Research on Jamming Resource Allocation Technology Based on Improved GAPSO Algorithm

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Abstract—In this paper, firstly, the influence factors of different electronic loads on radar are analyzed from various angles, and a resource allocation model is built for penetration scenarios. Then, the evaluation indexes of radar in different working stages are explained and fused to construct a scientific and reasonable objective function. Finally, a genetic particle swarm (GAPSO) algorithm based on two-dimensional parallel coding is creatively proposed, and the parameters of the algorithm are adjusted adaptively to improve the performance of the algorithm. The simulation results show that the improved GAPSO algorithm has obvious effectiveness and superiority in solving the resource allocation problem in process of jammers shielding target penetration.

1. Introduction
The wide application of radar networking and information fusion technology has greatly promoted the modernization of air defense system[1]. The cross deployment of heterogeneous radars in different spatial directions makes the whole system have strong anti-jamming capability[2~3]. Firstly, this paper describes the electronic jamming scene and the electronic load pattern, and constructs the influence factor matrix by analyzing the influence factors of various load patterns on heterogeneous radars. Secondly, the working state of each radar in the penetration process is divided into two stages, corresponding to two evaluation of detection probability and positioning accuracy. Thirdly, the crossover, mutation and selection operators in GA algorithm are integrated into PSO algorithm, and a GAPSO algorithm based on two-dimensional parallel coding is proposed to optimize and solve the model. Finally, the improved GAPSO algorithm is verified by algorithm comparison and simulation experiments. The convergence speed is faster, the global optimization ability is stronger, and the convergence stability is better.

2. Resource allocation model of cooperative jamming
In the electronic countermeasure scenario of jammers covering the penetration of man-machine, it is assumed that the set of jammers is \( J = \{J_1, J_2, \ldots, J_N\} \), the set of optional jamming mode is \( P = \{P_1, P_2, \ldots, P_L\} \), and the set of netted radar needing jamming is \( R = \{R_1, R_2, \ldots, R_M\} \). A cooperative jamming resource allocation model as shown in Figure 1.
In view of the above-mentioned jamming scenarios, the most effective electronic loads are random noise, dexterous noise and dense false targets[4~5]. In essence, they make use of noise modulation technology to make the target signal submerged in the jamming signal, so as to effectively suppress the radar and make it difficult to extract the target information from the complex electromagnetic waveform.

The influence of different electronic loads on radar is mainly reflected in time domain, spatial domain, frequency domain and processing domain[6]. Among them, the expressions of influence factors in time domain, spatial domain and frequency domain are shown in equations (1) ~ (3). The influence factors in processing domain need to be analyzed according to the jammed radar system, mainly reflected in pulse pressure and coherence.

$$e_{\mu} = 10\log\left(\frac{t_j}{p_w}\right)$$  \hspace{1cm} (1)

$$e_{\mu} = 10\log(\theta_{r0.5} - \theta_{j0.5})$$  \hspace{1cm} (2)

$$e_{j\nu} = 10\log\left[\frac{\min(f_{j2}, f_{j1}) - \max(f_{r1}, f_{j1})}{f_{j2} - f_{j1}}\right], \left(f_{j1} \leq f_{j2} \text{ and } f_{j2} \geq f_{r1}\right)$$  \hspace{1cm} (3)

Where, $t_j$ is the jamming duration of jammer; $p_w$ is the working pulse width of radar.

To sum up, the influence factor benefit matrix of single jammer on single radar is

$$E_j = \omega e_j = [\omega_1, \omega_2, \omega_3, \omega_4] [e_{\mu1}, e_{\mu2}, e_{\mu3}, e_{j\mu1}, e_{j\mu2}, e_{j\mu3}, e_{j\rho1}, e_{j\rho2}, e_{j\rho3}]^T$$  \hspace{1cm} (4)

Where, $\omega$ is the influence factor weight matrix, which represents the relative weight of different influence factors; $e_j$ is the electronic load influence factor matrix, which represents the effect of different electronic loads on different radar domains.

