

A Fast Route Conflict Detection Method based on Space Box

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Abstract

Routes Conflict detection is of great importance to air traffic control. Due to previous route conflict detection algorithm has a large number of computations, high time complexity and low reliability. This paper proposes a fast route conflict detection method based on the space box. Firstly, the space to be detected is divided into several space boxes, and the space box numbers of the track in the airspace are calculated according to the track coordinates. Secondly, in the case that multiple batches of tracks exist in the same space box, the location of the tracks is predicted according to the current track parameters. If the distance between the tracks gradually decreases, it is judged that the tracks have conflict risk and an alarm is required. The simulation results show that the algorithm has low time complexity, and high efficiency, and is suitable for parallel processing and large-scale route conflict detection, which has high application value.

Keywords

Conflict Detection; Air Traffic Management; Space Box; Geodetic Coordinate System.

1. Introduction

Route conflict detection is an important part of air traffic control and military operational command and is significant to flight safety and mission assurance. The risk of collision exists when the route of multiple aircraft has less horizontal distance than the safe horizontal distance and the altitude difference is less than the safe altitude distance at a given moment.

The first model in the field of aircraft conflict, the aircraft collision model [1], was proposed by Reich, in the 1960s. This model sets the airspace of an aircraft at a certain moment as a rectangular body of specified size, thus converting the conflict probability of two aircraft into the probability of conflict between a point and a rectangular body. Havel proposed a cylindrical flight model [2] based on the aircraft collision model. The cylindrical flight model uses the center of mass of the aircraft as the center of a circle, the flight safety radius as the radius, and the height of the cylinder according to different flight altitudes. This model is more realistic than the vehicle collision model. The probabilistic analysis method of airspace safety proposed by Prielli, introduces a probabilistic algorithm [3] for the conflict detection of two aircraft located in the same altitude layer. The probability of one vehicle entering the safety zone of the other vehicle at a future moment is found using a probability distribution function, assuming a fixed series of coordinate point locations on the route of the two vehicles, and that both vehicles have their own constant flight speed. Fulton analyzed the complexity of multiple vehicles flying through the air and proposed the concept of Voronoi polygons [4], which can be used to simplify the number of vehicles and increase the speed of computation.

The route detection algorithm research has developed rapidly in recent years in China. Zhao Hongyuan conducted an in-depth study on the aircraft conflict between two intersected routes [5], proposed the concept of air conflict region, and studied the situation of intersected routes belonging to the same flight altitude layer. Based on this, the number of flight conflicts occurring

per unit time for each aircraft in the airspace was calculated. Chen processed the flight target conflict detection with a probabilistic statistics-based algorithm [6], analyzed various factors affecting the airspace flying, and calculated and simulated the flight conflict probability based on two-dimensional Brownian motion. Through the simulation experiments of the airspace traffic control system improved by this algorithm, it is proved that this algorithm can meet the basic requirements for flight conflict detection in the airspace traffic control system. Liu Xing conducted computational and simulation experiments on flight impulse detection using genetic algorithm according to domestic air control regulations [7]. However, due to the high algorithmic complexity of genetic algorithm, it is not suitable for detection in large-scale flight scenarios. If there are multiple aircraft flying at the same time, it will lead to an enormous amount of calculations. Generally speaking, many aircraft are far away from each other at the same time and will not clash, so it is not necessary to perform comparisons between all aircrafts one by one. Appropriate methods can be used to filter out aircraft pairs that do not clash at all in advance. Traditional filtering algorithms are based on 3D projection or distance judgments, these have high time complexity [3, 8-10]. To reduce the computational complexity of flight conflict detection, the Delaunay theory in imaging has been used for flight conflict detection in recent years, and the Delaunay triangulation method is used to filter potential conflicts, and the time used is independent of the number of aircraft, which reduces the computational effort [11-12], and the locally updated triangulation algorithm [13-15] can use the temporal inheritance of the position relationship between aircraft to update the grid locally, which is computationally more efficient for single time period conflict detection, and therefore is mostly used for short-time conflict alerts.

