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Algorithm for Low Altitude Penetration Aircraft Path Planning with Improved Ant Colony Algorithm

YE Wen, MA Deng-wu, FAN Hong-da
(Department of Ordnance Science and Technology, Naval Aeronautical Engineering Institute, Yantai 264001, China)

Abstract: The ant colony algorithm is a new class of population basic algorithm. The path planning is realized by the use of ant colony algorithm when the plane executes the low altitude penetration, which provides a new method for the path planning. In the paper the traditional ant colony algorithm is improved, and measures of keeping optimization, adaptively selecting and adaptively adjusting are applied, by which better path at higher convergence speed can be found. Finally the algorithm is implemented with computer simulation and preferable results are obtained.

Key words: ant colony algorithm; path planning; keeping optimization; adaptively adjusting; low altitude penetration

基于改进蚁群算法的飞机低空突防航路规划. 叶文, 马登武, 范洪达. 中国航空学报(英文版), 2005, 18(4): 304-309.

摘 要: 蚁群算法是一种新型的基于群体的仿生算法。采用蚁群算法实现了飞机低空突防的航路规划, 为航路规划问题提供了新的解决思路。并对原始蚁群算法进行了改进, 提出了保留最优解、自适应选择策略和自适应信息素调整准则, 有效地提高了算法的收敛速度和解的性能。最后用计算机进行了仿真, 取得了较好的结果。

关键词: 蚁群算法; 航路规划; 保留最优解; 自适应搜索; 低空突防

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Path planning is to search the optimal movement track from start place to goal place which satisfies certain capability in the special restricted condition and space. The flight path planning is very important for the improvement of mission survivability and success ability of the aircraft. In the course of TF/TA^2 (terrain Following/Terrain Avoidance/Threat Avoidance), it is necessary to do flight path planning[1, 2]. The flight path planning in a large mission area is a typical large-scale optimization problem, a series of algorithms such as the A* search, the potential theory. Those methods do not solve the contradiction between the global optimization and excessive information. This paper uses the ant colony algorithm to optimize the flight path. In this paper, the ant colony algorithm is improved properly, and measures of keeping optimization, adaptively selecting and adaptively adjusting are applied in order to make the ant colony algorithm adapted well to the flight path planning. At last, the optimized flight path is searched by the cooperation of ant colony.

1 Ant Colony Theory

The ant colony approach is based on the behavior of real ant searching for food. Real ants communicate with each other using an aromatic essence called pheromone, which they leave on the paths they traverse. In the absence of pheromone trails ants more or less perform a random walk. However, as soon as they sense a pheromone trail on a path in their vicinity, they are likely to follow that path, thus reinforcing this trail. More specifically, if ants at some point sense more than one pheromone trail, they will choose one of these trails with a probability related to the strengths of the existing trails. This idea has first been applied to the TSP, where an ant located in a city choose the

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next city according to the strengths of the artificial trails[3,4].

In artificial terms the optimization method uses the trail following behaviour described above in the following way. Ants construct solutions by making a number of decisions probabilistically. In the beginning there is no collective memory, and the ants can only follow some local information. As some ants have constructed solutions, pheromone information is built. In particular, the quantity of pheromone deposited by the artificial ants depends on the solution quality found by the ants. This pheromone information guides other ants in decision making, *i.e*, paths with high pheromone concentration. On the other hand, the pheromone deposited is not permanent, but rather evaporates over time. Thus, over time, paths that are not used will become less and less attractive, while those used frequently will attract ever more ants.

