Research on Ship and Aircraft Joint Multi-Task Management Based on Discrete Particle Swarm Optimization Algorithm

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Abstract. The problem of joint operations is a hot issue in the field of military research, and has become the main mode of warfare for future information warfare. In this paper, a multi-task management method for ship and aircraft joint operation based on discrete particle swarm optimization (PSO) is proposed. First, a mathematical model of joint multi-task management is established. Then, the discrete PSO algorithm is introduced. Finally, simulation proved the effectiveness of the method. The research results can provide theoretical basis and technical support for ship and machine joint command and control.

Problem Description

In modern warfare, it is often necessary for one or more ships to carry many carrier-based aircrafts to carry out reconnaissance, anti-submarine, attack, and electronic confrontation. In the course of task implementation, it requires the two kind of moving platforms (ships and aircrafts) cooperation tightly. In this paper, a ship carrying multiple carrier-based aircraft scene is assumed. The focus of this paper is to combine both the operational effectiveness and making the cost of completing the reconnaissance mission at the lowest level. According to the different operations of the ship's different functions, make the following definition:

\textbf{Definition 1:} Tactical Nodes: The best location of the ship to complete the joint operational mission.

\textbf{Definition 2:} Target node: The best task location of every aircraft carried on the ship to complete the joint operational mission.

Taking into account the complexity of the battlefield environment, a single ship may not only need to complete a reconnaissance mission, the corresponding implementation of a reconnaissance mission of the carrier-based aircraft is not unique. So for each reconnaissance mission need to determine which carrier-based aircraft perform and determine the order of execution. In addition, the ship is moving, and its position is constantly changing, in order to shorten the voyage as much as possible to complete the task, the aircraft can choose to take the appropriate location to go to combat targets. The scouting mechanism of carrier-based aircraft is not the focus of this paper, and the way of naval auxiliary function is not taken into account. The two combat missions are simplified into nodes that need to be warned. In order to facilitate the study of the problem, some assumptions are made as follows:

(1) The losses of aircrafts does not take into account in the implementation of the task.
(2) Carrier-based aircraft can only take off when the ship is in tactical node position.
(3) The longevity of the ship is strong enough to support the ship to complete all combat missions until it returns to base. That is to say regardless of the voyage of the ship.
(4) After return to the ship, carrier-based aircraft can be fuel and other supplies of supplies, then it can continue to follow the implementation of the subsequent combat missions;
Since the carrier-based aircraft flying speed is usually much faster than the speed of the ship, the relative displacement of the ship after the take-off of the carrier is negligible, that is, regardless of the change in the position of the ship.

In summary, a single ship multi-carrier aircraft collaborative task assignment problem can be described as: one ship and many carrier-based aircrafts were completed by the combat tasks were distributed in the tactical nodes and target nodes. For tactical node tasks, it is necessary to determine the order in which it is executed by the ship. For the task of the target node, it is necessary to determine which order the carrier is executed from which tactical node it is, and the final requirement is to make the total cost of the whole fleet complete.

Mathematical Model

Figure 1 is a single ship equipped with three heterogeneous carrier-based aircraft to carry out the task of the allocation of the program diagram. The fleet from the base, sailing to the tactical node 1, by the carrier-based aircraft I, carrier-based aircraft II take off to reach the target node in accordance with the established operational order of the combat mission, the task is completed after the two carrier-based aircraft back in the tactics Node 1 of the ship. After the ship carrying three carrier-based aircraft to the tactical node 2, at the tactical node 2 only by the carrier-based aircraft III to perform combat missions, at the tactical node 3 on the carrier-based aircraft I, carrier-based aircraft III assigned combat missions, when Sailing to the tactical node 4 only need to carry out combat missions, at the tactical node 5, 6 only need carrier-based aircraft II take off alone to perform. According to this allocation scheme, all tasks can be implemented and cost the least.

Figure 1. Single-ship multi-machine collaborative task allocation diagram.