To improve the route conflict detection function in the ATC system, this paper proposes a fast route conflict detection method based on spatial division. First, the space of the area to be detected is divided into several rectangular-shaped conflict detection units, and the trajectory is divided into areas according to the conflict detection units. And, only for the traces in the same conflict detection cell, route prediction is performed to determine whether there is a risk of route conflict.

2. Route Conflict Detection Method

2.1. Coordinate System Selection

Usually, both ADS-B and radar systems use a geodetic coordinate system to report air situations, but a geodetic coordinate system is not convenient to deal with spatial position relationships, therefore, in this paper, the relevant calculation will be carried out under the Rectangular coordinate system, and the geodetic coordinates are also converted to Rectangular coordinate system firstly in the actual engineering application.

2.2. Space Box Division

The air space to be detected $CS=\{x_0,y_0,z_0,Len, Wid, Hig\}$, where x_0,y_0,z_0 are the starting coordinates of the space, and Len,Wid,Hig are the length, width and height of the space. The space of the region to be detected is divided into numbers of rectangular space box, each of which is represented by a number, center coordinates, length, width and height. The space box $CU = \{No,cx,cy,cz,tl,tw,th\}$, where No is the space box number in the format $\{ijk|i, j, k \in N; |i| \leq 3; |j| = 3; |k| = 3\}$, cx,cy,cz are the center coordinates of the space box. tl,tw,th are the length, width, and height of the space box.

If the space to be detected is directly sliced into equal parts, air collisions near the boundary of detection units cannot be detected in the red grid, as shown in Figure 1(a). To solve this problem, the coverage of space box should overlap each other. The overlap factor $ck=100\%$ in the case of Fig. 1(b) indicates that the coverage is completely overlapped once. Due to space

overlap, tracks may exist in more than one space box. When a space box to which a track belongs is found, in order to optimize the algorithm, it is only necessary to judge whether the track exists in the 26 space boxes around the space box.

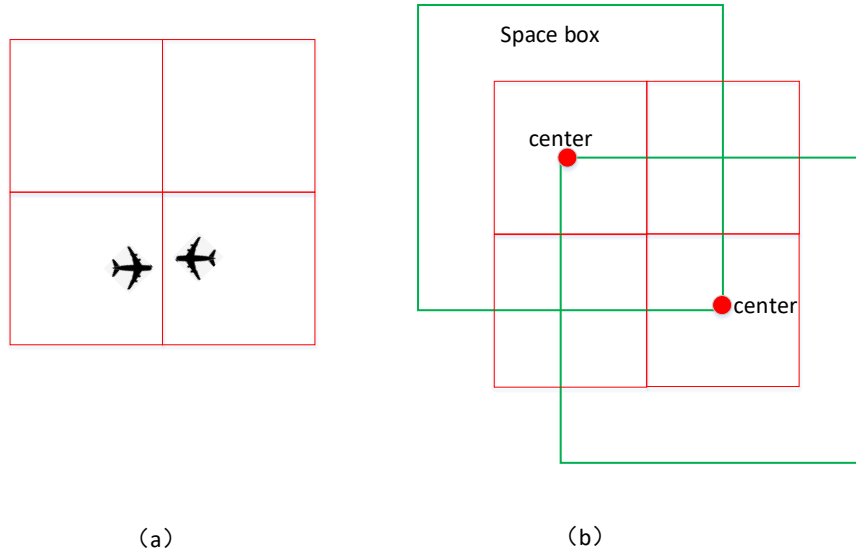


Figure 1. space box division

The starting coordinates x_0, y_0, z_0 and the length, width and height Len, Wid, Hig of the space CS, the length, width and height tl, tw, th of the space box CU, and the total number of space box $Cu_Sum()$ are calculated as follows.

$$\begin{aligned}
 Num_x &= \left(\frac{Len}{tl}\right) \\
 Num_y &= \left(\frac{Wid}{tw}\right) \\
 Num_z &= \left(\frac{Hig}{Th}\right) \\
 Cu_Sum() &= Num_x \times Num_y \times Num_z
 \end{aligned} \tag{1}$$

