Research on Jamming Resource Allocation Based on Improved Pelican Optimization Algorithm

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***Abstract*—To get the best jamming effect of limited jamming resources in electronic warfare, this paper focuses on the problem of jamming resource allocation. An objective function of jamming resource allocation is built, which is based on the calculation by the probability formula of jammer pressing, and an improved Pelican Optimization Algorithm is designed. By simulating the pelican's natural behavior of approaching prey and searching the nearby area in the process of hunting, the algorithm creates the corresponding mathematical model, and obtains the global optimal allocation strategy by solving the model. The simulated results indicate that the probability of obtaining the optimal solution and optimal allocation strategy of the algorithm are better than the traditional Simulated Annealing Algorithm, whether it is the situation of "single jammer to single radar" or "multi-jammer to single-radar".**

Keywords-component; resource allocation; radar jamming; swarm intelligence algorithm; Pelican Optimization Algorithm

I. Introduction

Weapon-Target Assignment (WTA) is a very important problem in modern electronic warfare. It has a great significance to battlefield situation to find a reasonable and efficient allocation scheme. The interference resource allocation problem is a typical WTA problem. The solution space of this problem is often discrete, distributed, and multi-constrain. It is a NP hard problem [1]. With the increase of our interference resources and enemy attacking targets, its solution space shows a trend of combination explosion, and may even have no solution. Therefore, the search speed of the traditional exact algorithm and dynamic programming algorithm will be very slow, and they are often unable to converge quickly.

With the advent of heuristic algorithms, such as genetic algorithm, particle swarm optimization algorithm, immune algorithm and so on, it is possible to solve this kind of problems. On this basis, many scholars have proposed many effective algorithms, such as improved genetic algorithm [2], simulated annealing algorithm [3], improved swarm intelligence algorithm [4], artificial bee colony algorithm [5]. However, these improvements have some limitations and do not completely solve the defects of the algorithm.

In view of this, a jamming resource allocation model based on the probability formula of jammer pressing is proposed in this paper. The improved Pelican algorithm is used to search the global optimal solution, and compared with the traditional Simulated Annealing algorithm (SA). Simulation results have proved that the effectiveness and superiority of the proposed algorithm.

II. Jamming Resource Allocation Model

A. The probability formula of jammer pressing

Generally, under the condition that the false alarm probability is determined and there is no external noise interference, the detection probability of radar is an increasing function with the signal-to-noise ratio SJR as the independent variable. The false alarm probability means that in the process of radar detection, due to the widespread existence and fluctuation of noise when the threshold detection method is adopted, there is a probability that there is no target but there is a target. The signal-to-noise ratio reflects the power relationship between the target echo signal and the noise signal. It can be seen from literature [6].

$$P_d = \int_{U_T}^{+\infty} r \cdot \exp\left[-\frac{r^2 + A^2}{2}\right] I_0(rA)dr \tag{1.}$$

$$U_T = \sqrt{-2 \cdot \ln(P_x)} \tag{2.}$$

$$A = \sqrt{2 \cdot SJR} = \sqrt{2 \cdot \frac{S}{P_n}} \tag{3.}$$

where U_T is the minimum detectable signal threshold voltage; $I_0(z)$ is a Bessel function of zero order; r is signal voltage; S is the target echo signal power received by the radar. When the jammer starts jamming the radar, the signal-to-noise ratio of the radar receiver will be reduced, thus reducing the detection probability of the radar. At this time, equation (3) becomes

$$A = \sqrt{2 \cdot SJR} = \sqrt{2 \cdot \frac{S}{P_{J+}P_n}} \tag{4.}$$

where P_J is the jamming power of the jammer, so when the jammer is jamming the radar, the probability formula of jammer pressing is

$$Q = 1 - P_d \tag{5.}$$

It can be seen that the greater the pressing probability of the jammer, the smaller the probability that the target will be detected by the radar. So, equation (5) can be used as the evaluation criterion for jamming pressing effect.

B. Objective function model

Assuming that we have M jammers in total, we need to jam N enemy radars. The i-th jammer is expressed by $J_i(\mathrm{i} = 1,2,3,\cdots,\mathrm{M})$, and the k-th radar is expressed as $R_k(k = 1,2,3,\cdots,\mathrm{N})$ and the threat coefficient to us is expressed as $w_k(k = 1,2,3,\cdots,N)$. The jamming strategy is set to prioritize the allocation of jammers to jam the radar with high threat coefficient, so the following jamming effectiveness matrix is obtained.

