Application of Ant Colony Algorithm to Air Route Planning in Helicopter Submarine Searching

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Abstract. Air route planning system is the core of antisubmarine call-search mission which is carried out by an ASW helicopter, and the efficiency of mission completion is decided by the algorithm adopted. Considering actual army training and combat, this paper analyses the basic elements of responding-antisubmarine air route planning system systematically, constitutes assessment index of air route planning system, presents the constraint conditions which should be considered by the system and carries out simulation calculation by ant colony algorithm. Finally, this paper summarizes the applicable circumstances of responding-antisubmarine air route planning methods based on ant colony algorithm, which will be of great value to improve army combat and training efficiency.

Keywords: Ant colony algorithm; Antisubmarine call-search; Air route planning.

1. Introduction

Aircraft route planning came into being with the emergence of missiles, which was first put forward in the 1950s and developed rapidly. The research on route planning in China started relatively late, and the earliest research on route planning of anti-ship missiles began in the 1990s. Usually, the process of helicopter anti-submarine warfare includes four stages: search, identification, location and tracking or attack. Search is the most important part in helicopter anti-submarine operation. If you can't find the target, you can't attack the target. Search includes three ways: antisubmarine call-search, patrol search and inspection search. Call-search is the most frequently used tactical method in anti-submarine warfare and training. How to improve the efficiency of call-search is an issue of great concern to the army. Currently, there are no published research works and academic papers on helicopter antisubmarine call-search route planning in China. This paper attempts to carry out research in this area, hoping to play a positive role in route planning and improving the efficiency of helicopter submarine search in military training.

2. System composition

Considering the fact that the antisubmarine call-search is widely used in the actual combat training and has more tactical value, this paper takes the helicopter call submarine search route planning as the research object to carry out related research. From the point of view of whether the submarine has been found before carrying out the anti-submarine mission, the call-search means that the information of the
target has been obtained before going to the target area, and based on the small amount of information obtained (a submarine in a certain state is found at a certain approximate location at a certain time, there may be information such as the course and speed of the submarine, etc.), so that after the anti-submarine helicopter arrives in the target area, it will search and locate again. Therefore, the task of helicopter antisubmarine call-search route planning system is to find the optimal flight path from the initial point to the target point and meet the certain index requirements under specific constraints conditions.

Helicopter antisubmarine call-search route planning system can be divided into two parts: software and hardware. The hardware can be composed of various general-purpose or special-purpose computers and related peripherals. The software is an important part of the system to realize its function, which determines the completion of the helicopter route planning task. Helicopter antisubmarine call-search route planning system is mainly composed of the following aspects:

2.1. Geographic Information
Geographic information is the most important basic information for helicopter route planning. In order to ensure the normal and safe flight of the helicopter, the geographic information must be taken into account when the helicopter is flying, and its accuracy determines whether the route designed by the planning algorithm is reliable or not. Geographic information is static and constantly changing digital map, which can be obtained from the map database. Since the flight area of helicopter submarine search is mainly at sea, the digital chart is selected as the reference geographic information database. The format of the digital map describing geographic information in the database also affects the performance of route planning, so different route planning needs to prepare a special data format.

2.2. Battlefield Situation Information
Battlefield situation information is to obtain real-time situation information on the battlefield from the combat system, which mainly includes the deployment of enemy forces, enemy firepower distribution, enemy combat system detection area, strategic evasion area and so on. It not only provides the possible obstacles or dangers of the helicopter in the submarine search route, but also helps to analyze the threat cost, and provides a strong support for the establishment of a reliable and safe anti-submarine route.

