

UAV Three-dimensional Hierarchical Path Planning

Baosheng Li

College of Electronic Engineering, Tianjin University of Technology and Education, Tianjin, 300222, China

Abstract: Aiming at the disadvantages of low efficiency and long operation time of UAV path planning in traditional 3D mountain environment, this paper proposes a layered path planning model for 3D mountain environment. Firstly, three-dimensional elevation diagram is used to model the three-dimensional space, and the three-dimensional space is divided into horizontal and vertical directions, which effectively improves the efficiency of path planning. Secondly, B-spline curve method is used to fit the trajectory points of UAV. Finally, the simulation experiment is carried out. The results show that the generated UAV path is smoother and converges faster, which can meet the task requirements.

Keywords: UAV, Hierarchical path planning, Three-dimensional elevation map.

1. Introduction

The UAV path planning problem is actually a multi-objective constraint problem, and different flight environments have different constraints on the UAV [1]. For UAV path planning in three-dimensional mountain environment, the challenges and constraints faced by UAV are mainly the constraints of altitude corresponding to different latitude and longitude in three-dimensional environment space, which is also one of the most important reasons for the difficulty of UAV path planning. However, when faced with the problem of UAV path planning, most of the predecessors fixed the UAV in a certain plane and ignored the impact of height on the UAV. As a result, it is difficult to apply the research results to the real three-dimensional environment. Therefore, this paper focuses on the UAV path planning in the real three-dimensional environment space.

Due to the addition of the attribute of height in three-dimensional space, connectivity constraints like two-dimensional plane maps are no longer present [2]. Instead, mountain heights corresponding to different two-dimensional coordinates are taken as constraints, and other three-dimensional Spaces are taken as free solution Spaces. If the conventional two-dimensional path planning algorithm is still used, the operation time and efficiency of the algorithm will be seriously reduced, and the appropriate three-dimensional path cannot be planned finally. In order to solve this problem, a hierarchical path planning method is proposed in this paper. Firstly, the three-dimensional space is sliced and stratified in the direction of height, and the plane of each layer is divided into several grids. Among them, the grids intersecting with obstacles in the direction of height are obstacle grids, while the unintersected ones are free grids. Obstacle grids are impassable while free grids can pass. Secondly, the UAV's 3D path planning problem is transferred to a 2D plane, and a different free grid is selected in different sliced 2D planes. Finally, these selected free grids are fitted into a smooth curve by B-spline curve method, which is the planned flight path of UAV.

2. Three-dimensional Environment Modeling

In order to accurately reflect the flight condition of UAV in 3D mountain environment, it is necessary to establish a

relatively real 3D mountain environment space model of UAV. At present, there are four common modeling methods of three-dimensional environment space, which are: raster map modeling method, point cloud map modeling method, three-dimensional geometric map modeling method, three-dimensional elevation map modeling method, etc. Raster map modeling is often used in two-dimensional environment modeling and is widely used in path optimization of robots [3]. For three-dimensional space, raster map can only store limited obstacle information, and in the face of three-dimensional mountain environment, raster map can not well represent the relief information of terrain in three-dimensional mountain environment. The point cloud map modeling method is more suitable for the small task space with high precision requirements [4], but it is not suitable for the task space with large three-dimensional space. Geometric map modeling method mainly uses points, lines and surfaces for geometric modeling [5], which is generally more suitable for simple environment space. For complex environment such as three-dimensional mountain, geometric map modeling method is not applicable. Three-dimensional elevation map modeling method is a way of modeling in the form of array [6]. This method can not only truly restore the topography and geomorphic information of three-dimensional mountain environment, but also highlight the height, slope and slope direction information of the mountain. Therefore, for the three-dimensional mountain environment studied in this paper, three-dimensional elevation map modeling is very suitable.

According to the actual 3D mountain model data, the digital 3D space coordinate system is established first to determine the size of the environment space. This paper takes $100 \times 100 \times 100$ environment space as an example to establish O-XYZ three-dimensional space coordinate system. Wherein, let O be the origin, x axis be the direction of increasing longitude, y axis be the direction of increasing dimension, and z axis be the direction perpendicular to the sea plane. Then, the configuration space is determined in the coordinate system, and 100 unit lengths are taken in the directions of x, y and z axes respectively. The specific configuration space is shown in Figure 1. Where OA, OC and OE are 100 unit lengths, and the path planning of UAV is carried out in the cube OABC-EFGH.