2 Problem Statements

2.1 Environments and path statements

In the mission area shown in Fig. 1, the flight mission is flight A to B at low altitude. Let the distance between A and B be L, the width be $2C$, then the possible flight paths must lie in the rectangle area. The fixed threat areas such as radars and anti-air missiles are described as circles, the radii of which are their functional areas. Define the coordinate. Let point A be the initial point, line AB be the x axis, the vertical line to AB be y axis. Line AB is divided into n equal parts, and the vertical line to AB at each part point is created. Lines L_1, L_2, …, L_{m-1} are given. Then each vertical line is divided into $2n$ equal parts, and there are $2n+1$ points in each vertical line. At last, there are $(m-1)\times(2n+1)$ path points in the mission area, such as

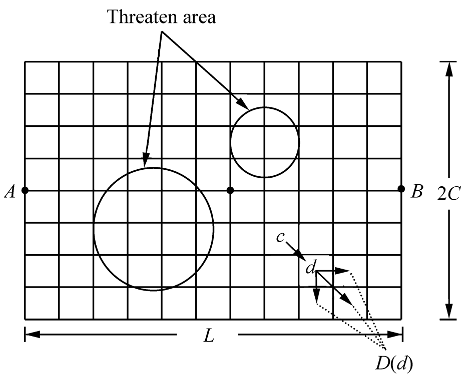

Fig. 1 Aircraft mission area

$L_1(x_1, y_1), L_1(x_1, y_2), \cdots, L_1(x_1, y_{2n+1}),$

……

$L_{m-1}(x_{m-1}, y_1), L_{m-1}(x_{m-1}, y_2), \cdots, L_{m-1}(x_{m-1}, y_{2n+1})$

where $L_i(x_i, y_j)$ is point j in the vertical line i. So the path from start point to goal point can be denoted as follows:

$$\text{Path} = \{A, L_1(x_1, y_{k1}), L_2(x_2, y_{k2}), \cdots, L_{m-1}(x_{m-1}, y_{k(m-1)}), B\}(k_i = 1, 2, \cdots, 2n+1) \tag{1}$$

2.2 The cost function of the fight path

First define the cost function of the low altitude penetration. The mission survival probability is a function of the probabilities of not being detected by enemy radar, not being killed if detected, and not crashing against the terrain, so a cost function is used in this paper,

$$j = \int_0^{\tau_h}(w_1 c^2 + w_2 h^2 + w_3 f_{\tau_h})\,\mathrm{d}t \tag{2}$$

where the first term penalizes the large cross-track deviations from the line connecting the start and target points, the second term penalizes the penetration paths that come dangerously close to known threat sites, and the third term minimizes the aircraft's altitude above level h.

In this paper, only the horizontal path optimization is considered, so the cost function can be simplified to contain only the forenamed two terms[5]:

$$J = L_k + \delta\sum_{i=1}^{m-1}\frac{1}{d_{i\min}} \tag{3}$$

where L_k is the flight distance, $d_{i\min}$ is the distance from the node to the nearest threat, δ is the threat avoided coefficient and δ is more bigger and more safer for the flight.

The flight distance is showed to be the sum of line distances between nodes in the flight line. The distance from node $a(x_i, y_g)$ in vertical line L_i to node $b(x_{i+1}, y_j)$ in vertical line L_{i+1} can be described as $d_{ab} = \sqrt{\left(\frac{|AB|}{m}\right)^2 + (y_j - y_g)^2}$ $(j, g =$

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$1, 2, \cdots, 2n+1$). So the flight distance can be described as follows:

$$L_k = \sqrt{\left(\frac{|AB|}{m}\right)^2 + (y_{ki} - 0)^2} + \sum_{ki=1}^{m-2} \sqrt{\left(\frac{|AB|}{m}\right)^2 + (y_{k(i+1)} - y_{ki})^2} + \sqrt{\left(\frac{|AB|}{m}\right)^2 + (y_{k(m-1)} - 0)^2} \qquad (4)$$

Suppose that there are q threats every of which is described by a circle with the centre point (x_j, y_j) and the radius r_j, the distance between the node (x_i, y_{ki}) and the threat j can be described as $d = \sqrt{(x_i - x_j)^2 + (y_{ki} - y_j)^2} - r_j$. So the distance between the node (x_i, y_{ki}) and the nearest threat can be described as follows:

$$d_{i\min} = \min\{(\sqrt{(x_i - x_1)^2 + (y_{ki} - y_1)^2} - r_1), \cdots, (\sqrt{(x_i - x_q)^2 + (y_{ki} - y_q)^2} - r_q)\} \qquad (5)$$

