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Application of Improved Northern Goshawk Optimization Algorithm in Radar Networking Optimization

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***Abstract*—Aiming at the characteristics of many problems and difficulties in the optimization of radar system networking, a mathematical model of radar optimization networking is established, and an improved northern goshawk optimization algorithm is proposed. The algorithm initializes the population through the cubic chaotic map, adds nonlinear weight factors, and uses the Cauchy-Gaussian mixture mutation operator to perturb, and achieves a better optimization effect than the basic northern goshawk algorithm. Then, the improved northern goshawk optimization algorithm is used to solve the established radar optimization networking model, and two algorithms are selected for comparative analysis. Simulation experiments show that the radar networking scheme optimized by the improved northern goshawk optimization algorithm is effective, feasible and better.**

Keywords- Radar networking; Radar engineering; Northern goshawk optimization;

I. INTRODUCTION

With the advancement of technology, various new intelligent weapon systems have been widely used in the military field. This causes the traditional single radar system to face four major threats: radiating missiles, stealth targets, ultra-low-altitude high-speed small targets and integrated electronic jamming. The radar networking system not only has the technical performance of full frequency band, multiple systems, and multiple overlapping coefficients, but also can form an all-round, three-dimensional, and multi-level combat system. However, under the background of complex modern battlefield, the problem of radar networking is restricted by many factors such as battlefield situation and military expenditure, so far it has not been able to form a mature theoretical system. Therefore, it is very necessary to carry out research on radar networking.

In recent years, a large number of heuristic algorithms have come out, and many scholars have begun to apply them to radar station layout. Reference [1] uses Genetic Algorithm (GA) to simulate the optimal station layout model, and achieves ideal results. Reference [2] extends its mathematical model and uses an improved genetic algorithm for optimization, which improves the calculation accuracy. Reference [3] uses a hybrid method of Particle Swarm optimization (PSO) and coordinator to solve the radar networking model and achieves good optimization results. References [4] and [5] respectively use the Improved Shuffled Frog Leaping Algorithm (ISFLA) and the Improved Chaotic Self-adapting Monkey Algorithm (ICSAMA) to solve the problem of radar network deployment question.

However, the above studies all have certain limitations. Therefore, this paper models the radar networking problem based on the idea of [1], and introduces a newer heuristic algorithm—Northern Goshawk Optimization (NGO) [6] algorithm. This algorithm is a new swarm intelligence optimization algorithm proposed by MOHAMMAD DEHGHANI and others in 2022. This algorithm, like other swarm intelligence algorithms, has the same problems of low convergence speed, low precision and easy to fall into local optimum. Therefore, this paper improves the NGO algorithm and proposes an improved Northern Goshawk Optimization (INGO) algorithm. First, INGO uses the cubic chaotic map to initialize the population, which makes the initial population more evenly distributed in the search space, improves the diversity of the population, and increases the solution efficiency. Secondly, the step size factor in the NGO development stage is improved, and the nonlinear weight factor is used to replace the linear weight factor, which not only enhances the global search ability of the algorithm, but also improves the local adjustment ability. Then, the Gauss-Cauchy mixed mutation operator was introduced to perturb each individual in the population, which improved the optimization performance of the algorithm. Finally, this paper uses the INGO algorithm to solve the radar optimization network model, and conducts simulation experiments to compare and analyze with other intelligent algorithms.

II. RADAR OPTIMIZATION NETWORKING MODEL

A. Principles of Radar Networking

For a specific application background, the following principles should be followed when optimizing networking: (1) In the warning zone, to achieve the largest possible detection range. (2) Cover the key detection area as completely as possible. (3) It has a higher airspace coverage, that is, a larger overlapping area of multiple radar detection areas, so as to improve the anti-interference ability. In view of these three principles, this paper uses the coverage rate of warning area f_{alert}, the coverage rate of key detection area f_{core} and the overlap rate of airspace range f_{cover} to describe. In order to facilitate theoretical research, this paper decomposes the area of radar network into K layers according to the height [1], the importance of each height layer is

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measured by w_j, and its value can be given by the C^3I system, and $\sum_{j=1}^{K} w_j = 1$. The specific evaluation formula of each principle is as follows:

1) The coverage rate of the warning zone

$$f_{alert} = \sum_{j=1}^{K} w_j \frac{(\bigcup_{i=1}^{M} S_{ij}) \cap S_{alert}}{S_{alert}} \tag{1}$$

where S_{ij} is the area of the detection area of the ith radar on the jth layer, and S_{alert} is the total area of the warning area.

