Study of Multi-aircraft Conflict Resolution and Algorithm Optimization Based on Genetic Algorithm

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Abstract - In order to resolve the conflict among multiple aircrafts, a method to get the optimal route quickly and accurately based on genetic algorithm is proposed. By applying genetic algorithm, the conflict is resolved between two aircrafts as well as among multi-planes. An optimization method to accelerate the convergence of the algorithm is proposed. Simulation results show that the algorithm can get the optimal conflict resolution route quickly. This method is of significance for actual path planning.

Index Terms - free flight, genetic algorithm, conflict resolution, algorithm optimization

1. Introduction

With the growing demand of airline transportation, the air traffic is facing increasingly serious routing congestion problems, which bring unprecedented pressure to the existing air traffic control system. Under the current air traffic control mode, civil aircraft flights is arranged in compliance with routes established by the ground radio beacon and defined by ground-based navigation system. [1] The aircraft must fly along a fixed route composed of a series of navigation stations. As these facilities cannot built everywhere, the aircraft cannot select the direct route to the destination. This leads to an increasingly crowded traffic route and low overall utilization of airspace. The "free flight" is an effective way to solve this problem.

However, the increase in the number of flights and diversify of free flight routes lead to inevitable increase in the possibility of flight conflict. Flight conflict detection and resolution method is essential, and will be a key technology for the realization of free flight.[2] Getting the aircraft's current position by using of the variety of existing data and information, consequently making reasonable judgment to avoid flight conflict has become an urgent task, as well as a hot research focused by scholars around the world in recent years.

As a new overall optimization search algorithm, and due to its simplicity, robustness and suitability for parallel processing, genetic algorithm is one of the key intelligent algorithms in the 21st century.[3] In this article, conflict among two and multi-aircraft is resoluted by applying genetic algorithm. The results has also optimized by accelerating algorithm convergence.

2. Algorithm Modeling

According to the national Air Traffic Control (ATC) safety regulations and the specific circumstance of the actual flight control, the following simplifications to the practical problems is given.

(1) The problem is simplified as a two-dimensional conflict resolution issues, as the aircrafts always fly at a certain height besides the take-off and landing phases. This also makes passenger comfortable and saves fuel.

(2) Considering that aircrafts will not change dramatically in azimuth during flight, we assume the aircraft azimuth angle range from -35 °to 35 °. In order to obtain the optimal flight path, a detailed research on the dividend of azimuth angle is carry out.

(3) To ensure the aircraft arriving on time, the velocity alone the flying path is assumed constant. The velocity perpendicular to the flying path changes according to the azimuth angle.

(4) According to China's ATC safety regulations, under the radar control conditions, a distance between aircrafts large than 20km is considered safe. So in our simulation work, distance less 20km is considered unsafe and needs to take measures to avoid it.

3. The Conflict Resolution Based on Genetic Algorithm

According to the algorithm process, specific approaches are as follows:

(1) Encoding: The binary coding is chosen. 6-bit binary code represents the azimuth angle, which ranges from -35 °to 35 °. N is the number of aircraft, so N aircraft require 6 × N-bit binary number to represent the azimuth angle.

(2) The determination of the objective function and constraints is shown。

as follows. In terms of fuel consumption, the plane is desired to fly along the shortest path without conflict, that is:

$$y = \min \sum_{i=1}^{n} S_i \tag{1}$$

Where S_i represents the total flight distance of a plane, from entering to leaving the conflict area.

Meanwhile, it should be ensured that the distance between aircrafts meets the national ATC safety regulations, that is:

$$d = \sqrt{\left(x_i - x_j\right)^2 + \left(y_i - y_j\right)^2} \geq 20 \tag{2}$$

Where, (x_i, x_j),(y_i, y_j) represent the coordinates of aircrafts in the area.

For the flight path which does not meet the safety distance requirement, penalty function should be used to make it hard to enter the next generation calculation, that is:

$$y = \sum_{i=1}^{n} S_i + m \times (d - d_i) \tag{3}$$

Where $\sum_{i=1}^{n} S_i$ represents the aircraft flight path length, and m is a proportional coefficient, $(d - d_i)$ is the difference between minimum safe distance and the actual distance of the two aircraft. The total length of the flight path which does not meet the minimum safety distance is much longer than the one meets, which makes the former is less likely to be chosen in the selection process.

(3) Selection[5]: Using ergodic random selection method, shown in Figure 1, NVAR is set to the number of individuals needed selected, and select individual equidistantly, 1/NVAR is the distance of the pointer to select, and position of the first pointer is determined by the uniform random number of [0,1/NVAR].