2.3. Information Model Description
The description of the information model is the concrete embodiment and application description of the above two important components in the program. It properly describes the geographic information and battlefield situation information, so that the performance and response speed of the system can be made to the best state. For example, in the design of the main program, the enemy radar search threat area is represented as a circle (two-dimensional space, in three-dimensional space can be described as a hemisphere), Despite the fact that the curvature of the earth and obstacles such as islands to block the radar search area, because the environment we are facing is over the sea surface, we can ignore the terrain blocking the radar signal. At the same time, the influence of the curvature of the earth can be ignored in order to more visualize and facilitate the description of the curvature of the earth. This paper will describe the appropriate information according to the specific situation of helicopter anti-submarine route planning.

2.4. Route Planning Algorithm
Route planning algorithm is the core of helicopter antisubmarine call-search route planning, and its method selection will directly determine the performance level of the whole system. The common algorithms suitable for route planning are simple route planning, SAS algorithm, genetic algorithm, ant colony algorithm and improved particle swarm optimization algorithm and so on. When selecting the helicopter antisubmarine call-search route planning algorithm, it is necessary to consider many aspects, such as whether the algorithm can properly describe the route planning information, the degree of difficulty of implementation of the algorithm, the way the algorithm is applied, and whether the algorithm can be further optimized. It is also necessary to fully consider the complex battlefield
environment and the requirements for algorithm efficiency when the helicopter carries out the antisubmarine call-search mission. Through the research and comparison of these algorithms, this paper attempts to use ant colony algorithm to plan the helicopter antisubmarine on-search route.

In addition to the above contents, the helicopter antisubmarine call-search route planning system should also include situation information analysis, pre-selection scheme design, experience effect evaluation optimal scheme selection and so on, and its composition is shown in figure 1.

3. Evaluation index
For anti-submarine helicopters, the time of antisubmarine call-search missions usually includes training, exercises, operations and so on. In any case, the actual searching effect is the only criterion to evaluate the merits and demerits of the submarine search route planning system, which can be divided into tactical effect index, range index, safety index and flight time index.

3.1. Tactical Effectiveness Index
The tactical effect indicator is the most concerned issue for the commander, which directly affects the success or failure of the submarine search mission, and requires the anti-submarine helicopter to reach the target area in the most scientific and reasonable way. The main influencing factors are the range of submarine search equipment mounted by the anti-submarine helicopter, the movement speed and direction of the target and the necessary tactical maneuver, namely:

\[ H_E = F_m(r_{ss}, \alpha_{ss}, v_{ms}, x_{ms}, y_{ms}, z_{ms}) \]

In the formula, \( H_E \) is the tactical effect index, \( r_{ss} \) is the range of the submarine search equipment, \( \alpha_{ss} \) is the sector angle search, \( v_{ms} \) is the target velocity, \( (x_{ms}, y_{ms}) \) as the target coordinates, \( z_{ms} \) as the necessary tactical maneuver factors adopted by the anti-submarine helicopter.

3.2. Range Index
The range index is used to reflect the total distance of the anti-submarine helicopter from the mother ship or base to the target search area. In general, it is hoped that the submarine search flight of the anti-submarine helicopter should be as short as possible, because the long flight will naturally shorten the submarine search time in the target area, and also give the enemy submarine more time to escape, which will directly affect the submarine search efficiency of the anti-submarine helicopter. Moreover, if the flight range is too long, the probability of being detected by enemy radar, early warning aircraft and other detection equipment will also increase. At the least, it will delay the plan of action, at the worst it will be attacked by enemy. This index is very important for the anti-submarine helicopter. The range
The safety index is related to the number of key points, turning radius, turning angle and other factors on the helicopter flight path, namely:

$$H_D = \sum_{i=1}^{n-1} f(d_i, \alpha_i, r_i)$$

In the formula, $n$ is the number of key points on the route; $f(d_i, \alpha_i, r_i)$ is the flight distance between the “i” waypoint after the turning radius is taken into account and the “i + 1” key point of route, $d_i$ is the distance between the two key points of route, $\alpha_i$ is the turning angle of the ith waypoint, $r_i$ is the turning radius at the ith waypoint. Because $f(d_i, \alpha_i, r_i)$ is a nonlinear function, $S_D$ is also nonlinear.