The centre coordinates $Cu_Center(ijk)$ of the space box Cu numbered ijk is calculated as follows:

$$Cu_Center(ijk) = \begin{pmatrix} x_0 \\ y_0 \\ z_0 \end{pmatrix} + \begin{pmatrix} tl \times \frac{2i+1}{2} \\ tw \times \frac{2j+1}{2} \\ th \times \frac{2k+1}{2} \end{pmatrix} = \begin{pmatrix} cx \\ cy \\ cz \end{pmatrix} \tag{2}$$

2.3. Track Calculation

The track calculation is a direct projection of the current position $Track_pos()$, according to the current heading and speed. $track_pos(t)$ after moment t is calculated as follows:

$$Track_pos() = \begin{pmatrix} p0_x \\ p0_y \\ p0_z \end{pmatrix}$$

$$Track_pos(t) = Track_pos() + \begin{pmatrix} v_x \\ v_y \\ v_z \end{pmatrix} \times t = \begin{pmatrix} pt_x \\ pt_y \\ pt_z \end{pmatrix} \tag{3}$$

2.4. Calculation of Space Box

Knowing the track position (x,y,z), use Formula 4 to calculate which space box the route belongs to.

$$\begin{pmatrix} i \\ j \\ k \end{pmatrix} = \begin{pmatrix} \frac{x-x_0}{tl} \\ \frac{y-y_0}{tw} \\ \frac{z-z_0}{th} \end{pmatrix} \tag{4}$$

The space box is overlapped with each other by an overlap factor ck, which means a track could belong to more than one space box. Thus Formula 4 is not sufficient to calculate all the space box a track belongs to. We can calculate the 26 detection units that surround space box (i,j,k) and check whether the track belongs to any one of them.

Knowing the track position (ptx,pty,ptz), the method to determine whether the track belongs to the space box numbered ijk is as follows:

(cx,cy,cz) is the center coordinates of space box calculated using formula 2.

If:

$$\begin{aligned} |pt_x - ca| &\leq tl*(1+ck)*0.5 \text{ and} \\ |pt_y - cb| &\leq tw * (1 + ck) * 0.5 \text{ and} \end{aligned} \tag{5}$$

$$|pt_z - cc| \leq th*(1+ck)*0.5$$

Then:

The track position(ptx,pty,ptz) belongs to the space box which center is (cx,cy,cz).

2.5. Calculation of Distance between Tracks

The trajectory t1(x1,y1,z1) and the trajectory t2(x2,y2,z2) are known in the same space box and the distance Dis between the two tracks is calculated by:

$$Dis = \sqrt{(x1 - x2)^2 + (y1 - y2)^2 + (z1 - z2)^2} \tag{6}$$

2.6. Conflict Detection Calculation Process

Based on the definition of the above equations, the flow of the fast route conflict detection method is shown in Figure 2. First, initialize the space of the area to be detected , calculate the number of space box and the center coordinates of the space box (Formula 1 and Formula 2); calculate the space box to which all traces belong (Formula 4 and Formula 5); for the case that the number of traces in each space box is greater than one, calculate the predicted position at moments t1, t2, t3.....tn, and calculate the distance between two traces at moments t1, t2, t3.....tn (Equation 6), and if the distance is decreasing, an alarm message is added to the track marker to alert traffic controllers.