The basic mathematical model of the cooperative task assignment problem of multi-carrier ship machine is also proposed by the following formula (1) - (3)

\[
\min \ z = \sum_{i} \sum_{j} \sum_{k} c_{ijk} x_{ijk} 
\]

\[
\sum_{i} x_{ij} = \sum_{j} x_{js} = 1
\]

\[
\sum_{i} \sum_{j} c_{ijk} x_{ijk} \leq D_k
\]
Equation (1) is the objective function. Under normal circumstances, the multi-machine coordination problem is the optimal target of the path cost and threat cost of the carrier. Equation (2) is the execution of a task constraint, meaning that each task to be executed must be executed and can only be executed once. Equation (3) is a voyage constraint, meaning that the flying distance of each carrier cannot exceed its maximum range.

According to the above description of the single-ship multi-machine cooperative task assignment problem, the directed map $G = \langle V, E \rangle$ denotes the combat area of the whole fleet, $V = \{0, V_F, V_U\}$ represents the node set, 0 indicates the base of the fleet departure and return, $V_F$ represents the set of tactical nodes set of the ship, $V_U$ represents the set of tactical nodes set of aircrafts. $E = \{<i, j> | i, j \in V, i \neq j\}$ represents the set of edges formed by any two points in the set $V$. The set $x_i, x_j, y_i, y_j$ represents a collection of the single ship and many carrier aircrafts, where: $s$ represents the ship, $K_U$ represents a collection of heterogeneous carrier aircrafts. $m$ represents the number of carrier-based aircrafts, $D_k$ represents the maximum range of carrier-based machine $k$, $c_{ij}$ represents the Euclidean distance between node $i$ and node $j$. The formula is shown by the following equation (5) Y-axis.

$$c_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$$  

(5)

The decision variables that define the problem are as follows:

$$x_{ij} = \begin{cases} 1, & \text{if the ship } s \text{ pass across the edge } <i, j> \\ 0, & \text{else} \end{cases}$$  

(6)

$$x_{ijk} = \begin{cases} 1, & \text{if aircraft } k \text{ pass across the edge } <i, j> \\ 0, & \text{else} \end{cases}$$  

(7)

$$y_{ijl} = \begin{cases} 1, & \text{if the edge } <i, j> \text{ starting from the tactical node} \\ 0, & \text{else} \end{cases}$$  

(8)

According to the above definition, the problem of task allocation for single-ship multi-carrier aircraft is modeled as follows:

$$\min z = \sum_{k \in K_U, i,j \in V} c_{ij} x_{ijk} + \lambda \sum_{i,j \in V} c_{ij} x_{jis}$$

(9)

$$\sum_{k \in K_U} x_{ijk} = \sum_{k \in K_U} y_{ijl} = 1, \forall j \in V \setminus V_U$$

(10)
The particle swarm algorithm is reasonably introduced into the process of solving the cooperative task assignment model, mainly considering that in the algorithm, each particle can be equivalent to one of our distribution schemes. By analyzing the coexistence of multiple particles, the process of cooperative optimization can find an optimal solution. The key to the formation of cooperative target distribution is to find a suitable way to make the feasible solution of the particle correspond to a distribution scheme.

Through the analysis and comparison of the similarities between the two, the formation of collaborative task allocation decision is mainly to solve the formation of a combat aircraft which combat mission objectives of the problem. We can use the natural number encoding to express the length of the particles in the particle group to indicate the total number of targets to be hit, the particles by the order of the number of aircraft assigned to the number of composition, said a possible distribution program. For example, as shown in Figure 4-3, the number of aircraft n take 8, the
number of targets m take 3. So the first 1, 3, 5 aircraft attack the first goal, the first two aircraft attack the second target, the first 4, 7, 8 aircraft attack the first three goals, the unit range of particles, can guarantee each target must allocate at least one aircraft limit.

**Location and Speed Updating Formula of Discrete Particle Swarm Optimization**

Particles in the flight process, according to the flight experience to adjust the position, and gradually adjust the process is to the optimal position of the process. The location of the particle update is formed by the combined effect of the velocity, the individual extremum and the global extremum interaction. Location update formula consists of three parts, set \( \Psi_i, \Phi_i \) as a temporary variable:

\[
(1) \quad \Psi_i(t) = \omega \otimes F_1(X_i(t)) = \begin{cases} 
    F_1(X_i(t)) & \text{rand}(\cdot) < \omega \\
    X_i(t) & \text{rand}(\cdot) \geq \omega 
\end{cases}
\]

\[
(2) \quad \Phi_i(t) = c_1 \otimes F_2(\Psi_i(t), p_i(t)) = \begin{cases} 
    F_2(\Psi_i(t), p_i(t)) & \text{rand}(\cdot) < c_1 \\
    \Psi_i(t) & \text{rand}(\cdot) \geq c_1 
\end{cases}
\]

\[
(3) \quad X_i(t+1) = c_2 \otimes F_3(\Phi_i(t), p_g(t)) = \begin{cases} 
    F_3(\Phi_i(t), p_g(t)) & \text{rand}(\cdot) < c_2 \\
    \Phi_i(t) & \text{rand}(\cdot) \geq c_2 
\end{cases}
\]