3. Jamming benefit evaluation

3.1 Detection probability of radar network

It is known to all, SJR is the key factor that affecting the radar detection performance in the
cooperative jamming scenario. Since the jamming signals are independent of each other, when \( n \) jammers to suppress radar \( m \), the SJR of target echo is[6]

\[
\text{SJR} = \frac{P_{\text{tr}}}{P_{\text{js}}} = \frac{1}{4\pi} \sum_{j=1}^{N} \frac{P_j G_j \sigma_j L_j R_{jr}^2}{P_{\text{tr}} G_j L_j R_{jr}^2 E_{jr}}
\]  

(5)

Where, \( P_{\text{tr}} \) is the radar transmitting power; \( G_t \) is the radar antenna transmitting gain; \( \sigma \) is the target cross-sectional area; \( L_r \) is the radar comprehensive loss; \( R_{jr} \) is the distance between the radar and the target; \( P_j \) is the jammer transmitting power; \( G_j \) is the jammer antenna gain; \( \gamma \) is the polarization mismatch factor; \( L_j \) is the comprehensive loss of jammer; \( R_{jr} \) is the distance between jammer and radar; \( E_{jr} \) is the effect factor benefit of jamming mode on radar.

Assuming that the radar consists of \( N \) detection inits, the threshold factor is \( \alpha = N(P_{fa}^{-1/N} - 1) \). So the detection probability of radar \( m \) to the target at any position in space is

\[
P_{\text{dm}} = \left(1 + \frac{\text{SJR} \cdot \alpha}{N(1 + \text{SJR})}\right)^{-N}
\]  

(6)

In order to observe the jamming effect of jammers on netted radar more obviously, it is assumed that the radar network adopts rank 1 decision rule, so the detection probability of radar network is

\[
P_{d} = 1 - \prod_{m=1}^{M} (1 - P_{\text{dm}})
\]  

(7)

The detection probability of radar network in the scene without any electronic interference is \( \hat{P}_d \). The jamming effectiveness of jammers on radar network in detection probability index can be quantified as

\[
y_1 = \left| \frac{\hat{P}_d (\text{SNR}) - P_d (\text{SJR})}{\hat{P}_d (\text{SNR})} \right|
\]  

(8)

### 3.2 Positioning accuracy of radar network

According to reference [6], in the jamming environment, the measurement errors of radar to the target radial distance \( r \), azimuth \( \phi \) and elevation angle \( \epsilon \) obey normal distribution. After converting the measurement error of radar observation vector into rectangular coordinates, the positioning error is as follows:

\[
\begin{align*}
\sigma_{rj} &= \cos^2 \phi \cos^2 \epsilon \cdot \sigma_r^2 + r^2 \sin^2 \phi \cos^2 \epsilon \cdot \sigma_e^2 + r^2 \cos^2 \phi \sin^2 \epsilon \cdot \sigma_e^2 \\
\sigma_{\phi j} &= \sin^2 \phi \cos^2 \epsilon \cdot \sigma_r^2 + r^2 \cos^2 \phi \cos^2 \epsilon \cdot \sigma_e^2 + r^2 \sin^2 \phi \sin^2 \epsilon \cdot \sigma_e^2 \\
\sigma_{\epsilon j} &= \sin^2 \phi \cdot \sigma_r^2 + r^2 \cos^2 \phi \cdot \sigma_e^2
\end{align*}
\]  

(9)

Therefore, the positioning accuracy GDOP of radar in jamming environment is

\[
P_g = \sqrt{\sigma_{rj}^2 + \sigma_{\phi j}^2 + \sigma_{\epsilon j}^2}
\]  

(10)

In the scene without electronic jamming, the positioning accuracy GDOP value of radar network is \( \hat{P}_g \). Then, the jamming effectiveness of jammer group on radar network in positioning accuracy index can be quantified as follows

\[
y_2 = \left| \frac{P_g (\text{SJR}) - \hat{P}_g (\text{SNR})}{\hat{P}_g (\text{SNR})} \right|
\]  

(11)
3.3 Establishment of objective function

In the process of penetration, the detection and positioning ability of radar network to targets at different positions does not change linearly. Therefore, the piecewise weighted integral method is used to construct the target function of cooperative jamming of jammer group against netted radar, as shown in the following formula:

$$F = \int_{R_{\min}}^{R_{\max}} w(R)f(R)dR = \int_{R_{\min}}^{R_{\max}} w(r)\lambda Y(r)dr = \int_{R_{\min}}^{R_{\max}} w(r)[\lambda_1 y_1(r) + \lambda_2 y_2(r)]dr$$ (12)

Where, $R_{\min}$ and $R_{\max}$ are respectively the minimum burn through distance and the maximum detection distance of netted radar; $w(r)$ are the weights of different track points of the target; $\lambda = [\lambda_1 \lambda_2]$ are the weights of detection probability and positioning accuracy of the netted radar, and $\sum_{i=1}^{2} \lambda_i = 1$; $Y = [y_1 \ y_2]$ are the jamming effectiveness values of two evaluation indexes of the radar network by the jammer formation at a certain track point. Obviously, the larger the value of the objective function, the better the shielding effect of jammer group on the target of manned aircraft.