3 The Algorithm Realization

Firstly, the original pheromone matrix T is formed by giving the appropriate original value in all nodes in the grid map of the mission area. Suppose that the original value of node in the threat area is zero, and the original value of other node is a constant C, so that ants can not reach nodes in the threat area because there is no pheromone. Ants only can search in the safe area, and the path searched by this way can well avoid the threat area. Then all ants are placed at the start point, and simultaneity go to the goal point together, and reach the goal point at last. In the process each ant chooses the next node by which the ant maybe can reach in the next vertical line by state diversion rule. When the ant chooses the next nodes, some enlighten rules can be adaptively added to this rules. Such as, nodes at which the change of flight direction is little in the condition of the same value can be chosen. Suppose that the time spent from one node in the line L_i to the random node in the line L_{i+1} by the flight is the same, having no relation with distance, all ants will reach the goal point at the same time, and simultaneity complete one cycle. After all ants reach the goal point, the whole pheromone in all nodes will be updated based on the cost function of the viable flight path which is searched by each ant, and the pheromone in the node which the ant can not reach only is evaporated. Repeat this process until the optimization flight path is searched.

3.1 The rule of choosing node

Ants move to the vertical line L_i at time t. Suppose that ant k is at point $a(x_i, y_g)$, and b_j ($j = 1, 2, \cdots, 2n+1$) is a node on the line L_{i+1}, and $\tau_{ab}(t)$ denotes the remained pheromone at the node b at time t. In the course of the movement, ant k chooses the diversion direction through the pheromone on the line. $P_{kab}(t)$ denotes the diversion probability for ant k from position $a(x_i, y_g)$ to position $b(x_{i+1}, y_j)$ at time t,

$$p_{kab} = \begin{cases} \dfrac{\tau_{ab}^{\alpha}(t)\,\eta_{ab}^{\beta}(t)}{\sum \tau_{ab}^{\alpha}\eta_{ab}^{\beta}(t)} & b \in \text{the safe area} \\ 0 & b \in \text{the threat area} \end{cases} \qquad (6)$$

where η_{ab} denotes the visibility on the line ab, α denotes the relative significance of the pheromone ($\alpha \geqslant 0$), and β denotes the relative significance of the visibility ($\beta \geqslant 0$). The visibility η_{ab} is the reciprocal of the distance from point a to point b, that is, $\eta_{ab} = 1/d_{ab}$.

3.2 The rule of adjusting pheromone

Ants determine the next point by computing the probability of reaching each next node using the state diversion rule. Repeat this process, until the goal point B is searched. In the course of a circle, the pheromone of all nodes in the grid map is updated using the whole update rule after all ants search viable paths. The pheromone of the node passed by ants is updated by the whole update rule, and the pheromone of other node is only evaporated. $\tau(j)$ denotes the remained pheromone at the node b at time t. The whole update rule is showed as follows:

$$\tau(j) = (1 - \rho)\tau(j) + \rho\Delta\tau(j) \qquad (7)$$

where ρ is the evaporation gene of the pheromone ($0 < \rho < 1$), and $\Delta\tau(j)$ is the whole update gene,

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which is determined by the following formula:

$$\Delta\tau(j) = \sum_{k=1}^{h}\Delta\tau_k(j)\ \Delta\tau(j) = \sum_{k=1}^{h}\Delta\tau_k(j)$$

where h is the sum of ants, and

$$\Delta\tau_k(j) = \begin{cases} \dfrac{Q}{J_k} & \text{ant } k \text{ passes node } j \\ 0 & \text{otherwise} \end{cases}$$

where Q is a constant, and J_k is the cost function of the viable path which ant k searches in this cycle.