### 3.3. Safety Index

The safety index is used to reflect the danger degree of the helicopter flying according to the planned route in the process of anti-submarine warfare. Usually, the threat to the helicopter caused by the enemy threat area and terrain factors due to the flight navigation azimuth deviation or the failure to update the enemy and our situation information and geographic information in time, this is the primary factor to be considered in anti-submarine operations. Considering the possibility of the helicopter falling into the sea due to sea conditions or operation, the safety index can be described as follows:

$$H_S = P_S \cdot \prod_{n=1}^{m} (P_{D_n} + P_{D_n} \cdot P_{K/D_n})$$

In this formula: $P_S$ is the survival probability of the task, $P_D$ is the capture probability of the enemy detector, $P_{D_n}$ is the probability of not being detected by the enemy detector, $P_{K/D_n}$ is the probability of being detected but not shot down, $P_C$ is the probability of not falling into the sea, $m$ is the number of times the helicopter passes through the threat zone.

### 3.4. Flight Time Index

The flight time index is used to reflect the time when the anti-submarine helicopter arrives at the target submarine search area according to the predetermined route. In general, the flight time index to be as small as possible. If the flight time is too long, the target submarine will be given more time to maneuver and escape, and the scope of submarine search will be expanded, which is not allowed in anti-submarine warfare. Therefore, it is an important index to be considered in the process of route planning of anti-submarine helicopter. Flight time is related to flight speed curve and flight distance, namely:

$$H_t = \int_{h}^{s} \frac{1}{v(h,s,c)} \, ds$$

In the formula, $v(h,s,c)$ is the flight speed curve of the helicopter; “h” is the flight altitude of the helicopter; “s” is the flight distance of the helicopter; “c” is the comprehensive influence of environmental factors such as sea conditions on the flight speed of the helicopter.

What should be considered in the planning process of helicopter call-search route is not only the optimization of a certain index, but also the weighing of advantages and disadvantages among these important indexes. According to the specific situation and requirements, the weight ratio of each index in the whole route process of route planning should be weighed to select the optimal route. It should be noted that there is a certain connection among these indicators. For example, when the range index is large, its flight time will also be affected, after all, the speed of the helicopter is limited. Therefore, when setting the weight, there is no need to set the two indicators larger at the same time.

### 4. Constraint conditions

When evaluating the helicopter anti-submarine call-search route, only the evaluation index will likely be in imbalance condition, so the environment in which the helicopter carries out the mission and its own characteristics must also be taken into account. In other words, the constraints of threats, tactics, maximum range and maneuverability must be taken into account.

#### 4.1. Threat Constraint

Threat constraint is a very important constraint for helicopter anti-submarine call-search route planning. In route planning and design, threats are dynamic constraints that change with time. The main threat sources faced by anti-submarine helicopters are radar, air defense equipment, surface ships, and enemy
fighters in the air. Since threats must be avoided in the process of carrying out the mission, this constraint is also summed up as an impenetrable obstacle area, and its area is appropriately expanded in the specific experimental simulation. In order to ensure the serious adverse consequences of the anti-submarine helicopter mistakenly entering the threat area due to the cumulative deviation in the process of carrying out the mission.

Suppose the set of all fire threat zones and designated no-fly zones in the process of the helicopter leaving the mothership or land-based flight to the search area is \( R \), \((x, y, t)\) representing the longitude and latitude coordinates at any point of the air route curve \( x, y, t \) is the helicopter’s flight time. The terrain and threat constraints in the planning area can be described as

\[ \forall x, y, t, f(x, y, t) = 0 \quad (x, y) \notin R \]

4.2. Tactical Constraints

In the actual anti-submarine operations, the time from the discovery of the target to the disappearance of the target is usually relatively short, which requires that the anti-submarine helicopter must search the target with the highest efficiency. Therefore, the tactical constraint is an important factor in whether the anti-submarine helicopter can search the submarine.