4. Improved GAPSO algorithm based on two dimensional coding

4.1 Inertia factor setting

The value of inertia factor can not be generalized[7~9]. It should be set according to the following formula, so that it can be adjusted adaptively with the change of iteration times.

$$w = w_{\text{max}} - \text{index} \left(\frac{w_{\text{max}} - w_{\text{min}}}{\text{epoch}}\right)$$ (13)

Where, $w_{\text{max}}$ and $w_{\text{min}}$ represents the maximum and minimum inertia factors respectively; $\text{index}$ is the current number of iterations; $\text{epoch}$ is the total number of iterations.

4.2 Crossover and mutation operation

In the early stage of evolution, the algorithm has not yet converged, and the population needs to generate new and better individuals with higher crossover probability $P_{\text{cross}}$ and smaller mutation probability $P_{\text{var}}$ to maintain the diversity of individuals in the population. However, in the later stage of evolution, the algorithm has almost converged, and the individuals have been basically concentrated near the optimal solution[10]. At this time, not only $P_{\text{cross}}$ should the algorithm be appropriately reduced, but also the excellent individuals found should be retained, And we need to increase $P_{\text{var}}$ to stimulate the search[10~11]. Therefore, this algorithm introduces two threshold sum of concentration degree. If the two conditions of $\frac{\text{fitness}_{\text{min}}}{\text{fitness}_{\text{max}}} > \theta_1$ and $\frac{\text{fitness}_{\text{mean}}}{\text{fitness}_{\text{max}}} > \theta_2$ are satisfied in the evolution process, the distribution of individuals in the population is over concentrated, and the crossover probability and mutation probability should be adjusted according to the following formula

$$P_{\text{cross}} = \frac{P_{\text{cross}}}{\text{ratio}1}$$
$$P_{\text{var}} = \frac{P_{\text{var}}}{\text{ratio}1}$$ (14)

4.3 Two dimensional parallel coding

Since the jamming resource allocation is based on the jammer as the quantitative and the jamming object and electronic load as the distribution variables, it is necessary to realize the resource allocation
through two-dimensional parallel gene coding, as shown in equation (17).

\[
Z = [X, Y] = \begin{bmatrix}
  x_1 & y_1 \\
  x_2 & y_2 \\
  \vdots & \vdots \\
  x_M & y_M \\
\end{bmatrix}
\]

(15)

Where, \(X\) is the jamming target allocation matrix, which corresponds to the distribution vector of different jammers to the netted radar members; \(Y\) is the electronic load distribution matrix, corresponding to the selection vector of different jammers for various electronic loads.

5. Simulation verification

5.1 Space interference scene setting

It is assumed that the penetration formation uses four jammers as the advance cover, followed by the aircraft for penetration. Among them, the RCS of the manned aircraft is 1m². It is assumed that the netted radar consists of six member radars, two of which work in S-band and four in X-band. The parameters are shown in Table 1.

Table 1. Reconnaissance results of working parameters of netted radar

| Radar Number | 1     | 2     | 3     | 4     | 5     | 6     |
|--------------|-------|-------|-------|-------|-------|-------|
| \(P_i\) (kw) | 630   | 630   | 630   | 630   | 630   | 630   |
| \(G_i\) (dB) | 35    | 35    | 35    | 35    | 35    | 35    |
| \(G_r\) (dB) | 10    | 7     | 4     | 7     | 10    | 4     |
| \(B_r\) (MHz) | 20    | 10    | 15    | 20    | 30    | 15    |
| \(\lambda\) (m) | 0.075 | 0.085 | 0.0265 | 0.0295 | 0.032 | 0.0375 |
| \(\rho w\) (\(\mu s\)) | 10    | 25    | 45    | 15    | 28    | 60    |
| \(N_f\) (dB) | 3     | 3     | 3     | 3     | 3     | 3     |
| \(L_s\) (dB) | 6     | 6     | 6     | 6     | 6     | 6     |
| Location(km) | (4,-15,6) | (-4,-15,6) | (12,-8,6) | (-12,-8,-6) | (20,0,6) | (-20,0,6) |

The working parameters of jammers are shown in Table 2.

