Research on Path Planning of Aircraft Based on Improved Genetic Algorithm

Yang Li*,1,a, Dang-Min NIE2,b, Xiang-Xi WEN3,c and Han Li4,d

1-4 School of Air Control and Navigation, Air Force Engineering University, Xi’an 710051, China

a liyangisvip@163.com, b 384400978@qq.com, c 2263488440@qq.com, d 704107612@qq.com

*Corresponding author

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Abstract. As for the optimal design of aircraft, route planning is an important part of mission planning system and a key technology for autonomous control of aircraft. In order to find the optimal route quickly, an aviation network model based on navigation point flight is designed. The cost function is generated by considering the distance between nodes, weather and the density of the aircraft, and the optimal route in the model is planned by using the improved genetic algorithm. The simulation results show that this method can realize the optimal design of the flight path of the aircraft in the aviation network.

1. Introduction

Route planning is to find out the optimal flight route which can meet some performance indicators under certain limiting factors, according to the terrain and threat information, so as to ensure the successful completion of the flight mission.

At present, many practical and feasible methods have been put forward for aircraft path planning. Traditional algorithms, such as Voronoi graph method [1], are relatively simple and slow to run. Literature [2] uses ant Colony Algorithm and Genetic Algorithm to propose a three-dimensional route planning method. Literature [3] proposes an improved ACO algorithm to classify different aircraft and collect basic information. In order to improve the obstacle avoidance performance of the aircraft, the literature [4] proposes a route point search method for the efficiency of the route planning and the adaptability to the threat body.

Genetic algorithm is a randomized search algorithm that simulates natural selection and natural genetic mechanism in biological field. It has the characteristics of simplicity, efficiency and good optimization effect. In this paper, according to the relevant regulations, an aeronautical network based on the distribution of navigation platform is established, and three factors containing distance, weather and aircraft density are taken into consideration. The simulation experiment is carried out by using the improved genetic algorithm to optimize the vehicle routing problem. The simulation results show that the algorithm can be applied to the path planning problem of the aviation network model, and the effect is better.

2. Aero network model

Air route refers to a certain width of air passageway which is built on the ground navigation station facilities for the flight of the aircraft. The route planning is mainly based on the land based navigation platform, which is generally designed according to the distribution of the ground navigation station and the actual situation of the airspace. The aircraft operates on one of the navigation stations according to the designated routes.
2.1 Aero network

Building aviation network according to relevant regulations, as shown in Figure 1, is the main form of construction. The circle represents the route node, and the connection between nodes is the actual flight path. In the process of building the aeronautical network, a large and economically developed city is chosen as the hub airport, and the airline is set up between the other large and medium-sized cities, and the aviation network model is set up between the large and medium-sized cities and the middle and small cities nearby. The hub radiation structure is the product of the pursuit of economies of scale. By concentrating many routes into the hub airport, the maximum number of passenger and cargo flows can be completed in the shortest possible time in order to gain more benefit.

Figure 1. Hub radiation structure aeronautical network.

As in Figure 1, the hub radiation structure of an aeronautical network can be represented as $G=(V, E)$, where $V$ represents a collection of network nodes, and $E$ represents a line between each node, that is, a set of edges. Each edge in $E$ has a pair of nodes corresponding to it. The connection between the two nodes forms this edge. In the weighted network, each edge is assigned a certain weight to indicate the difficulty or importance of the connection between the two nodes.

2.2 Influence factor

The path planning problem of aircraft needs to calculate a path with the least value according to the preset cost function, so we need to comprehensively analyze the factors that affect its flight. This paper mainly analyzes the flight constraints from the following factors.

(1)Distance.

Distance factor is one of the most important factors in route planning. In the actual flight, the distance between the two navigation stations will greatly affect the planning and selection of the aircraft route. In the case of other conditions, the shorter distance and shorter running time will be preferred in the case of oil consumption and safety. In the aviation network model, the distance between the route points indicates the actual distance, and the route point without route is recorded as "0", which indicates that the route points can’t be reached directly.

Because the distance is larger in the practical application, direct use will restrict the effect of other factors, so the distance factor is normalized. The expression is $s = x / \text{max}$, in which $s$ is a distance constraint, $X$ is the real distance between the two route points, and Max is the maximum distance between the route points.

