An Improved Cuckoo Search Algorithm for Target Assignment

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Abstract. The purpose is to study an improved cuckoo search algorithms in target assignment via the analysis of the characteristics of air defense interception and the demand for weapon target assignment (WTA). As for the threat of multi-batches and saturating targets, the random coding method based on the minimum position rule is used to initialize the population. In addition, the results' accuracy and fast convergence are ensured by adding adaptive communication and mutation operator. The improved algorithm is then simulated and analyzed by the air defense target interception case, and the results indicate that the improved algorithm is effectiveness and superiority in solving the problem of WTA, compared to the standard cuckoo and immune algorithm. The current study indicate that the improved algorithm provides a kind of effective method for solving the problem of WTA.

1. Introduction

With the development of the current air combat mode, the threat of air defense has changed, which the interception mission is transforming from a single target to multiple batches and saturated targets. In air defense interception, it is the key link of command and control system that how to use limited resources rationally to achieve the optimal allocation of WTA and response to multiple batches and saturated targets. As we know, the problem of WTA is a multi-parameter and multi-constrained Non-deterministic Polynomial (NP) problem, which solution space increases exponentially with the number of defensive weapons and incoming targets. Although many intelligent algorithms are introduced into resolve the WTA problem by domain experts [1-3], the traditional optimization algorithm doesn't take into account the actual demand for air defense operation. When faced with multiple targets and saturated attacks, it is unable to achieve fast and accurate target assignment, and play the combat effectiveness of weapon systems. Therefore, it is the key issue to design an efficient algorithm of target assignment to intercept multiple batches and saturated targets [4].

The cuckoo algorithm has the advantages of few parameters, easy realization and strong ability of searching. It simulates cuckoo parasitic behavior and uses the Levy flight mechanism, by walking randomly to search for an optimal nest to incubate their eggs [5]. In this way, we can get an efficient optimization model. In this paper, according to the characteristics of the weapon-target assignment problem, we design an extendible coding method to initialize population, dealing with multiple batches and saturated targets. Based on cuckoo algorithm, the convergence and accuracy of the algorithm are improved by adding the self-adaption exchange mechanism and mutation operation, resulting in high efficiency and accuracy.

2. Improved Algorithm

2.1 Standard Cuckoo Algorithm

The main idea of the cuckoo algorithm is that it generates candidate nest by Levy flight path and updates the current position of the nest by the elitist strategy. Finally, the location of nest can reach or be close to the global optimum [6].

In the process of looking for the nest, three principles are given as follows: (1) The cuckoo randomly selects the parasitism nest, and produces one egg at a time. (2) The selected nest will be

saved to the next generation in accordance with certain conditions. (3) The number of the bird nests that are parasitic is fixed. Meanwhile, the probability discovered by host is P_a. Based on the above three principles, the update formula of location and path is given as follows:

$$x_i^{(t+1)} = x_i^{(t)} + \alpha \oplus L(\lambda), \ i = 1, 2, \cdots, n \tag{1}$$

The location of the nest is represented by the variable $x_i^{(t)}$, and in this variable, the "i" is the nest location and the "t" is the breeding times; the symbol of "$\oplus$" represents point-to-point multiplication; the variable "a" is the step length; $L(\lambda)$ is the random step following Levy distribution. After using the formula to update the location, we compared random numbers of $r \in [0,1]$ with the probability of p_a. If the equation of $r > p_a$ is right, the variable $x_i^{(t+1)}$ is changed, otherwise unchanged. Finally, the nest of better fitness can be saved, being recorded as $x_i^{(t+1)}$.

The search mechanism of cuckoo algorithm depends entirely on the random walk, so the optimal solution will be found when sufficient calculation is given. However, this mechanism leads to the reduction of the search efficiency and lack of local search precision. Therefore, the convergence and accuracy of the algorithm can't be guaranteed. We propose an improved algorithm for WTA to meet operational requirements.