3.3 The improvement of the algorithm

The results of imitation show that the ant colony algorithm can availably solve the problem of the path planning and the results correspond to those of the genetic algorithm. But in the course of imitation, it is found that the traditional ant colony algorithm as other bionics algorithm also has bug. The traditional ant colony algorithm often converges at the local least value and the convergence speed is slow. In order to overcome these bugs, enhance the whole search capability and quicken the convergence speed, and the traditional ant colony algorithm is improved.

(1) The reserve of the best solution

In the end of every circle, the best solution is searched and reserved.

(2) The rule of adaptively choosing node

In the course of constructing solution, the traditional ant colony algorithm adopts random choosing rule by the probability, and this rule makes the evolution speed slow. The positive feedback theory aims at strengthening the better solution, but the stagnation phenomena is easy appeared. So the choosing rule is adjusted. The determinate choice and random choice are combined, and the probability of the determinate choice in the course of the search is dynamically adjusted. After the certainty times, the direction of search is already ascertained. Then properly increasing the probability of the random choice will benefit more absolute search for the whole space. And it effectively overcomes the shortage of the traditional ant colony algorithm[6].

Ants move to the vertical line L_i at time t. Suppose ant k at point $a(x_i, y_g)$, the next node which the ant k will reach at the next time is confirmed by following formula:

$$j = \begin{cases} \max\limits_{u \in \text{the safe area}} \{\tau_{au}^{\alpha}(t)\,\eta_{au}^{\beta}(t)\} & r \leqslant r_0 \\ \text{choose } b \text{ through the probabiliy } p_{kab}(t) & r > r_0 \end{cases} \tag{8}$$

where r is a random number equally distributing at $(0, 1)$, $r_0 \in (0, 1)$. With the progress of search, the value of r_0 can be dynamically adjusted. By this improvement, it not only can quicken the convergence speed and save the searching time, but also can overcome the premature appearance of stagnation conduct. It is in favor to find better solution. It is very available for the large scale optimizing problem.

(3) The rule of adaptively adjusting whole pheromone

When the problem scale is relatively large, because of the existence of pheromone evaporation gene ρ, the pheromone at those nodes never searched will be decrease and close to zero, which reduces the whole search ability of ρ algorithm. When ρ is very small, the possibility that the solution searched is chosen repeatedly becomes very big, and the whole search ability of algorithm is affected.

The whole search ability of algorithm can be enhanced through increasing the value of ρ, but at the same time it reduces the convergence speed of algorithm. So in this paper the value of ρ is adaptively changed with the initial value of 0.1. When the best solution is not changed in evidence, ρ is increased as follows:

$$\rho = \begin{cases} 1.05\rho(t-1) & \rho \leqslant \rho_{\max} \\ \rho_{\max} & \rho > \rho_{\max} \end{cases} \tag{9}$$

where $\rho_{\max}$ is maximum, by which the decline of the convergence speed which the great value of ρ causes is prevented.

3.4 The process of the algorithm

The process of searching the optimized path for the plant with the ant colony algorithm is as follows.

(1) Initialize the pheromones of all nodes in

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the grid map, and form the original pheromone matrix $\boldsymbol{T}$;

(2) M ants are placed at the start point waiting for start off;

(3) Every ant chooses the next node in the grid map based on the diversion rule, and reach the goal point and form one viable path at last;

(4) Compute the cost function of viable path searched by every ant, and save the optimized solution;

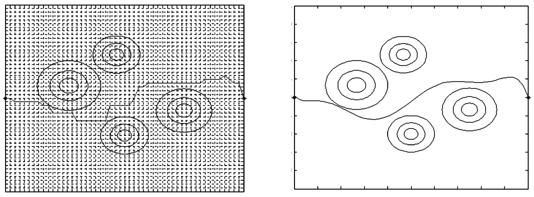
(5) Adjust the pheromone of every node based on cost function according as pheromone adjusting rule.

(6) Examine the optimized solution, and decide if pheromone evaporation gene ρ needs to be adjusted. If it needs, the pheromone evaporation gene ρ will be adjusted according to Eq. (9).