**Algorithm Flow**

1. Initialize \( \omega, c_1, c_2 \) and \( \lambda \) (\( \lambda \) for inertia weight drop rate).
2. Randomly initialize the position of the particles in the particle group and evaluate the performance index of the target distribution scheme as the fitness of the particle.
3. Define \( p_i(t) = X_i(t) \), \( p_g(t) \) represents the position of the best particle in the initial population.
4. Determine whether the algorithm convergence criterion is satisfied, if satisfied, then output \( p_g(t) \), and \( p_g(t) \) the best target allocation program, the algorithm ends; otherwise, the implementation (5).
5. Perform the following operations for all the particles in the population:
   a. update the particle position, and calculate the fitness.
   b. if the particle fitness is better than \( p_i(t) \) then \( p_i(t) = X_i(t) \).
   c. if the particle fitness is better than \( p_g(t) \) then \( p_g(t) = X_i(t) \).
6. Define \( \omega = \lambda \omega \), then turn (4).

The flow of discrete particle swarm optimization is shown in Figure 2.
Simulation and Analysis

Assuming that we have a total of three operations in the range of combat radius, our attack feet is carried out by one ship carrying seven aircrafts. The degree of damage to the various targets of the aircraft and the degree of threat to the target in general before the war by the command of command personnel according to master the information set by themselves. The target value and the probability of aircraft on the target kill are shown in Table 1.

Table 1. Table of Target value and ship/aircraft to target the probability of killing.

|    | v ship | aircraft 1 | aircraft 2 | aircraft 3 | aircraft 4 | aircraft 5 | aircraft 6 | aircraft 7 |
|----|--------|------------|------------|------------|------------|------------|------------|------------|
| target1 | 0.47   | 0.37       | 0.87       | 0.87       | 0.87       | 0.87       | 0.62       | 0.48       |
| target 2 | 0.97   | 0.05       | 0.52       | 0.52       | 0.78       | 0.52       | 0.52       | 0.87       | 0.20       |
| target 3 | 0.76   | 0.01       | 0.11       | 0.11       | 0.11       | 0.21       | 0.11       | 0.70       | 0.42       |

The number of the first line of the table is the number of the aircraft. The number in the first column of the table is the target number, the second column of the table is the value of the target, or the target is the probability of the aircraft’s combat target, or the damage rate to different targets.

The program runs on the Celeron m 1.5G, 512M memory microcomputer. In MATLAB10, the algorithm described in this chapter is simulated by discrete particle swarm algorithm function. Program initialization, read into the table data, and parameters are set as follows:
(1) The number of particles of the population size is 30. (2) Cognitive coefficient $c_1$ and social coefficient $c_2$ are 2. (3) The inertia coefficient $\omega$ between 0.9-0.4 linear value. Figure 3 shows the best solution, the mean solution and the worst solution of the discrete particle swarm optimization algorithm in 60 iterations. The results of the operation are shown in Table 2.

![Figure 3. The convergence curve of discrete PSO.](image)

| target number | target 1 | target 2 | target 3 |
|---------------|----------|----------|----------|
| task management results | ship, aircraft 1, aircraft 2 | aircraft 3, aircraft 5 | aircraft 4, aircraft 6, aircraft 7 |

The optimal benefit value $g_s = 6.4719$ corresponding to this allocation scheme. From the distribution results we can see that we have a better distribution of the results.

**Summary**

In this paper, a mathematical model of joint multi-task management is established, which is based on the discrete particle swarm optimization (PSO) algorithm, and the effectiveness of the method is verified by simulation. The research results can provide theoretical basis and technical support for ship and machine joint command and control.

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