1) The direction and position constraints of entering the search area

For anti-submarine helicopter search, when entering the search area along different directions, the probability of the target being found is different, which results in the corresponding target dispersion probability model is also different. Furthermore, the anti-submarine helicopter is required to search the submarine along different directions and in accordance with different submarine search methods, that is, to restrict the entry direction and position of the anti-submarine helicopter in the search area, that is, to restrict the entry direction and position of the anti-submarine helicopter in the search area:

\[ |H_S - H(X_f, Y_f, X_t, Y_t)| \leq D_H \]

In the formula, \( H_S \) is the pre-determined direction of entry; \((X_f, Y_f)\) and \((X_t, Y_t)\) represent the latitude and longitude coordinates of the last route point of the helicopter and the target submarine when they are found; \( D_H \) is the maximum deviation of the allowed entry direction.

2) Time constraints

In the process of carrying out submarine searching mission, in many cases, the time to arrive at the predetermined sea area is constrained, especially in the multi-aircraft, warship-aircraft coordination operation demands more constraints. In this process, weather, environment, speed and airway track are all factors that affect time. If the time is too long, it will give the target submarine more escape time and increase the difficulty of searching submarine. Therefore, it is required to plan the route as reasonably as possible to ensure the efficiency of searching submarine.

4.3. Maximum Range Constraints

For the anti-submarine helicopter, the aviation fuel it carries is limited, and it has to carry out anti-submarine operation in the target area for quite a period of time. Therefore, in the process of air route planning, it is required that the air route it designs should not be too long. If airway points are set for route planning, the sum of total distance between nodes of each segment should not be too long, and the range constraint is:

\[ J_c \leq L_{max} \]

In this formula, \( J_c \) is the range index of a certain air route; \( L_{max} \) is the maximum allowed by the fuel consumption indicator.

For an air route with \( N \) route points (including initial point and target point), its range constraint can be expressed as

\[ J_S = \sum_{i=1}^{n} L_{i-1} \leq L_{max} \]

In this formula, function \( L_{i-1} \) represents the distance between two adjacent waypoints.
4.4. Minimum Turning Radius
The minimum turning radius is the maximum ability value considering the helicopter's heading turning maneuver horizontally. It mainly considers the influence of the threat zone and the maneuver for searching and tracking in time when the target submarine conducts a sharp maneuver. The two key points of the airway should be set as follows:

\[ |K_A K_B| \leq 2r_{\text{min}} \cdot \sin \theta \quad \text{turning when go through the point} \]
\[ |K_A K_B| \geq r_{\text{min}} \tan \theta / 2 \quad \text{no turning when go through the point} \]

In this formula, \(|K_A K_B|\) is the distance between two key points of the passage, which can be obtained by Bowring formula; \(\theta\) is the angle of turn; \(r_{\text{min}}\) is the minimum turning radius.

4.5. Other Constraints
In addition to the above factors, such as aviation control zone, no-flying zone and flight restriction zone of a third country are also important factors to be considered. These factors are rarely involved in daily training, but considering the needs of shipborne anti-submarine helicopters for ocean training and combat missions, the above situations also need to be considered. For the convenience of simulation, these factors are simplified and regarded as the obstacle model of threat zone in the simulation route planning and design.

5. Simulation analysis
The process of helicopter antisubmarine call-search route planning is as follows: first, to get the enemy submarine's general location and relative position of our helicopter from data link or other ways, then obtain the map information, battlefield situation information and other area location information of other factors such as no-fly zone that cannot be leaped from the data link or internal storage. The no-fly zone map needed by the algorithm program is obtained by analyzing and processing these information, and no-fly zone in the diagram is enlarged appropriately. Finally, the optimal route is obtained through the route planning algorithm and shown to the pilot to guide the pilot to fly quickly to the target sea area for submarine search. The following part introduces how to use ant colony algorithm to plan the helicopter antisubmarine call-search route.