2) Coverage of key detection areas

$$f_{core} = \sum_{j=1}^{K} w_j \frac{(\bigcup_{i=1}^{M} S_{ij}) \cap S_{core}}{S_{core}} \tag{2}$$

where S_{core} is the total area of the key detection area.

3) Overlapping rate of airspace range

$$f_{cover} = \frac{\sum_{j=1}^{K} w_j \left(S_{overlaps} \cap S_{alert}\right)}{S_{alert}} \tag{3}$$

$$S_{overlaps} = \bigcup_{\substack{i,e=1 \\ i<e}}^{M} (S_{ij} \cap S_{ej}) \tag{4}$$

where $S_{overlaps}$ is the overlapping detection range area of M radars on the jth layer.

B. Objective function

In practice, the three deployment principles are often opposed. According to the three deployment principles and their formulas, this paper uses the weighting method to construct the objective function of the radar optimization network, and converts the multi-objective optimization problem into a single-objective optimization problem. The specific objective function formula is as follows:

$$maxf = \lambda_1 \cdot f_{alert} + \lambda_2 \cdot f_{core} + \lambda_3 \cdot f_{cover} \tag{5}$$

where the sum of λ_1, λ_2, and λ_3 is 1, and λ_1, λ_2, λ_3 can be determined according to the actual situation.

III. NORTHERN GOSHAWK OPTIMIZATION ALGORITHM

A. Basic Northern Goshawk Optimization Algorithm

The northern goshawk algorithm is inspired by the hunting behavior of northern goshawks. The hunting process of the northern goshawk is divided into two stages: prey identification and attack (exploration stage), chase and escape operation (development stage). In the northern goshawk algorithm, the northern goshawk population can be represented by the following matrix:

$$X = \begin{bmatrix} X_1 \\ \vdots \\ X_N \end{bmatrix}_{N\times m} = \begin{bmatrix} x_{1,1} & \cdots & x_{1,m} \\ \vdots & \ddots & \vdots \\ x_{N,1} & \cdots & x_{N,m} \end{bmatrix}_{N\times m} \tag{6}$$

where X is the population matrix of the northern goshawk, X_i is the position of the ith northern goshawk, $x_{i,j}$ is the jth dimension of the ith northern goshawk, N is the population of the northern goshawk, m dimension of the problem.

1) Prey identification: The northern goshawk chooses a random prey and then quickly attacks it. This stage conducts a global search of the search space, increasing the exploration capability of the NGO to determine the optimal area. The specific location update formula is as follows:

$$P_i = X_k, i = 1,2,\cdots,N, k = 1,2,\cdots,i-1,i+1,\cdots,N \tag{7}$$

$$x_{i,j}^{new,P1} = \begin{cases} x_{i,j} + r\left(p_{i,j} - I x_{i,j}\right), & F_{P_i} < F_i \\ x_{i,j} + r\left(x_{i,j} - p_{i,j}\right), & F_{P_i} \geq F_i \end{cases} \tag{8}$$

$$X_i = \begin{cases} X_i^{new,P1}, & F_i^{new,P1} < F_i \\ X_i, & F_i^{new,P1} \geq F_i \end{cases} \tag{9}$$

where P_i is the position of the prey of the ith northern goshawk, F_{P_i} is the objective function value of the position of the prey of the ith northern goshawk, k is a random integer in the range of $[1, N]$, $X_i^{new,P1}$ is the new position of the ith northern goshawk, $x_{i,j}^{new,P1}$ is the new position of the jth dimension of the ith northern goshawk, $F_i^{new,P1}$ is based on The objective function value of the ith northern goshawk individual after the first stage update, r is a random number in the range of $[0,1]$, and I is 1 or 2.

2) Chase and escape: After the northern goshawk attacks the prey, the prey will try to escape, and the northern goshawk will continue to chase the prey and eventually succeed in capturing it. This stage is used to perform a local search of the solution space. Assuming that the radius of the attack range of the northern goshawk is R. The specific update formula is as follows:

$$x_{i,j}^{new,P2} = x_{i,j} + R(2r-1)x_{i,j} \tag{10}$$

$$R = 0.02\left(1 - \frac{t}{T}\right) \tag{11}$$

$$X_i = \begin{cases} X_i^{new,P2}, & F_i^{new,P2} < F_i \\ X_i, & F_i^{new,P2} \geq F_i \end{cases} \tag{12}$$

where t is the current number of iterations, T is the maximum number of iterations, $X_i^{new,P2}$ is the new position of the ith northern goshawk, and $x_{i,j}^{new,P2}$ is the ith northern goshawk The new position of the jth dimension, $F_i^{new,P2}$ is the objective function value of the ith northern goshawk individual updated based on the second stage.