2.2 Improved Algorithm Design

The main idea of the improved algorithm is to improve the convergence and local search ability of the algorithm by introducing the adaptive operator, and to increase the evolutionary vitality and accuracy of the algorithm by adding the adaptive mutation operation. In this way, not only the global search ability of the algorithm is guaranteed, but also convergence is increased.

2.2.1 Adaptive Communication Operator

In the cuckoo algorithm, each nest is independent and updated by their individual flight mode, leading to no information exchange between the nests. Therefore, we propose an exchange operator, which increases the exchange of information so that the nest updates towards the optimal direction. After these nests are updated by Levy flight, there will be nest with best fitness recorded as x_{ibest}^t, and average fitness value is recorded as f_{iavg}^t. It is assumed that the communication operator is named as β, and the communication strategy is given as follows:

$$x_{inew}^t = \begin{cases} \beta x_{iold}^t + (1-\beta)x_{ibest}^t, & f_i^t \le f_{iavg}^t \\ x_{iold}^t + r_i \left| x_i^t - x_j^t \right|, & f_i^t > f_{iavg}^t \end{cases} \tag{2}$$

In this equation, $\beta = \dfrac{x_{ibest}^t - x_i^t}{x_{ibest}^t - x_{worst}^t}$, and the variable "r" is the random number between zero and one.

2.2.1 Adaptive Mutation Operator

The mutation operation can increase the diversity of solutions and improve the evolutionary vitality of the algorithm. Therefore, an adaptive mutation operator is introduced based on Gauss and Cauchy mutation. Gauss mutation produces a small step variation in a small neighborhood with high probability [7], which improves the local search ability. However, it is easy to make the algorithm into local optimum. Cauchy mutation has strong ability to escape from local optima [8], which can increase the diversity of the population and obtain the global convergence. Therefore, a hybrid mutation operator is designed based on gauss and Cauchy mutation. The hybrid mutation operator can adjust adaptively according to the fitness of the population, which guarantees the local search and escape ability. This operator is given as follows:

$$x_i' = x_i + \sigma_i M_i(0,1) \tag{3}$$

$$M_i(0,1) = \frac{S}{S + f(x)} C(0,1) + \frac{f(x)}{f + f(x)} N(0,1) \tag{4}$$

In this equation, $C(0,1)$ is the Cauchy mutation operator, and $N(0,1)$ is the Gauss mutation operator. The variable S is the population diversity that is calculated by the Hamming distance [9].

When the S is larger, the diversity of population is worse. When the diversity of population becomes smaller, the S becomes bigger, and the variation can be carried out in the direction of increasing population diversity. Conversely, the variation increases the local search ability of the algorithm to speed up the convergence of the algorithm..

3. Solution of WTA Problem

3.1 Problem Description and Basic Model

According to the demand for the current air defense operation, the problem needs to be solved for multiple batches and saturated target assignment. Thus we assume three principle of WTA: (1) Every incoming target is under being attacked as much as possible, (2) The number of targets assigned to combat weapons can't exceed the weapon capacity, and (3) when there is a surplus of weapons, the target can be hit by many multiple batches.

It is assumed that the targets at a certain time are $T = \{t_1, t_2 ... t_{N_T}\}$, which reaches defense zone by multiple batches. There are multiple intercept weapons, recorded as $W = \{w_1, w_2 ... w_{N_W}\}$. The number of fire units for weapon w_j is r_j, and that its intercept probability is p_{ij}, and threat level of the target is V_j. Meanwhile, the fire unit s_j is assigned to the target t_j. According to the WTA maximization principle, the equation is given as follows:

$$
\begin{cases}
f(z) = \max \sum\limits_{i=1}^{N_T} \{V_i \times \{1 - \prod\limits_{j=1}^{N_W} (1 - p_{ij})^{x_{ij}}\}\} \\
\sum\limits_{j=1}^{N_T} x_{ij} \leq r_i, \\
\sum\limits_{i=1}^{N_W} x_{ij} \leq s_j, \\
\sum\limits_{i=1}^{N_T} \sum\limits_{j=1}^{N_W} x_{ij} = N_W, \\
1 - \prod\limits_{j=1}^{n} (1 - p_{ij})^{x_{ij}} \geq P_{ij},
\end{cases}
\tag{5}
$$