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$$E = \begin{bmatrix} Q_{11} & \cdots & Q_{1N} \\ \vdots & \ddots & \vdots \\ Q_{M1} & \cdots & Q_{MN} \end{bmatrix} \quad (6.)$$

where $Q_{ik} = 1 - P_{di}$ is the jamming pressing probability J_i to R_k. Set x_{ik} assigns decision variables to tasks, then

$$x_{ik} = \begin{cases} 0, & Do\ not\ assign\ the\ i-th\ jammer\ to\ the\ k-th\ radar \\ 1, & Assign\ the\ i-th\ jammer\ to\ the\ k-th\ radar \end{cases} \quad (7.)$$

Through the above formulas, the objective function model of M jammers jamming N radars can be obtained

$$\begin{cases} maxE = \sum_{k=1}^{N} w_k \left(1 - \prod_{j=1}^{M}(1 - x_{ik}Q_{ik})\right) \\ (a) \sum_{k=1}^{N} x_{ik} = 1, \quad i = 1,2,\cdots,M \\ (b) 1 \le \sum_{i=1}^{M} x_{ik} \le S_k, \quad k = 1,2,\cdots,N \\ (c) \sum_{k=1}^{N} S_k \le M, \quad x_{ik} = 0\ or\ 1 \end{cases} \quad (8.)$$

In equation (8), $maxE$ is the objective optimization function. (a) It indicates that the relationship between jammer and radar is "single jammer to single radar", and one jammer can only jam one radar; (b) It indicates that one radar is assigned at least one jammer, S_k is the number of jammers allocated to the k-th radar among the M jammers; (c) It indicates that the number of jammers allocated to any radar cannot exceed the sum of our jammers. It can be seen that as the number of jammers and enemy radars increases, the solution space will increase exponentially. The traditional solution speed is too slow. Although the simulated annealing algorithm can solve this problem, it has some disadvantages, such as too slow convergence speed and too sensitive initial parameters. Through the improved Pelican algorithm, it can achieve rapid convergence and find the global optimal solution more stably.

III. PELICAN OPTIMIZATION ALGORITHM

Pelican optimization algorithm (POA) was proposed by Pavel trojovský And Mohammad dehghani in 2022[7]. The algorithm simulates the natural behavior of pelicans during hunting. Pelicans are large, have a long beak, and have a large bag in their throat for catching and swallowing prey. This kind of bird likes group and social life. Pelicans often hunt together in groups. After determining the location of their prey, pelicans dive into the prey from a height of 10-20 meters. Of course, some species also find their prey at low altitudes, and then they spread their wings on the water surface to force the fish into shallow water so that they can easily catch the fish. After catching the fish, a large amount of water enters the pelican's beak and moves the head forward to remove the excess water before swallowing the fish.

The behavior and strategy of pelican in hunting is an intelligent behavior process, which makes this bird a skilled hunter. The pelican optimization algorithm is mainly inspired by the modeling of the above strategies.

A. Mathematical model of algorithm

The pelican algorithm consists of two phases. The first phase is the phase of moving towards prey, which simulates the pelican's behavior of approaching prey. The second phase is the phase of winging on the water surface, which simulates the pelican's behavior of searching prey near the water surface. At the beginning of the algorithm, the population is initialized first, and then the location of prey is randomly selected. The pelican population is initialized to

$$x_{ij} = l_j + rand \cdot (u_j - l_j), i = 1,2,\cdots,N, j = 1,2,\cdots,m \quad (9.)$$

where x_{ij} is the location of the j-th dimension of the i-th pelican, N is the number of Pelican species, and m is the dimension for solving the problem; $rand$ is a random number in the range [0,1], u_j and l_j is the upper and lower boundary of the j-th dimension of the problem.