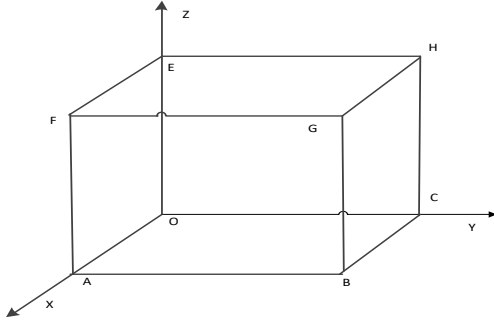


Figure 1. Three-dimensional configuration space

According to the three-dimensional configuration space model, the UAV flight environment was modeled by using the three-dimensional elevation map method, and the UAV flight environment was confined in the configuration space of $100 \times 100 \times 100$. Three-dimensional elevation map method is a modeling method that uses the mathematical model $z=z(x,y)$. All obstacle information is expressed in the form of coordinates, and then the information data is stored in an array. Finally, the space flight map of UAV can be established by using the array information. The specific modeling formula of 3D elevation chart is shown in Equation (1):

$$z(x, y) = \sum_{k=0}^n h_k \exp \left[- \left(\frac{x-x_k}{c} \right)^2 - \left(\frac{y-y_k}{d} \right)^2 \right] \quad (1)$$

In the above equation, n represents the total number of peaks and valleys in the three-dimensional mountain environment; h_k is the height of the k th peak; (x_k, y_k) represents the central coordinate of the k th peak; c and d represent the slope of the k th peak along the x and y axes, respectively.

The resulting three-dimensional environment map is shown in Figure 2 below:

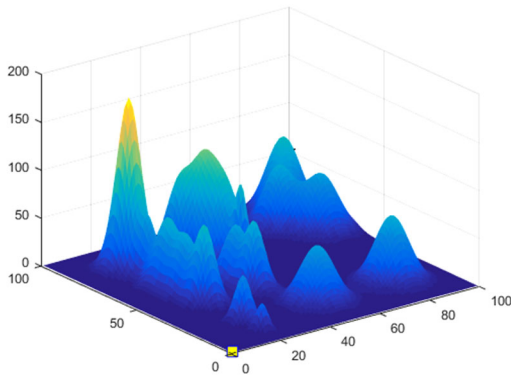


Figure 2. Three-dimensional environment map

3. Hierarchical Path Planning Model

Compared with two-dimensional environment path planning, three-dimensional path planning is more complex, more difficult and more factors need to be considered [7]. Therefore, aiming at the difficulty of 3D path planning, a new path planning method, namely hierarchical path planning model, is proposed in this paper. Firstly, slice and layer the three-dimensional configuration space in the direction of Z -axis, each layer of plane is parallel to the OXY plane, then

raster each separate layer of plane, each layer of plane is divided into several grids, then transfer the problem of three-dimensional path planning of UAV to a two-dimensional plane, and finally determine different free grids in different slice two-dimensional planes. Connecting these free grids is the flight path of UAV. Therefore, the environmental modeling methods adopted in this paper are divided into horizontal direction and vertical direction. The horizontal direction determines the free grids of each layer, and the vertical direction uses the horizontal free grids for three-dimensional path fitting. Figure 3 shows the specific layered structure model of the three-dimensional configuration space.