5.1. Ant Colony Algorithm
Ant Colony Optimization (ACO), also known as Ant algorithm, was proposed in 1992 and widely used in bionics algorithm to find the optimal path. The algorithm uses seven rules in the ant's life: search range, environment, foraging, movement, obstacle avoidance and pheromone dispersal to find the optimal solution. These rules are the characteristic rules of the ant colony algorithm and the basis of the ant algorithm to find the optimal route.

Ant colony algorithm has the following characteristics:

1) It is a self-organizing algorithm. That is, an algorithm in which the system is dominated by the algorithm and has no external factors, and the elements of the system will make the system tend to a stable state with the passage of time and the algorithm.

2) It is an algorithm capable of fast and parallel computation of large-scale data. The algorithm can perform parallel computing search and has strong reliability and global character.

3) Positive reinforcement feedback. The key reason why this algorithm can find the optimal path is that with the superiority of the optimal path, pheromones on the path are strengthened continuously, so that more ants can pass through this path, and then more pheromones can be formed and positive feedback can be formed. This is also the key feature of the algorithm.

4) Strong adaptability and reliability. The algorithm has strong adaptability and can be migrated quickly with only a few changes of parameters and model description.
5.2. **Applicability Analysis**

Ant colony algorithm (ACO) has strong reliability and adaptability in the ability to find the optimal solution, and has the parallelism, and can carry out parallel search processing on a relatively large scale at the same time. Therefore, the algorithm has been widely applied in the optimization and other aspects, especially in the air route planning. However, this algorithm also has some shortcomings. For example, in parameter setting, this algorithm is sensitive to parameter setting when dealing with different problems. Improper parameter setting will lead to problems such as slow convergence speed and easy to fall into local optimum. However, these shortcomings can be overcome. The diversity of this algorithm ensures that the ant colony algorithm can comprehensively search for possible optimal solutions, and can better find the full optimal solution, so as not to fall into the local optimal or dead-cycle state. Moreover, the positive feedback property of the algorithm ensures that excellent subgroups are preserved and highlighted.

Considering the advantages and disadvantages of the algorithm, the application characteristics and the actual environment, the algorithm is adopted for simulation verification.

5.3. **Simulation Verification**

In the design process of ant colony algorithm, in order to adapt to the rule of searching the path of the algorithm, specific map information is displayed by grid diagram, and the no-fly zone is also enlarged appropriately. The specific load map data can be either randomly generated map matrix information or TXT document matrix loaded. Fig. 2 shows the algorithm flow of applying ant colony algorithm to plan the helicopter's call search submarine route.

![Ant colony algorithm flow chart.](image)

In this algorithm, the genetic algorithm function of the main function call is:

function $[\text{ ROUTES}, \text{ PL}, \text{ Tau } ] = \text{ yiqun} (G, \text{ Tau }, K, M, S, E, A, B, R, Q)$

Through many experiments, suitable path function parameters were found. Parameters of G, K, M, A, B, R and Q were set respectively. Tau was set by changing the battlefield environment needed to be used. For the convenience of pilots, the start point S and target point E are still set using the NORTHEAST coordinate system. On this basis, the route is planned and designed in order to achieve the best effect.
At the same time, the space proportion of the generated no-fly zone in the total geographic information map can be changed by adjusting the parameter value, so as to realize the setting of the initial battlefield environment. The ROUTES were generated by calling the ACO function ‘function [ROUTES, PL, Tau] = ant colony (G, Tau, K, M, S, E, A, B, R, Q)’. The route effect generated by this method is shown in Fig. 3. However, there are drawbacks, because the generated no-fly area is random, it may cover the starting point or target point, and the correct flight path cannot be generated.