Table 2. Working parameters of jammers

| \(P_j\) (W) | \(B_j\) (MHz) | \(L_j\) (dB) | \(\gamma_j\) |
|-------------|---------------|--------------|--------------|
| 50          | 50            | -8           | 0.5          |

The false alarm probability is set to 10^-6. The simulation results show that the detection probability of each radar and radar network to targets at different positions is shown in Figure 2 when the netted radar is not subject to the cooperative interference of jammers.
Figure 2. Pd of each radar without jamming

It can be seen from the figure that when the detection probability is 0.5, the detection range of netted radar can reach 220 km in no jamming. While the detection probability of the radar network at the distance of 400 km is less than 0.1. And the detection ability of netted radar to each penetration track point of target is not linear, the weight factor is shown in Figure 3.

Figure 3. Track point weight of netted radar

The AHP method is used to analyze the influence factors of electronic load. So in time domain $\omega_1 = 0.10$, in spatial domain $\omega_2 = 0.15$, in frequency domain $\omega_3 = 0.1$ and in processing domain $\omega_4 = 0.65$, and $\omega_{41} = 0.3$, $\omega_{42} = 0.7$. Therefore, when a single jammer uses three kinds of electronic loads to jam within 100us jamming duration, the effect on each member radar of netted radar is shown in Figure 4.

It can be seen from the above figure that for radars 1, 3, 4 and 5, the effect of smart noise jamming is more obvious, while for radars 2 and 6, the effect of deception jamming of false targets is more significant, and radar 6 has the ability of anti-jamming against two kinds of electronic loads, random noise and smart noise. However, the penetration distance covered by this "one to one" jamming mode is very limited, which can not meet the actual penetration requirements.
Figure 4. Jamming effect of different electronic load patterns acting on different radars.

5.2 GAPSO optimizes jamming resource allocation

The population size is 50 and the maximum evolution algebra is 200. The crossover and mutation probabilities are 0.6 and 0.4 respectively. So the learning probability is $c_1 = c_2 = 1.49445$, inertia factor $\omega_{\text{max}} = 0.9$, $w_{\text{min}} = 0.4$, and threshold factor $\theta_1 = 0.95$, $\theta_2 = 0.99$. The improved GAPSO is used to solve the resource allocation problem through 10 iterations, while compared with the PSO algorithm and CPSO algorithm, the fitness curve is shown in Figure 5.

Since GAPSO algorithm is based on the self iterative search of PSO algorithm and integrates the ideas of GA's selection, crossover and mutation operators, with the increase of evolutionary algebra, GAPSO can break through the limitation of PSO's local convergence and quickly converge to the optimal value in the 90th generation. Although the PSO algorithm has the fastest convergence speed, it still fails to converge to the global optimal value. Although CPSO algorithm introduces chaos factor, trying to change the PSO algorithm is easy to fall into the local optimal value, but to a certain extent, it slows down the convergence speed of the algorithm.

When the objective function value of GAPSO algorithm converges to the maximum value, the corresponding allocation strategy is shown in Figure 6.
It can be seen from the figure that jammer 1 uses the second kind of electronic load to jam radar 1, 2 and 3; jammer 2 uses the second kind of electronic load to jam radar 4, 5 and 6; jammer 3 uses the third kind of electronic load to jam radar 1, 2 and 6; jammer 4 uses the third kind of electronic load to jam radar 2, 5 and 6.

Under the above allocation scheme, the detection probability of radar network to targets at different track points in space is shown in Figure 7.

It can be seen from the above figure that the jamming resource allocation scheme corresponding to the convergence of GAPSO algorithm has obvious advantages compared with PSO algorithm and CPSO algorithm, which can effectively suppress the detection performance of radar network, and cover the target to the favorable combat position 32 km away from the netted radar, so as to meet the actual needs of electronic countermeasures.

6. Conclusion
Firstly, a three-dimensional jamming resource allocation model is established aiming at the distribution of jamming objects and the selection of electronic loads of jammers. Secondly, an objective function is constructed for the purpose of maximizing the safety of the target in the process of penetration. The objective function integrates the detection probability and the positioning accuracy, which improves the defects of the previous single evaluation index. Thirdly, improves the GAPSO algorithm from three aspects of inertia factor, cross mutation probability and coding gene dimension. Finally, through experimental simulation, the GAPSO algorithm is applied to solve the jamming resource allocation problem in the penetration process, which effectively verifies the effectiveness and superiority of the improved algorithm.

Figure 6. Resource allocation strategy corresponding to convergence of GAPSO algorithm

Figure 7. Comparison of jamming effects of different algorithms
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