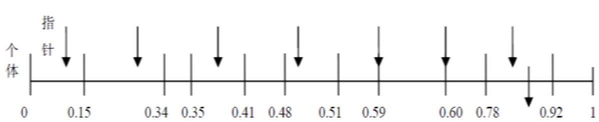

Fig. 1 Ergodic random selection method

Thus, by computing the fitness of each individual, the individual flying shorter has a greater fitness value, occupy a larger distance on axis in Fig. 1, and is more likely to be selected into the next generation for computing.

(4) Crossover and mutation: Use single-point crossover operator by only setting one crossover point randomly in individual encoded string and then exchanging some genes mutually at that point. Use discrete mutation operator, mutate an element of the current population with a specific probability (mutation rate is taken as 0.02), and achieve a change in the yaw angle of the aircraft at this point.

(5) Termination of genetic algorithm: Set of genetic algorithm running times for 1000 generations, and set if the result of the operation for 30 consecutive generation ranges is less than 0.000001, then the algorithm ends. If it doesn't meet the criteria in calculation of 1000 generations, the algorithm stops accordingly, then some parameters need to be adjusted or restarted.

4. Algorithm Simulation and Results

4.1 simulation and results

Simulation parameters are set as follows: Two aircraft, one flying from west to east, the other flying from south to north. Flight distance is set to 900km, a safe distance between the two planes is 20km. Gap is set to 0.7, that is to pass up 70% of parent generation to the next generation in each of the selection process. Mutation rate is set to 0.02, population size is 600, the maximum number of iteration is 1000, and simultaneously, when the adjacent 30 successive generations population change by less than 0.000001, then this solution is considered as an approximate optimal solution, and the algorithm terminates. Figures 2a, 2b and 2c show a simulation of the genetic algorithm.

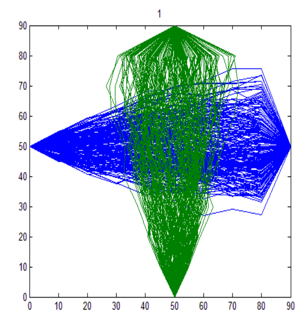

Fig. 2a 1st generation

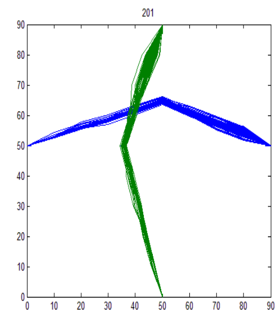

Fig. 2b 201st generation

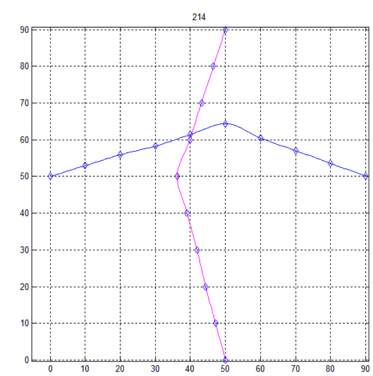

Fig. 2c 214th generation

In order to investigate the algorithm performance, the related results of five aircraft conflict resolution are shown in the following Figure 3a, 3b and 3c.

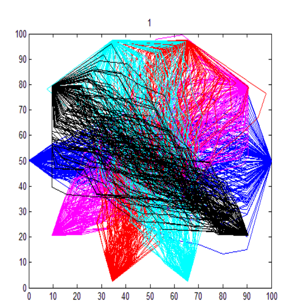

Fig. 3a 1st generation

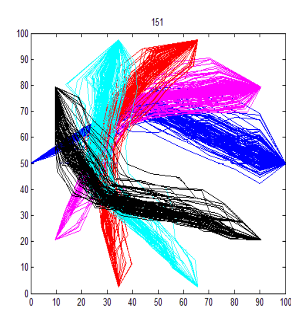

Fig. 3b 151st generation

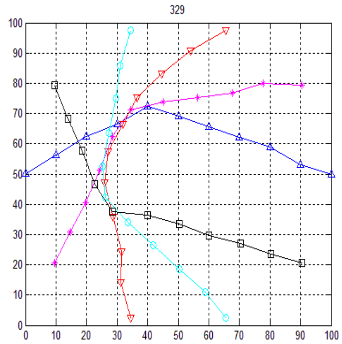

Fig.3c 329th generation

Further deepen the study of the 5 aircraft conflict resolution problem. Assuming that there are two planes in each direction opposite to the flight, and then the problem becomes a ten aircraft conflict resolution issue which contains opposite flight. Figures 4a, 4b and 4c are the related results of ten aircraft conflict resolution.

These results indicate that the designed algorithm performs well. Whether it is a two or multi-aircraft conflict, the algorithm has a good performance. However, concerning the optimization of the result of genetic algorithm, there is no absolute optimization. Each step of algorithm design details is worth researching, and these will affect the performance of the algorithm, such as population diversity, convergence speed and so on. Therefore, it is necessary to research the possible influence of various factors on the performance of the algorithm.

