probability $P_d \leq 0.1$ with jamming. The simulation parameters are shown in tab.1.

| Simulation parameters | Value |
|-----------------------|-------|
| Radar transmitting power $P_t$ | 630kw |
| Radar antenna gain $G_t$ | 33dB |
| Jamming power $P_j$ | 5W |
| Jammer antenna gain $G_j$ | 9dB |
| Target RCS $\sigma$ | 5m$^2$ |
| Radar signal wave-length $\lambda$ | 0.1m |
| Radar signal pulse width $T$ | 20us |
| Radar signal band-width $B$ | 10MHz |
| Scaling factor $K$ | 36.58 |

4.2 Simulation results of noise convolution joint jamming

In MATLAB environment, carry out Monte Carlo simulation for 10000 times, the results are shown in fig.5.

4.3 Simulation results of dense false target joint jamming

Suppose $P_{fa} = 10^{-8}$, $M_j = 8$, $\delta r = \pm 100 m$, the other parameters are the same as tab.1, the simulation results are shown in fig.6.

4.4 Simulation results of noise-dense false target joint jamming

Suppose the simulation parameters are the same with above, one jammer transmit noise convolution jamming signal, the other transmit dense false target jamming signal, the simulation results are shown in fig.7.
Figure 7. Simulation results. (a) positions under two jammers; (b) probability under two jammers

From fig. 5, the detection probability is over 0.1 without jamming, moreover, it is close to 1.0 when the radial range is under 20km; still in the same range scope, the detection probability cannot be lower than 0.1 with single jammer, but with four jammers it is lower than 0.1 all the time.

From fig. 6, if there exists deviation between the real target position and false target position, the suppression effect of single jammer is bad; however, if with two jammers, the target detection probability is about zero when the radial range is larger than 20km.

From fig. 7, when exert noise-dense false target joint jamming, the real target’s detection is not only suppressed by the noise, but also deceived by the false targets, so the detection probability is very small (about 0.1) if the range is 10km, besides, it is rapidly decreased with the radial range’s increasing, and is about zero when the range is larger than 30km.

5. Conclusions
This paper studies the modeling and simulation of three distributed cooperative suppressive jamming modes, theoretic analyses and simulation results show that the cooperative jamming can suppress the detection probability to a very low value, and can deceive the real target’s detection, compared with single jamming style and pure noise cooperative jamming, the three cooperative modes dramatically improves the jamming effect. The study enriches the cooperative mode of distributed jamming, and provides instructions in making reasonable jamming tactics in radar EW.

6. References
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