B. PHASE 1: Moving towards prey

In the first phase, the location of the prey is determined, and the pelican's strategy of approaching the prey is modeled. The location of the prey is randomly generated in the search space, which solves the exploration ability of the POA algorithm in the accurate search problem. It can be modeled as following equation.

$$x_{ij}^{P_1} = \begin{cases} x_{ij} + rand \cdot (p_j - I \cdot x_{ij}), & F_p < F_i \\ x_{ij} + rand \cdot (x_{ij} - p_j), & else \end{cases} \quad (10.)$$

where $x_{ij}^{P_1}$ is the jth dimension location of the ith Pelican after the first phase update. $rand$ is a random number in the range of [0,1]; I is a random integer of 1 or 2; p_j is the location of the prey in the j-th dimension, F_p is the objective function value of the prey. The pelican algorithm requires that each individual cannot move to a non optimal region, which is called effective update, and is described as the following equation.

$$X_i = \begin{cases} X_i^{P_1}, & F_i^{P_1} < F_i \\ X_i, & else \end{cases} \quad (11.)$$

where $X_i^{P_1}$ is the new location of the ith pelican, $F_i^{P_1}$ is the objective function value updated in the first phase.

C. PHASE 2: Winging on the water surface

In the second phase, pelicans start searching in the nearby area after reaching the water surface, so that they can catch more fish. This phase is modeled as

$$x_{ij}^{P_2} = x_{ij} + R \cdot (1 - \frac{t}{T}) \cdot (2 \cdot rand - 1) \cdot x_{ij} \quad (12.)$$

where $x_{ij}^{P_2}$ is the j-th dimension location of the i-th pelican after the second stage update; $rand$ is a random number in the range of [0,1]; R is a random integer of 0 or 2; t is the current iteration number; T is the maximum number of iterations.

D. Improved pelican optimization algorithm

POA algorithm aims at solving the optimal solution problem with continuous spatial distribution. The solution space of the disturbance resource allocation problem is discretely distributed. In fact, it is a multi-constraint nonlinear integer programming problem. So, the following improvements are made to solve the problem.

1) Coding

The coding method adopts intuitive and concise matrix coding. The following equation.

$$A_i = \begin{bmatrix} x_{11} & \cdots & x_{1N} \\ \vdots & \ddots & \vdots \\ x_{M1} & \cdots & x_{MN} \end{bmatrix}, i = 1,2,\cdots,NP \quad (13.)$$

where A_i represents the location of the i-th pelican in the population, NP is the population size, x_{MN} indicates the allocation of the m-th jammer to the n-th radar. 1 is allocated and 0 is not allocated.

2) Fitness function

Fitness function adopts Equation (8)

3) Moving towards prey

In order to make the obtained new location as superior as possible to the original location when it is close to the prey in the first phase, the following equation is adopted when the jammer and the enemy radar are one-on-one

$$A_i^{new} = \begin{cases} A_i^{r_1 \leftrightarrow r_2}, & F_p < F_i \\ p^{r_1 \leftrightarrow r_2}, & F_p \geq F_i \end{cases}, i = 1,2,\cdots,NP \quad (14.)$$

where A_i^{new} is the new location obtained, $A_i^{r_1 \leftrightarrow r_2}$ means random swap the r_1 and r_2 lines of A_i, $p^{r_1 \leftrightarrow r_2}$ means random swap the r_1 and r_2 lines of p. If the number of radars is more than jammers, that means one jammer can jam multiple radars, equation (14) becomes the following equation

$$A_i^{new} = \begin{cases} A_i^{r_1 \leftrightarrow r_2}, & F_p < F_i \\ p \otimes A_i^{r_1 \leftrightarrow r_2}, & F_p \geq F_i \end{cases}, i = 1,2,\cdots,NP \quad (15.)$$

where $p \otimes A_i^{r_1 \leftrightarrow r_2}$ means crossing, and replace the random n columns of the $A_i^{r_1 \leftrightarrow r_2}$ with the corresponding columns in the prey p. After obtaining the new location, judge whether the new location is a feasible solution, that means the jamming quantity of the jammer to the radar cannot exceed the defined maximum jamming number of each jammer, and each radar must be jammed. If the solution is feasible, proceed to the next step. If it is not feasible, correct it, that is, correct the jammer exceeding the maximum jamming number to the maximum jamming number, and randomly remove several radars allocated. After correction, judge again whether it is a feasible solution. If it is feasible, go to the next step. If it is not feasible, set the location fitness to 0. Calculate fitness $F_{A_i^{new}}$ for new location A_i^{new}, if it is better than the original location, the new location will be accepted; Otherwise, the original location will be maintained, which can be expressed as the following equation.