(2) The weather

Weather factors have great influence on actual flight, so weather is a key factor to be considered when solving the problem of route planning. Due to the complexity of the weather, it is difficult to use an ideal number. Therefore, considering the effect of the weather on the actual flight, we divide the weather into 5 cases: the flight has no effect on flight (0), the effect on flight (0.2), the flight influence (0.5), and the greater impact on the flight (0.8), which has great impact on flight (1).

In the process of solving, the above 5 conditions are randomly generated, which is called $t$. When $t=1$, the weather has a great influence on the flight of the aircraft. In order to avoid the weather factors that affect the flight, it is dangerous. In the course of planning the route, it is not allowed to fly through this path.

(3)Vehicle density

In the course of flight, the number of aircraft carrying the flight route is inversely proportional to the safety level in the flight process. When the flight route is too large, the route density is large,
which may lead to the close distance between the aircraft and cause the flight accident. Therefore, when solving the problem of route planning, the density of aircraft on the route is also one of the factors to consider.

The density of aircraft is $\rho$, and $\rho = x/N$, of which $x$ is the number of existing aircraft on the route, and $N$ is the upper limit of the carrying capacity of the aircraft. When $\rho$ is 1, the density of aircraft on the route has a great influence on the flight of the aircraft. It is very easy to cause the collision in the air. In order to prevent the air collision, it is not allowed to fly through this route when planning the route.

Combine the above factors, set up the right side of the route

$$D_i = \begin{cases} \omega_i s_i + \omega_2 t_i + \omega_3 \rho_i, & t_i \neq 0, \rho_i \neq 0 \\ 0, & \text{else} \end{cases}$$

(1)

$\omega_1$, $\omega_2$, and $\omega_3$ are the weight of the three factors, and they are satisfied with formula

$$\omega_1 + \omega_2 + \omega_3 = 1.$$  

(2)

2.3 Modeling of Aeronautical network

The modeling of aviation network is based on graph theory, which mainly includes the following steps:

(1) Network nodes should select a fixed number of points that can be used as flight references and will not be increased, reduced, cancelled or moved without cause. This paper chooses the navigation station as the reference node when constructing the aviation network.

(2) Edge weight refers to the weight of the connection between nodes of a network, which represents the consumption level of the flight through these two nodes, and is usually expressed by the actual distance between nodes.

(3) The adjacency matrix is a matrix which is used to express the relationship between nodes of the network. It can accurately reflect the number of nodes, the connection of nodes and the edge weight of nodes in the network, which is convenient for computer processing. This paper chooses the navigation station as the reference node when constructing the aviation network.

3. Route planning based on Improved Genetic Algorithm

3.1 Genetic Algorithm

Genetic algorithm is a randomized search algorithm that simulates natural selection and natural genetic mechanism in biological world. Through the simulation of the evolutionary process of artificial population, three processes of selection, cross and mutation are completed to complete one iteration. The optimal individual is retained by selecting the optimal individual, and the process is carried out again and again to achieve the ultimate adaptive value.

3.2 Route planning process based on Improved Genetic Algorithm

(1) Gene expression

The solution of the optimal path planning problem in an aeronautical network is a path of minimum generation value from the starting point to the destination. Therefore, a chromosome is set in the genetic algorithm to represent a feasible path from the starting point to the end point. The expression is an integer string, and each position in the string represents a node in the network. The first node is the starting point of the planning path, the last position indicates the end of the planning path, and the rest of the location is taken as the starting point. Point to the end of the node. Such as chromosomes $(o, i, j, k, \ldots, d)$ represents a path $P(o, d)$ from the starting point $o$ to the endpoint $d$, through $i, j, k,$ and other nodes. The chromosome length is not fixed, but it will not exceed the sum of $N$ in the network, and the nodes are connected in the established aviation network.

(2) Population Initialization
The population quality initialized by genetic algorithm has great influence on the convergence and convergence of the algorithm. There are two commonly used initialization methods, namely completely random initialization and heuristic selection initialization. The population diversity generated by the complete random initialization is high, but it is easy to make the chromosomes with low adaptive value into the genetic iteration, which is adapted to the case of no prior knowledge of the optimal path. The heuristic selection initialization can generate more adaptable chromosomes in the direction, reduce the number of iterations, help the algorithm find the optimal solution quickly, but may initialize the generation of chromosomal diversity crossover, making the algorithm easy to be premature. In view of the characteristics of the aviation network, this paper proposes a randomized initialization method to initialize the population.