(7) Judge if it satisfies the iterative condition. If it satisfies, the process is completed. If it not, the process will be implemented again until it satisfies the condition.

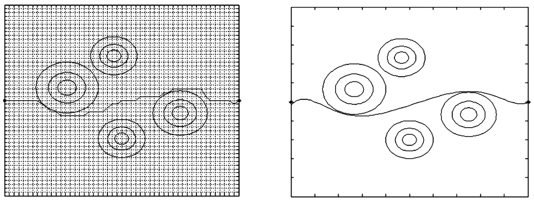
4　Experiments

In this section, some results obtained in simulation using the ant colony algorithm described previously are illustrated. Suppose that there are four threats in the aircraft mission area simplified by circle. The path start point is set A, and the goal point is set B. The parameters of the ant colony algorithm are determined by experiment, that is, $\alpha = 3$, $\beta = 3$, $Q = 100$. 20 ants are placed at the start point, and the traditional ant colony algorithm and the improved ant colony algorithm are imitated respectively. The results of the imitation are as follows. The optimal path and its inosculated path are obtained by the traditional ant colony algorithm in Fig. 2(a) and Fig. 2(b), in the condition that the value of ρ is constant 0.2 and the value of δ is 0.1. The optimal path and its inosculated path are obtained by the improved ant colony algorithm in Fig. 3(a) and Fig. 3(b), in the condition that the initial value of ρ is 0.1, the initial value of r_0 is 0.7 and the value of δ is 0.1. The optimal path and its inosculated path is obtained by the improved ant colony algorithm in Fig. 4(a) and Fig. 4(b), in the condition that the initial value of ρ is 0.1, the initial value of r_0 is 0.7 and the value of δ is 0.9. The results of imitation show that this algorithm can effectively solve the path planning, and improve the adaptability of the plant for the diversified material problem, because different optimized paths are gained by adjusting the threat avoided coefficient.



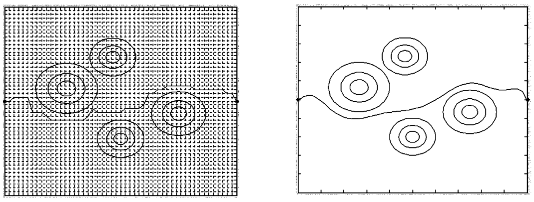
(a) optimal path by the traditional ant colony algorithm (ρ=0.2, δ=0.1)　(b) inosculated optimal path (ρ=0.2, δ=0.1)

Fig. 2



(a) optimal path by the improved ant colony algorithm(ρ=0.1, r_0=0.7, δ=0.1)　(b) inosculated optimal path (ρ=0.1, r_0=0.7, δ=0.1)

Fig. 3



(a) optimal path by the improved ant colony algorithm(ρ=0.1, r_0=0.7, δ=0.9)　(b) inosculated optimal path (ρ=0.1, r_0=0.7, δ=0.9)

Fig. 4

5　Conclusions

The paper discusses the problem that the low altitude penetration path of the plane is planned with the ant colony algorithm. The results of the imitation show that the optimized available solution is gained through the ant colony algorithm, and a

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new method for the route planning is provided. In this paper the original ant colony algorithm is improved, and measures of keeping optimization, adaptively selecting and adaptively adjusting are applied, by which the better path at higher convergence speed can be found. The study of the ant colony algorithm start just now, and there are many questions waiting for solving, but the results of the imitation show that the ant colony algorithm has the favorable foreground in the aspect of solving the optimize path problem.

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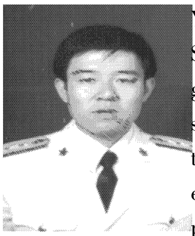

YE Wen Born in 1979, he received B. S. and M. S. from Naval Aeronautic Engineer Academy in 2001 and 2004 respectively, and then became a teacher there. From 2001 to 2004, he did cooperative research work about the aircraft path planning. E-mail: yewen22@sohu.com

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