B. Improved Northern Goshawk Optimization Algorithm

Although the NGO algorithm has better performance, it still has the disadvantages of slow convergence speed and easy to fall into local optimum. Therefore, it is of great significance to improve the NGO algorithm.

1) Initialize the population with cubic chaotic map: In order to make the algorithm have higher global search ability and population diversity at the beginning of the iteration, this paper uses the chaotic operator to initialize the northern goshawk population. The chaotic operator has the advantages of randomness and regularity. In the radar optimization networking problem, the position of the radar in the initial population needs to be evenly distributed in the warning area as much as possible. In this paper, a cubic chaotic map with more uniform variables is selected [7]. The formula is as follows:

$$y_{i+1} = 4y_i^3 - 3y_i \tag{13}$$

$$y_i \in (-1,1),\ y_i \neq 0,\ i = 0,1,\cdots,N \tag{14}$$

The position of each dimension of the northern goshawk individual is initialized according to (15).

$$x_{i,j} = X_{lb} + \frac{1}{2}(X_{ub} - X_{lb})(y_i - 1) \tag{15}$$

where $x_{i,j}$ is the mapped individual position of the northern goshawk, X_{ub} and X_{lb} are the upper and lower boundaries of each individual, here are the coordinate ranges of the warning area and the key detection area.

2) Introduce nonlinear weights: The inertia weight method [8] was first proposed by Shi and Eberhart in particle swarm optimization, which can greatly balance the global exploration ability and local development ability of the algorithm. The NGO algorithm introduces a linear weight R in the second stage and assigns a constant coefficient of 0.02. After analysis, it is known that the NGO algorithm using this linear weight, in the early stage of iteration, takes a long time to successfully capture the northern goshawk due to its small attack distance. Therefore, this paper introduces a nonlinear weight, as follows:

$$R = 0.1\left[\sin\left(\frac{\pi}{2} + \frac{\pi \cdot t}{T}\right) + 1\right] \tag{16}$$

The nonlinear weight calculated by (16) is brought into (10) for position update.

3) Using the Cauchy-Gaussian mixture mutation strategy: In the later stage of the NGO algorithm iteration, the northern goshawk individuals rapidly assimilate due to catching the same prey and other reasons, and it is easy to appear a local optimum. In response to this problem, this paper adopts the Cauchy-Gaussian mixture variation [9] strategy to perturb the position of each individual after successfully capturing the prey, and then compares the objective function value with the position before the perturbation, and chooses the better one's position. The specific formula is as follows:

$$X_i^{\text{variation}} = X_i^{new,P2}\left\{\begin{matrix}\lambda[1 + Gauss(0,1)] + \\ (1-\lambda)[1 + Cauchy(0,1)]\end{matrix}\right\} \tag{17}$$

$$\lambda = \frac{t}{T} \tag{18}$$

where $X_i^{\text{variation}}$ is the position of the ith individual after perturbation, and λ is a linear weight factor. By introducing λ, in the early stage of the iteration, the global optimization performance of the algorithm can be improved by the strong perturbation ability of Cauchy variation; in the later stage of the iteration, by Gaussian variation adds smaller perturbations.

4) INGO Algorithm step

The optimization steps of using the improved northern goshawk algorithm to optimize the radar network model are as follows:

a) Initialize parameters, including the population size N, the maximum number of iterations T, the range of the radar network warning area, the range of the radar network key detection area, and the detection radius of each radar, and the population is initialized using the cubic chaotic map of (13) and (14).

b) Calculate the objective function value of each radar networking system of the population, and find out the current optimal objective function value and the corresponding position of each radar station.

c) Randomly select an individual from the population as prey.

d) Start searching for prey, use (8) to get the new position, and then use (9) to judge whether to use the move to the new position.

e) Start chasing the prey, and at the same time the prey escape, use the (10) to obtain the new position, replace the calculation method of the weight factor R in the (10) with the (15), and then use the (12) to determine whether to accept the new position.

f) Use the Cauchy-Gaussian mixture mutation operator to perturb the individual position, and judge whether the perturbed position is better than the current position, and if it is better, update it.

g) Judge whether the algorithm satisfies the termination condition, if so, go to the next step, if not, go to step b.

h) At the end of the program, output the optimal objective function value and the optimal radar networking scheme.

