Research on technology of conflict about air route used for multiple UAVs flying in the sky

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Abstract—This electronic document proposes a route conflict detection method which uses time axis mapping. The method can solve the route conflict problem by transforming the original route conflict into x, y, z-axis conflict region and maps the three-axis conflict interval to the time axis to obtain the conflict time period, the final route conflict is determined by solving the intersection of three conflict time periods. In the specific simulation experiment, ADS-B working range reaches 100 (n mile). At this time, 1% of the aircraft have conflicts in the route conflict detection in the obstacle avoidance area specified by ATC, which is basically close to the collision avoidance area specified by ATC and the 100 (n mile) volume ratio of ADS-B working range. This experiment further proves the accuracy of the detection method. There is a solution to the problem of route conflict in multi UAV cluster operation.

1. Introduction
With the development of domestic aviation industry and the opening of low altitude areas, UVAs and general aviation have developed rapidly in recent years. It leads to more and more congestion in domestic low altitude airspace, further highlights the flight safety problems, and increases the probability of aircraft collision events year by year. According to the relevant data, at present[1], more than 90% of the aircraft collisions are at low altitude, most of them are general aviation. According to the relevant provisions of ATC, taking the aircraft as the center, it belongs to the collision avoidance area in the radius of 5 (n mile)[2], in which other aircrafts are forbidden to enter illegally, otherwise there may be a problem of aircraft collision[3]. TCAS is based on Ta and RA to achieve two-level collision avoidance. ADS-B is a broadcast type automatic related monitoring technology. In recent years, the technology which has rich information transmission and a wide range of work is widely used in the anti-collision system monitoring[4], management of general aviation, UAV and transport aviation. In the area specified by ATC, ADS-B can be used to build the protection area outside the collision area to avoid collision in advance. At the same time, it can also effectively avoid the occurrence of aircraft collision in medium and low airspace.[5]

2. Dividing the space around the aircraft
In this study, based on the route conflict detection in the advance collision avoidance area, for the aircraft space area, collision avoidance and protection are mainly concerned[6], as shown in the figure below:
For the collision avoidance area, the area specified by ATC can be used, with the plane as the center, the horizontal plane radius of 9.26 km and the up and down of 0.366 km. The protection area can be set according to the actual needs.

In this study, a sphere with a radius of 185 km is used as the working range of ADS-B[7]. The conditions of route conflict are as follows: when other aircraft enters the protection area, that is, there is conflict detection between the invading aircraft route and its own route. If the invading aircraft route enters the collision avoidance area of its own route, it is considered that there is a certain route conflict between the invading aircraft and its own route.

3. Algorithm of route conflict detection

In the process of route conflict detection, we need to solve the conflict time period of x, y and z axes. Because the three-axis direction detection algorithms are basically consistent, this study mainly takes x-axis as the research object. For example, for two aircraft A and B, the future position is related to their current speed and position. Assuming the speed is constant during the flight, the coordinates in the x-axis are Xa and Xb, and the corresponding functions are Vxa and Vxb, respectively. The speed is the vector, and the x-axis is the positive direction of flight[6]. When Xa > Xb and Vxa > Vxb, the distance in x-axis direction will be increased. When Xa < Xb and Vxa < Vxb, the distance in x-axis direction will be increased. When Xa > Xb and Vxa < Vxb, the distance in x-axis direction will be decreased. When Xa < Xb and Vxa > Vxb, the x-axis distance will also be decreased. The above two cases can be comprehensively expressed by the following formula: 

\[ (Xa - Xb)(Vxa - Vxb) \]

If the formula is greater than 0, the x-axis distance will be increased; if the formula is less than 0, the x-axis distance will be decreased. When Vxa=Vxb=0, the x-axis direction remains unchanged. Specifically, when there is a conflict in the x-axis direction, this situation can be divided into five cases: first of all, 

\[ (Xa - Xb)(Vxa - Vxb) \geq 0 \]

and Xa - Xb > 9.26, there is no route conflict, that is, there is no route conflict period and conflict area; Secondly, Xa-Xb is less than 9.26 and 

\[ (Xa - Xb)(Vxa - Vxb) = 0 \]

In this case, there are two cases: first, Xa - Xb is less than 9.26 and 

\[ (Xa - Xb)(Vxa - Vxb) > 0 \]