$$A_i = \begin{cases} A_i^{new}, & F_{A_i^{new}} \geq F_i \\ A_i, & else \end{cases}, i = 1,2,\cdots,NP \quad (16.)$$

4) Winging on the water surface

In the surface flight phase, the pelican's search behavior near its own location is simulated, which can make the algorithm jump out of the local optimal solution. The specific method is to use the neighborhood movement to get the location near its own location, as shown in the following equation

$$A_i^{neb} = \{A_i^{r_1 \leftrightarrow r_2} | 1 \leq r_1, r_2 \leq M\}, i = 1,2,\cdots,NP \quad (17.)$$

where A_i^{neb} is the set composed of all neighborhood locations of A_i, and M is the number of jammers. If the fitness of the new location searched in the set is better than the original location, the new location will be accepted; Otherwise, the original location will be maintained, as shown in the following equation

$$A_i = \begin{cases} A_i^{\max\_neb}, & F_{A_i^{\max\_neb}} \geq F_i \\ A_i, & else \end{cases}, i = 1,2,\cdots,NP \quad (18.)$$

where $A_i^{\max\_neb}$ is the position with the largest fitness in A_i^{neb}, $F_{A_i^{\max\_neb}}$ is the fitness of the location.

5) Termination conditions

Set the Maximum convergence iterations LIMIT and the maximum number of iterations of the algorithm. If the optimal solution does not change in the LIMIT iterations, it will be deemed to have converged, or the maximum number of iterations has been reached, and then end the algorithm to output the optimal solution.

6) Algorithm steps

a) Determine population size NP, iteration times Max_ Iterations, maximum convergence iterations LIMIT, maximum number of radars that can be allocated by jammer Max_ load.

b) Initialize population A, randomly generate NP feasible solutions, and randomly select prey p.

c) Calculate the fitness of the population and the fitness of the prey, and save the optimal solution of the current population.

d) Start to approach the prey. If the individual fitness is better than the prey, a new location will be generated near the individual, otherwise a new location will be generated near the prey.

e) Calculate the fitness of the new location. If it is better than the original location, receive it. Otherwise, go to Step *f*。

f) Search near the new location A_i^{new}. If a better solution is found, the original location will be updated.

g) Judge whether the algorithm meets the termination conditions. If so, terminate and output the optimal solution. If not, go to Step *c*.

IV. SIMULATION EXPERIMENT

Assuming that a certain army has 8 radar jammers and 8 incoming targets, the threat coefficient of radar radiation source is shown in Table 2. According to the respective parameter performance and spatial position relationship of jammers and radars, the countermeasure effectiveness table (Table 1) is calculated by using the jammer pressing probability model and objective function model given above. First conduct the one-to-one experiment, that is, one jammer only interferes with one radar, then conduct the one-to-many experiment, and compare the improved POA algorithm with SA algorithm.

A. One-to-one experiment

TABLE I. JAMMING EFFECTIVENESS

Jammer	***radar 1***	***radar 2***	***radar 3***	***radar 4***	***radar 5***	***radar 5***	***radar 7***	***radar 8***
1	0.22	0.79	0.05	0.65	0.77	0.34	0.03	0.79

Jammer	radar 1	radar 2	radar 3	radar 4	radar 5	radar 5	radar 7	radar 8
2	0.58	0.05	0.18	0.36	0.06	0.69	0.71	0.28
3	0.60	0.79	0.93	0.05	0.13	0.88	0.12	0.13
4	0.03	0.50	0.37	0.15	0.04	0.05	0.93	0.84
5	0.09	0.08	0.59	0.89	0.68	0.40	0.69	0.09
6	0.26	0.59	0.32	0.94	0.91	0.02	0.88	0.68
7	0.84	0.90	0.01	0.24	0.53	0.68	0.08	0.96
8	0.18	0.54	0.04	0.64	0.91	0.52	0.03	0.66

TABLE II. RADAR THREAT WEIGHT

radar 1	radar 2	radar 3	radar 4	radar 5	radar 6	radar 7	radar 8
0.62	0.79	0.64	0.88	0.54	0.68	0.72	0.46