The decision variable is $x_{ij} = \{0, 1\}$ when $x_{ij} = 1$, and the target t_j is intercepted by weapon w_j. When the number of incoming targets exceeds the maximum weapons, the targets of greater threat degree are intercepted. On contrary, when virtual target is added, its threat degree is zero. Other parameter can be evaluated by command and control system.

3.2 Encoded Mode

The WTA problem is a typical combinatorial optimization problem. When the improved cuckoo algorithm is used to solve the problem, the reasonable encoding is needed for population initialization to represent properties of solutions of the WTA problem. In the paper, the random coding method is based on the minimum position rule [10]. The continuous position vector $X = \{X_1, X_2, ..., X_n\}$ of the host nest selected by cuckoo is changed into the sequential vector $x = \{x_1, x_2, ..., x_n\}$ for the incoming target. Then the fitness value of WTA solution can be calculated according the corresponding nest position. This coding method can effectively deal with multiple batches targets. The nest can be extended randomly to ensure the feasibility of solution according the number of incoming targets.

3.3 Intial Poplation of Multiple Batch Target

When a new batch target is found, we will start with random coding to the initialize population, which is a great waste of system resources. Therefore, when faced with multiple batched targets, the nest, based on the current optimum group, can be extended randomly according the number of incoming targets. In this way, it not only ensures the rational use of system resources, but also

shortens the time of target assignment and improves the effectiveness of the command and control system.

3.4 Process

In summary, the process solving WTA problem by using improved cuckoo algorithm is given as follows:

Step 1: According to the number of weapon and target, the population can be initialized by encoding nest. Simultaneously, the algorithm parameters are set.

Step 2: According to the equation (1), the nest location can be updated, and the nest fitness value can be calculated by equation (5).

Step 3: The nest should exchange information for each other and be updated by equation (2). Then, the adaptive mutation operation is carried out by equation (2) and (3). It will be judged whether there is a satisfactory solution.

Step 4: When a new batch of targets is reached, the population is initialized on the basis of the population of the Step 3, by extended encoding. Then, the operation step2~step3 is repeated.

Step 5: The most satisfactory solution is found and decoded. Finally, the optimal WTA scheme is generated.

4. Simulation Analysis

In an air defense operation, there are nine targets as $T = \{t_1, t_2...t_9\}$, and they reach the defensive position, divided into two batches. One is $T_1 = \{t_1, t_3, t_4, t_5, t_6, t_7\}$, and the other is $T_2 = \{t_2, t_8, t_9\}$. It is assumed that there will be six weapons system as $W = \{w_1, w_2...w_6\}$ and the number of fire unit equipped on the system is {2, 1, 2, 1, 2, 1}. The threat degree of the target and the kill probability of fire unit are given through the command and control system, as shown in Table 1.

Tab 1 The threat degree of the target and the kill probability of fire unit

Target	Threat degree	Kill probability					
		1	2	3	4	5	6
1	0.9	0.4	0.2	0.8	0.7	0.2	0.3
2	0.5	0.8	0.3	0.8	0.8	0.3	0.4
3	0.4	0.2	0.2	0.7	0.4	0.2	0.3
4	0.3	0.5	0.3	0.8	0.8	0.1	0.3
5	0.5	0.8	0.8	0.4	0.7	0.2	0.5
6	0.8	0.4	0.6	0.3	0.5	0.7	0.4
7	0.6	0.3	0.6	0.1	0.1	0.4	0.3
8	0.4	0.5	0.6	0.4	0.3	0.7	0.7
9	0.7	0.8	0.1	0.2	0.6	0.8	0.9

The WTA problem is calculated under the same conditions, using this algorithm and cuckoo /immune algorithm. The results are shown in the Table 2.