![Fig. 3 Air route planning generated by random no-fly zone](image)

When TXT document matrix is loaded, the main function loads the combat environment information by loading TXT file. In practical application, the data can also be loaded by changing the type of loading information, so as to realize the purpose of real-time route planning in wartime. The renderings are shown in Figure 4 and Figure 5.

![Fig. 4 Optimal route diagram of TXT combat environment matrix loaded](image)

![Fig. 5 Route planning diagram of TXT combat environment matrix loaded](image)
set reasonably, the simulation program takes about 10s and the speed is very fast. When the parameter setting is close to the limit value, the simulation program takes about 45s and the speed is slow.

2) Set the number of ants at 100. After the enlargement of the map information, find the optimal path in the matrix graph of 84*84, the number of iterations is 50 (when the number of ants is 50, it is also 50), the time is more than 1000s, and the planning efficiency becomes worse obviously.

6. Conclusion
By using ant colony algorithm to carry out simulation calculation on the planning of the helicopter call-search route, the results show that:

1) In the case of the map information is not enough, the planning effect and system computing speed of helicopter response-type submarine route based on ant colony algorithm can better meet the requirements of combat and training. That is to say, it is more effective to use ant colony algorithm to plan the helicopter response submarine route under the general sea situation, in the non-belligerent environment to carry out submarine search mission or in the general enemy naval force under belligerent environment.

2) In the case of a large amount of map information, that is to say, when the sea conditions in the area where the called submarine search is conducted are relatively complex or the local sea forces are relatively strong, both the effect of route planning and the operation speed of the system will become worse, which is not suitable for the requirements of operations and training.

Therefore, it is necessary to fully consider the actual situation to make a reasonable choice in the algorithm selection of called submarine search, and pay attention to the filtering of battlefield information and necessary simplification to improve the planning efficiency without affecting the efficiency of submarine search.

References
[1] Xiaofang Xie, Tao Sun, Zhonghui Ouyang, Anti-ship Missile Route Planning Technology, Beijing: National Defense Industry Press, 2010, pp.6–17.
[2] Shengyun Zhang, An Zhang, Lizhu Wang, “Research on submarine Search Method for Anti-Submarine Aircraft,” Firepower and Command control, China, vol. 1, pp. 71–74, 2006.
[3] Genyuan Yang, Fuchu Wu, Guoqing Zhou, “Operational Application of sonobuoy in anti-submarine Helicopter call search,” Journal of Naval Aeronautical Engineering Academy, China, vol. 5, pp. 370–372, 2004.
[4] Cheng Xu, Jie Zhao, Youhong Yuan, “Submarine Combat Environment and Countermeasures Analysis” Ship Electronic Engineering, China, vol. 10, pp. 8–11, 2011.
[5] Xiaoqiang Cheng, “Research on Tactical Mission Planning System”. Master thesis of Beijing University of Aeronautics and Astronautics, 2004, pp. 45-76.
[6] Wen Ye, Hongda Fan, Aihong Zhu, “Unmanned Aerial Vehicle Mission Planning,” Beijing: National Defense Industry Press, 2011, pp. 27-36.
[7] Ming Huang, Changsheng Jiang, “Research on Flight path Planning and Trajectory Control of attack helicopters,” Master thesis of Nanjing University of Aeronautics and Astronautics, 2004, pp.10-11.
[8] Wenfeng Cao, Qingyu Xiong, “Research on Flight Path Planning of Aircraft Based on improved Ant colony Algorithm,” Master’s Thesis of Chongqing University 2017, pp.7-16.
[9] Ye wen, hongda Fan, “Aircraft low-altitude penetration route planning based on improved ant colony algorithm,” Flight mechanics.2004,5(2):98-101. China, vol. 2, pp. 8–11, May 2011.
[10] Gong Yingying, Xu Feng, “Study on improvement and Application of Ant colony algorithm,” Master thesis of Anhui University of Science and Technology, 2014, pp. 4-10.