In this case, there is route conflict and the conflict period is: Thirdly, Xa-Xb is less than 9.26 and 

\[ (Xa - Xb)(Vxa - Vxb) < 0 \]

In this case, there is route conflict and the specific time period of route conflict is: Fourthly, Xa-Xb is less than 9.26 and 

\[ (Xa - Xb)(Vxa - Vxb) < 0 \]

In this case, there is route conflict, and the specific time period of route conflict is:

\[ [t_{x1}, t_{x2}] = \{0, (9.26 - |Xa - Xb|)/|Vxa - Vxb|\} \]

Fifth, Xa-Xb > 9.26 and 

\[ (Xa - Xb)(Vxa - Vxb) < 0 \]

In this case, there is route conflict, and the specific time period of route conflict is:

\[ [t_{x1}, t_{x2}] = \{0, (|Xa - Xb| + 9.26)/|Vxa - Vxb|\} \]

In the above five cases, there is only one case have no route conflict, and for the case of route conflict, the corresponding conflict time can be calculated. First of all, we need to calculate case 1. If the formula is true, there is no conflict. If the time is the intersection of x, y and z axes, there is no need for subsequent calculation. If the formula is not true, there will be x-axis conflict. According to the actual situation, we can calculate the corresponding conflict time. Using the same method to solve
the y and z axis, the parameter of z axis changes from 9.26 to 0.366. The following is the algorithm flow of collision detection between the aircraft and the intruder in the collision avoidance area.

According to the flow chart, the order of x, y and z is not unique and unchangeable. The x, y and z axes in the graph can be advanced or backward. According to the calculation process above, it can be judged whether there is route conflict between the aircraft and the new aircraft in the collision avoidance area circumscribed cuboid. If there is route conflict, it needs to accurately judge whether the conflict exists in the cylinder. There is the following formula:

$$\left[ (V_{xa} - v_{xa})*(t_i + t_2)/2 + X_a - X_s \right]^2 + \left[ (V_{ya} - v_{ya})*(t_i + t_2)/2 + Y_a - Y_s \right]^2 > 9.26^2$$

If the above formula is true, there is no route conflict, otherwise there will be route conflict.

4. Simulation analysis

We make these supposes and test 100 times: 1. the speed of a transport aircraft is 700-1000 km / h; 2. 100 intruders enter the protection area during each experiment; 3. the coordinate is (0,0,0) and the speed is (900,0,0); 4. the working range of the protection area is 185 km and the route conflict handling range is 185 km. In this case, when 100 intruders enter the protection area, their corresponding positions are X, Y, Z, which are required to meet the following formula:

$$9.26^2 < (X^2 + Y^2 + Z^2) < 185^2$$

The flight direction is random, but in the navigation speed, VX, VY, VZ, should meet the following formula, as shown below:

$$700^2 < (VX^2 + VY^2 + VZ^2) < 1000^2$$

In 100 experiments, the flight position and speed of an invading aircraft were determined. The following figure shows the number of aircraft sorts with route conflict on X, Y and Z axes after case one calculation in 100 experiments.

Fig. 2 Airline conflict experiment

According to the results, it can be found that 530 aircraft sorts with route conflict exist [3] after calculate case 1 in x-axis, and only 53% of them need to calculate the subsequent conflict time. 290 aircraft sorts exist in y-axis after case 1, that is, 29% of them need to calculate the conflict time, and 145 aircraft sorts have route conflict in z-axis, Only 14.5% of them need time conflict calculation. In the case of three-axis horizontal conflict, three corresponding conflict time periods are calculated respectively, and the intersection of time is calculated to determine whether there is a conflict. The specific results are shown in the figure below,
The results show that only 1% of invaders has conflict with the aircraft, and the data is close to the volume ratio of ATC collision area and ADS-B working range, which proves the accuracy of the above route conflict detection method. Most of the collision detection methods mentioned above can be eliminated by simple calculation, so the calculation is small and easy to implement.

5. Conclusion
In a word, in this study, the three-dimensional space route conflict detection is solved by using the three-dimensional time axis [4], which can simplify the detection process and has a small amount of calculation, which is conducive to the realization. In this study, the detection range of ADS-B is 185 km, and the route conflict processing range is 185 km. Its selection range is large, so it needs 9 adjustments in actual use, appropriately narrow the detection range and expand the route conflict processing range, so as to increase the proportion of conflict detection.

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