The randomization initialization method is as follows: first add the starting point network node o, put the first position of the chromosome, then randomly select a node from the adjacent node of the first node o, add the next location of the chromosome, and repeat the method until the destination node is found, that is the terminal node d.

In the process of initialization, the following two constraints are followed: ① a node that has been added to a chromosome is not allowed to be selected again to avoid a ring in the chromosome; ② When a node does not have a selection of adjacent nodes, it indicates that the chromosome is unavailable. It should give up the formed chromosome and reinitialize it from the starting node.

(3) Fitness function
Each side of the aeronautical network has a certain edge right, indicating the loss of the aircraft during the corresponding flight path, including the influence of distance, weather and the density of the route aircraft on its flight. The specific calculation formula is given in the 2.2 chapter. The purpose of route planning is to plan a route that can arrive from the starting point to the terminal point and minimize the loss of flight. The fitness function is the evaluation of the individual, which indicates the loss function of each branch flight. The greater the fitness function, the more difficult to express the flight path through the route. The purpose of the algorithm is to find a path with the smallest fitness function. Therefore, the fitness function is designed: the fitness function of a chromosome P(o, d) is as follow.

\[
f(P) = \sum_{i=1}^{n} D_i = \sum_{i=1}^{n} \left(\alpha_1 s_i + \alpha_2 t_i + \alpha_3 \rho_i\right)
\]

In this, Di represents the cost of the side of the path I in the path, and the fitness function of a chromosome is the accumulation of the cost of all weighted edges passed by the chromosome.

(4) Selection strategy
Selection refers to the process of simulating the survival of the fittest in the biological world, selecting high-quality individuals from the old population, eliminating some individuals, thereby updating the population process. The selection process does not generate new individuals, and the average fitness function of population is worth improving.

Roulette selection strategy is a commonly used selection strategy in genetic algorithm. The basic realization of selection is that the selection probability of individual is proportional to the fitness value of individual. In this paper, we use the roulette wheel selection strategy to calculate the probability of chromosome I being selected using the following formula.

\[
p_i = f(P_i) / \sum f(P_i)
\]

f(Pi) indicates the fitness function value of individual Pi. It can be seen that the higher the fitness function, the larger the probability of being selected, the more individuals with higher fitness value, the more easy to be eliminated.

(5) Intersecting
In this paper, crossover is performed by single point crossover.

Two chromosomal individuals are randomly selected from the contemporary population as a cross individual, and there must be at least one common intermediate node, and one of the nodes is
selected to perform cross operation on the selected two parent chromosomes, thus generating two new offspring to determine whether the new body is feasible, and if feasible, cross knot. Beam, if it is not feasible, then give up the operation.

(6) Variation

Considering the diversity of population, the contemporary population is mutated. Select an individual as an individual to be changed, and randomly select a node from the path P(o, d), and the node is not allowed to start at o and end d.

Retains the path of the starting point o to the node, and uses the initialization method to regenerate the path of the node to the terminal d, and the path does not allow the occurrence of o to the node in the node to avoid the occurrence of the ring.

4. Simulation analysis

Considering the application of the algorithm in reality and consulting the relevant data, the optimal path between the two regions is solved by the improved genetic algorithm based on the air network in Beijing area, including 229 nodes.

By improving the genetic algorithm, the population size N=30, the cross probability p1=0.9, the mutation probability p2=0.25, the termination algebra are 30, ω 1=0.5, ω 2=0.3, ω 3=0.2, and weather factors are randomly generated. The simulation results are as follows:

Table 1. Simulation results.

| Route                  | Distance |
|------------------------|----------|
| Beijing - Fuzhou       | 1557     |
| Beijing - Hangzhou     | 1384     |
| Beijing - Hefei        | 809      |
| Beijing - Nanyang      | 897      |

5. Conclusion

According to the relevant regulations, the aircraft network model is built in consideration of many factors, such as distance, weather, density and so on. In view of the optimization of the running path of the aircraft in the aero network, the simulation analysis is carried out using the improved genetic algorithm. The results show that the algorithm can be applied to the solution of the optimal path in the model. It provides some technical support for path planning in real flight.

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