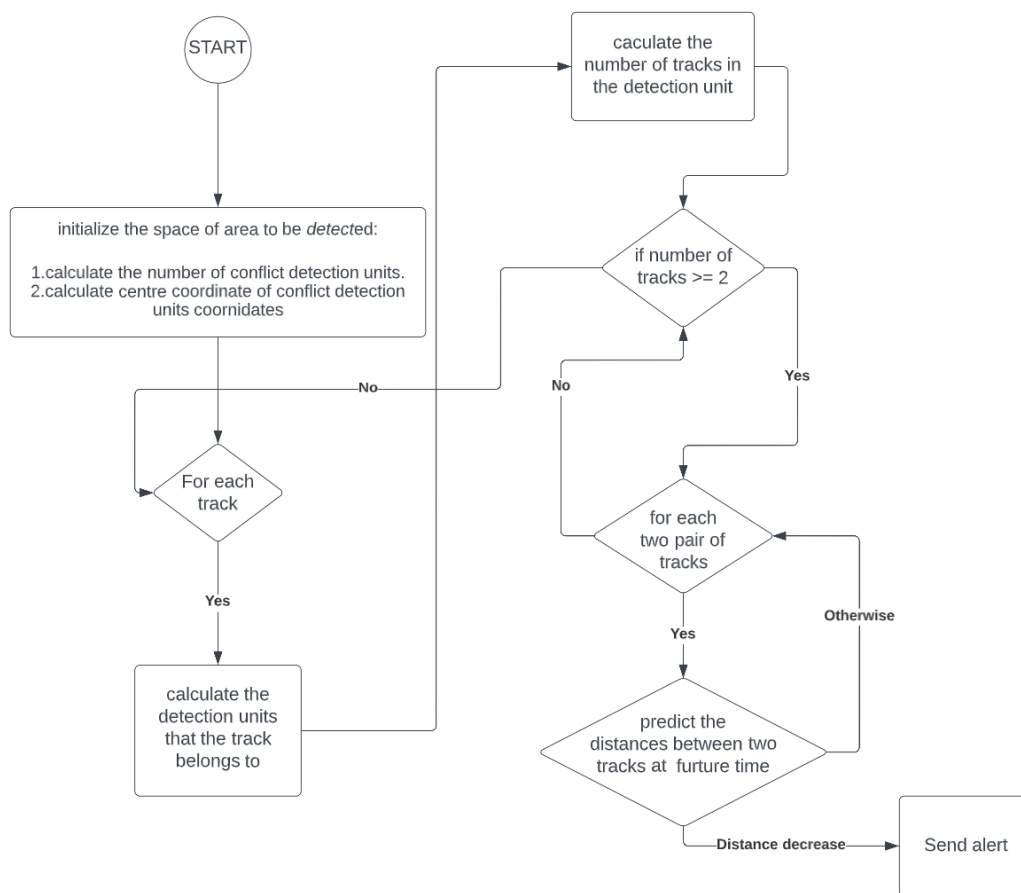


Figure 2. Algorithm processing flow

3. Algorithm Time Complexity

Suppose the number of routes is m , the number of space box is k , and the trajectory position is predicted n times. In the most complex case, the track initialization operation is m times, each time the operation of calculate which space box a track belongs is calculated $27m$ times, and the track prediction is calculated n times. The computational complexity is $O(28m+mn)$. The complexity is better than references 16 and 17.

4. Performance Simulation Experiment

The control area of an ATC is a space of 1000 km long, 1000 km wide, and 30 km high, divided into space box of 20 km long, 20 km wide, and 1 km high, and the number of space box is $50 \times 50 \times 30 = 75,000$.

In order to compare the performance with other algorithms, 19 sets of experiments are designed, and the number of traces corresponding to each set of experiments is 10, 20, 30, ..., 90, 100, 200, ..., 1000, and the flight speed is randomly set between 150m/s and 250m/s, and the traces are actually randomly set in position.

According to the experimental results, after adopting the conflict detection method with spatial division, the number of conflicts that need to be judged is greatly reduced and the time used for the calculation is significantly reduced. And as the number of tracks increases, the advantage of this algorithm in terms of time is greater. The algorithm in this paper is compared with the calculation time of route conflict detection given in literature [16] and literature [17], and the results are shown in the following table.

Table 1. Experiment result

tracks	Literature [16]time/ms	Literature [17]time/ms	Time of this algorithm /ms
10	15	7	1.071
50	383	164	1.224
100	1542	651	1.453
200	6244	2224	1.608

5. Conclusion

This paper proposes a fast route conflict detection method with spatial division, by dividing the space box where the trajectory is located, and predicting the position only for the trajectory in the same space box. The computational effort of the algorithm is mainly related to the number of tracks, and has little relationship with the size of the airspace. Simulation results show that the algorithm can effectively detect multi-route flight conflicts, and the time complexity of the algorithm is low. The algorithm is suitable for space-time related collision detection problems and has high application value. The algorithm is applicable to parallel computing and suitable for large-scale airspace conflict detection.

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