Tab 2 The results of simulation

Target	1	2	3	4	5	6	7	8	9	Profit
Improved cuckoo algorithm	3	1	3	4	1	5	2	5	6	3.79
cuckoo algorithm	3	1	4	3	1	2	5	5	6	3.52
immune algorithm	3	1	4	3	1	5	2	5	6	3.75

In order to verify the performance of the improved algorithm, stable results are obtained by several simulations, as shown in the Figure 1.
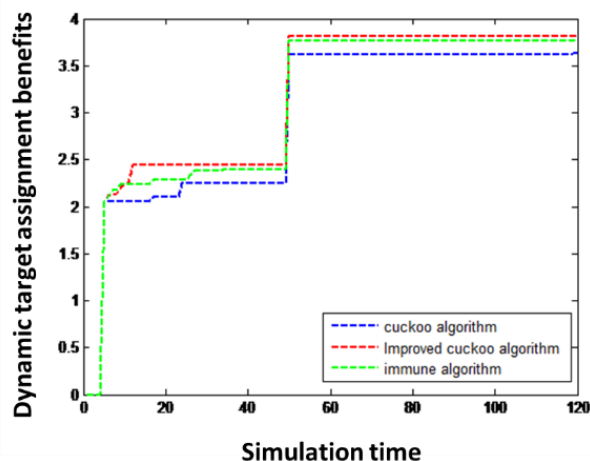
Fig. 1 The comparison chart of algorithm fitness

In figure 1, the combat effectiveness increases rapidly at the time of t=4 and t=50, because of arrival of a large number of targets. Because the random coding method based on the minimum position rule is used to initialize the population, the solution is calculated quickly when the second target comes. Among the three curves, the improved cuckoo algorithm designed to solve the WTA problem can achieve better convergence and accuracy.

In order to analyze the stability of the algorithm, simulation was achieved across 100 Monte-Carlo under the same condition. The comparison was shown in Figure 2.
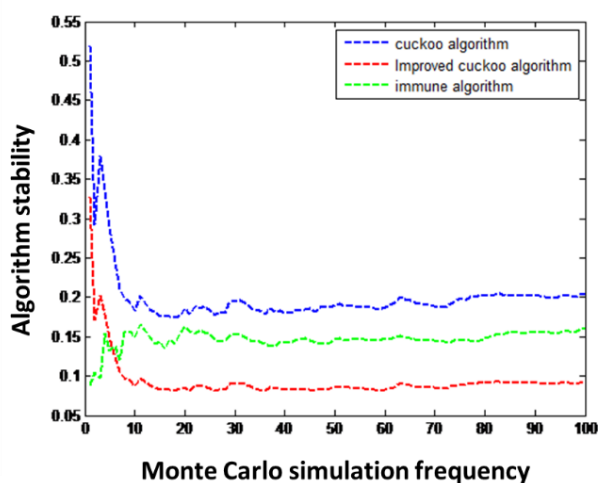

Fig.2 The algorithm for solving the stability analysis

By analyzing the simulation results, the improved algorithm can realize the fast convergence and the optimization ability of the algorithm. The reason is that the adaptive mutation and communication operator is added, which improves the convergence and stability of the algorithm. Therefore, the WTA problem can be solved significantly well by the improved cuckoo algorithm, which is efficient and feasible.

5. Summary

The WTA problem is one of the key links in the command and control system of air defense operations. The effectiveness of the system can be affected seriously by the stability and efficiency of the algorithm. The convergence and the optimization ability are improved by adding adaptive mutation and communication operator. The ability to deal with multiple batches of targets is achieved by encoding. The improved algorithm is proved to be feasible, which can provide new ideas for WTA problem.

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