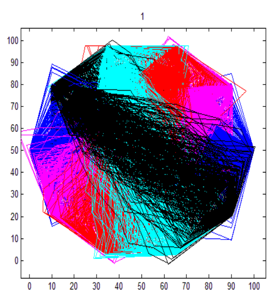

Fig. 4a 1st generation

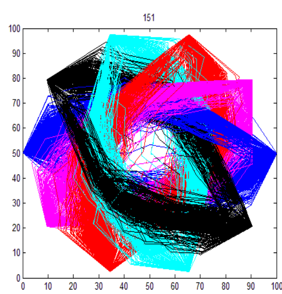

Fig. 4b 201st generation

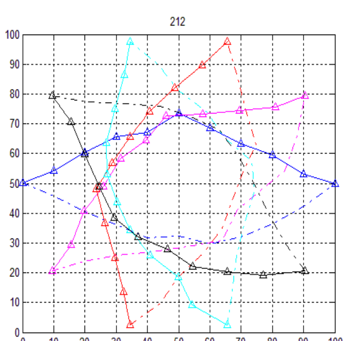

Fig.4c 212nd generation

4.2 Algorithm optimization and simulation results analysis

In terms of designed algorithm in this paper, the current design is to divide the sailing scope of -35 °~35 °into 64 parts (In a clockwise direction as the positive direction), with each part approximately equaling to 1 °. Consider that a smaller degree of actual flight cannot be achieved, it is not significant to select it. But in fact, this is a very critical factor affecting the algorithm execution speed of the algorithm. Because, the more parts are to be divided, the smoother route will be, but the slower the algorithm execution speed will be. And if less parts divided, then execution will be relatively much faster, but waypoints are slightly rough, not smoother than the former, so the selection must be depended on specific course of the actual situation. So the size of course selection is changed, dividing the search range of -35 °~ 35 °into eight parts, and then use the simulation for verification.

Taking the five-aircraft flight conflict as an example, because of the changes of the waypoints roughness, when the change in the magnitude of the continuous adjacent 30 generations population is less than 0.1, which is believed that this solution is an approximate optimal solution, the algorithm terminates, and the other conditions do not change. The results are shown in Figure 5a, 5b and 5c.

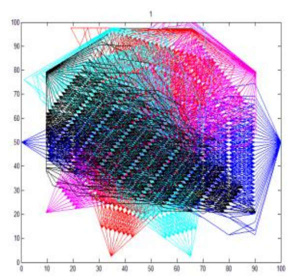

Fig. 5a 1st generation

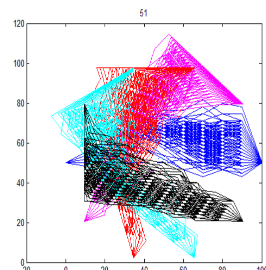

Fig. 5b 51st generation

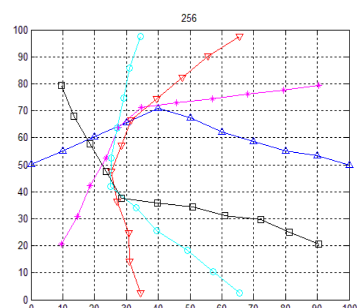

Fig.5c 256th generation

As is shown in Fig.5, the generated path with using optimization algorithm of five-aircraft conflict resolution is similar to the one in Fig.3, but granularity of the path is slightly large, the procedure repeating 5 times, and comparing with the former five-aircraft conflict resolution procedure, the results are shown in Table 1 and 2. It's clear that convergence speed and execution time of the algorithm greatly accelerated after optimizing.

Table 1: the result of the original five-aircraft conflict resolution

No.	Convergence Generation	Execution time (s)
1	359	132.66
2	274	100.73
3	253	93.07
4	245	89.50
5	400	145.60
Average value	306	112.31

Table 2: the result of optimized five-aircraft conflict resolution

No.	Convergence Generation	Execution time (s)
1	207	74.15
2	260	92.55
3	242	86.44
4	286	101.44
5	237	84.58
Average value	246	87.83

5. Conclusion

The correctness of the algorithm is verified by resolving conflict between two aircrafts and among multi-aircraft in the simulation work. The algorithm can also give an effective solution to complex conflict situations. Based on this, in-depth study of the algorithm optimization was conducted. This research lay a solid foundation for future research. These findings can play an active role for future research. Meanwhile, the results provide important theoretical basis for the free flight and ATC automation system. And it is of vital significance in increasing airspace capacity and ensuring flight safety.

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