IV. Simulation Analysis

In order to verify the effectiveness of the INGO algorithm in radar optimization networking, the following scenarios are simulated in this paper [3]. Assume that the area of radar network is a square area of $300km \times 300km$, and the area of $100km \times 100km$ in the center is listed as the key area. 5 radars of 4 different types (Type A, Type B, Type C, Type D) are deployed in the area (1 Type A, 2 Type B, 1 Type C, 1 Type D). It is assumed that the radars work in an ideal environment, and the detection area of the radar at each level is simplified to a circular area. At the altitudes of $1, 5, 8, 15km$, the maximum detection radius of the A-type radar is $80, 100, 120, 100km$. The maximum detection radius of the B-type radar is $60, 90, 120, 80km$. The maximum detection radius of C-type radar is $80, 100, 140, 120km$. The maximum detection radius of D-type radar is $60, 80, 120, 60km$. The importance of each height layer are $w_i = 0.25$, $i = 1,2,3,4$. The weights of the three principles are $\lambda_1 = 0.4$, $\lambda_2 = \lambda_3 = 0.3$. The algorithm population size is 30, and the maximum number of iterations is 200. According to the algorithm steps described in the previous section, the solution is carried out. The obtained radar positions are shown in Table 1. The objective function value at this time is 0.6857. The detection range of the radar networking at each altitude is shown in Figure 1. It can be seen that the radar networking scheme given by the algorithm has a good coverage at each altitude.

In addition, in order to further verify the superiority of the INGO algorithm, this paper selects the genetic algorithm (GA) [10] and the basic northern goshawk optimization algorithm (NGO) [6] to compare with the INGO algorithm. All three algorithms use the data above, and the test is run 100 times. The specific statistics are: the maximum value of the objective function obtained by GA is 0.6759, the minimum value is 0.6404, and the average value is 0.6565; the maximum value of the objective function given by the NGO algorithm is 0.6747, the minimum value is 0.6516, and the average value is 0.6647; The maximum value is 0.6857, the minimum value is 0.6701, and the average value is 0.6795. The statistical results of the objective function value of 100 times are shown in Figure 2. It is obvious from the figure that the objective function value solved by the INGO algorithm is always better than that of GA and NGO. algorithm. This also fully demonstrates the effectiveness of the INGO algorithm in the radar optimization networking problem.

TABLE I. INGO OPTIMIZED RADAR POSITION

Radar number	x/km	y/km
1	73.2395	65.0352
2	246.4453	249.9893
3	232.0861	84.8350
4	96.9054	224.1593
5	167.0591	152.9707

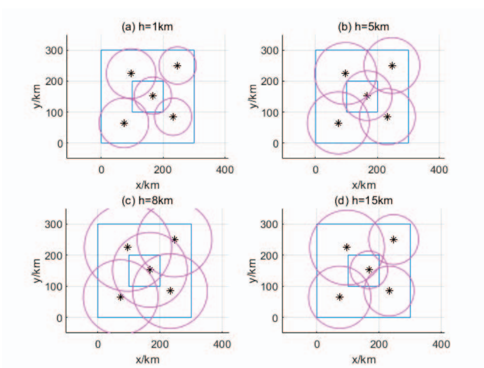

Figure 1. Schematic diagram of radar network at each level

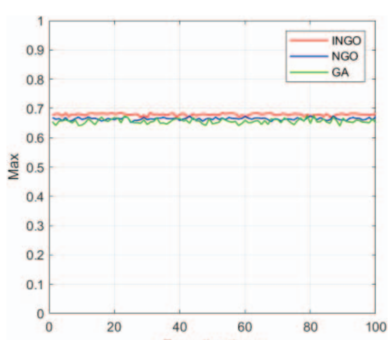

Figure 2. Comparison results of objective function values of the three algorithms executed 100 times

V. CONCLUSION

In recent years, the problem of radar network optimization has become an important topic that scholars at home and abroad pay attention to. Because the actual battlefield conditions are complex and changeable, and mixed with various natural environment factors, it is difficult to obtain real radar detection data. Therefore, this paper conducts modeling from the perspective of ideal environment. Subsequently, a new swarm intelligence algorithm, NGO, was introduced, improved, and applied to the optimized networking model built. Finally, the simulation experiment proved its effectiveness and superiority. However, this paper only proposes three principles, and does not consider the interference problem, and the field of heuristic algorithms is constantly innovating. Therefore, it is the next research direction to improve the optimized networking model in this paper and introduce a new algorithm to solve it.

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