Using the datas in Table 1 and table 2, set the population size NP as 50 and the maximum number of iterations max_ Iterations is 100, and the limit of maximum convergence Iterations is 30. After 300 times of execution, the experimental results are shown in Figure 1. The optimal results given by SA algorithm are: jammer 1 → radar 7, jammer 2 → radar 6, jammer 3 → radar 1, jammer 4 → radar 5, jammer 5 → radar 8, jammer 6 → radar 4, jammer 7 → radar 2, jammer 8 → radar 3. The optimal objective function value is 4.3371, of which the minimum value is 0.5034 and the average value is 2.4034. The optimal result given by the improved POA algorithm are: jammer 1 → radar 2, jammer 2 → radar 6, jammer 3 → radar 3, jammer 4 → radar 8, jammer 5 → radar 4, jammer 6 → radar 7, jammer 7 → radar 1, jammer 8 → radar 5. The optimal objective function value is 4.5039, of which the minimum value is 4.3270 and the average value is 4.4949. The improved POA algorithm searches the optimal value for many times, and the optimization probability is 0.9133. It can be seen that in the case of one-to-one jamming, the optimization probability and optimal objective function value of improved POA algorithm are better than SA algorithm.

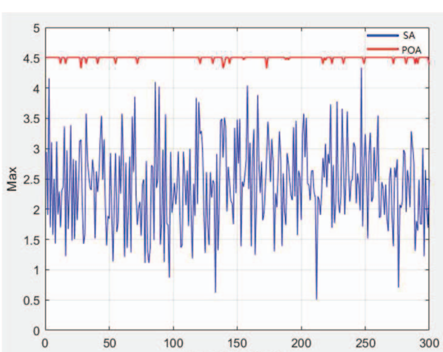

Figure 1. Results after 300 times of one-to-one jamming.

B. *One-to-many experiment*

The datas in Table 1 and table 2 are also used in the one-to-many experiment. Jammers 6, 7 and 8 are removed from table 1. Five jammers are used to allocate to eight radars. The experimental parameter settings: the population size NP is 15, the maximum number of iterations is 100, the maximum convergence iterations is 50, and the maximum number of jamming per jammer is max_ Load is 2. After 300 times of execution, the experimental results are shown in Figure 1. The optimal results given by SA algorithm are: jammer 1 → radar 3 and 7, jammer 2 → radar 6 and 8, jammer 3 → radar 5 and 6, jammer 4 → radar 3 and 5, jammer 5 → radar 1 and 2. The optimal objective function value is 5.2527, of which the minimum value is 1.0783 and the average value is 2.7827. The improved POA algorithm gives the optimal results as follows: jammer 1 → radar 2 and 4, jammer 2 → radar 1 and 7, jammer 3 → radar 3 and 6, jammer 4 → radar 7 and 8, jammer 5 → radar 4 and 5. The optimal objective function value is 5.4669, of which the minimum value is 5.3211, the average value is 5.4573, and the optimization probability is 0.75.

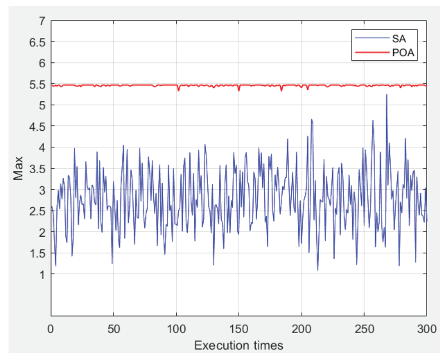

Figure 2. Results after 300 times of one-to-many jamming.

The experimental results showed that the optimized allocation strategy and reliability of the improved POA algorithm in solving the jamming resource allocation problem are better than SA algorithm in the case of one-to-one or one-to-many.

V. CONCLUDING REMARKS

The improved POA algorithm is used to solve the problem of jamming resource allocation optimization. It not only finds the global optimal solution from the solution space and provides a reasonable allocation strategy, but also provides a new idea for this kind of WTA discrete optimization problem. POA algorithm has been around for a short time. There is a lot of room for research and improvement of this algorithm, and the prospect is bright. More detailed work on this algorithm needs to be further carried out.

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