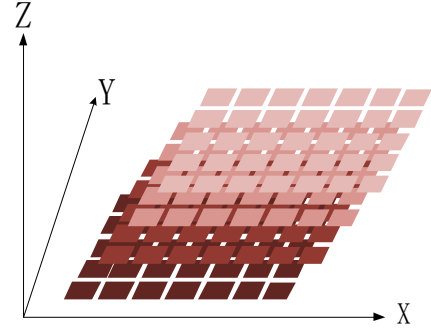


Figure 3. Three-dimensional space hierarchical structure model diagram

3.1. Horizontal direction

According to the hierarchical path planning model, the horizontal direction is the slice two-dimensional plane. In this paper, the two-dimensional grid map modeling method is used to divide each obtained two-dimensional plane into several grids of the same size on average. These grids are specifically divided into feasible grids and obstacle grids. When the grid intersects the mountain in the height direction, this grid is the obstacle grid; otherwise, when the grid does not intersect the mountain in the height direction, this grid is the feasible grid [8]. During path planning, a feasible grid should be selected from each two-dimensional plane, and then the flight path of UAV can be obtained by fitting the feasible grid selected from each plane. The advantage of this is that the difficulty of path planning in three-dimensional environment is greatly reduced, and the three-dimensional problem is reduced to a two-dimensional problem. In this process, in order to select feasible grids of two-dimensional plane relatively easily, each grid of two-dimensional plane is numbered in this paper. Meanwhile, in order to select path nodes, central coordinates of feasible grids are selected as path nodes. Of course, the grid number and grid size of each plane are also exquisite, which determines the precision of path planning. If the number of raster is larger or the size of raster is smaller, the precision of path planning will be higher and the optimization effect of path will be improved. However, the corresponding number of path nodes to be searched will be increased, and the time of path planning will be longer. If the number of grids is smaller or the size of grids is larger, the path optimization accuracy decreases.

In this paper, according to the characteristics of configuration space, it is assumed that each two-dimensional plane is divided into 10×10 raster space. The specific renderings are shown in Figure 4 below:

10							...	98	99	100
9										
8										
7										
6										
5										
4										
3	21	...								
2	11	12	13	14	15	16	17	18	19	20
1	1	2	3	4	5	6	7	8	9	10
0	1	2	3	4	5	6	7	8	9	10

Figure 4. Horizontal grid rendering

The two-dimensional plane starts from the origin (0,0) and is numbered from left to right along the X-axis. The numbers are 1,2,3... 99,100, so that the concrete coordinates of the viable grids can be determined based on the grid number. According to the previous introduction, the coordinates of each grid are the coordinates of the center point of the grid. Assume that the selected feasible grid number is 15, then its coordinates are (14.5, 1.5). The specific calculation formula is as follows:

$$\begin{cases} x_i = (i-1)\%10 + 0.5 \\ y_i = (i-1)/10 + 0.5 \end{cases}, i = 1,2,3 \dots, 99,100 \quad (2)$$

In the above formula, i represents the number of the grid, and the specific value is 1,2... , 99,100; x_i and y_i represent the x-coordinate and y-coordinate values of the i-th grid respectively. % stands for mod operation.

3.2. Vertical direction

According to the hierarchical path planning model, the three-dimensional environment space of UAV flight is sliced and stratified at the height. The vertical direction is the path planning model in the height direction. In the horizontal direction, a flightable grid will be generated in the two-dimensional plane of each layer. By integrating the flightable grid of each layer, the scatter set of flight path of space UAV can be obtained. In the vertical direction model, it is necessary to map the scattered points set obtained in the horizontal direction model to the vertical direction, that is, the plane YOZ, then use the curve fitting method to fit these scattered points, and finally optimize the path, calculate the length and feasibility of the path. Suppose the spatial model is divided into five layers in height, and the coordinate system is established with the horizontal path length as the horizontal axis and the position height of grid points as the vertical axis. Then the planned vertical model is as follows:

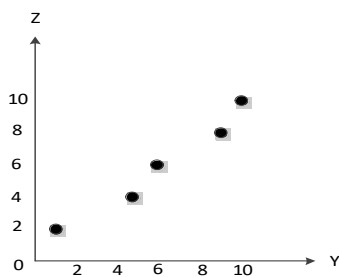


Figure 5. Vertical direction model

According to Figure 5, the height difference of the two feasibility grids selected in the vertical direction model is the same, but the spacing between the two feasibility grids in the horizontal direction is different, which verifies the characteristics of the layered path planning model. Next, it is necessary to curve fit these feasibility grids in the three-dimensional space environment, so that the flight path of the UAV can be obtained.

3.3. Feasibility path generation and optimization

When the feasible grids selected in the horizontal direction are mapped to the vertical model, multiple constraints need to be considered in the flight process of the UAV, and whether there are obstacles between the feasible grids is also a problem. Therefore, the flight path of the UAV does not directly connect these grids in a straight line, but needs to use the algorithm for curve fitting of the feasible grids. To meet the actual flight requirements of UAV. At present, there are three commonly used curve fitting methods, namely, circular arc fitting method, Bessel curve method and B-spline curve method.

The circular arc fitting method is a method mainly used to remove the sharp corners of the path. It has the characteristics of simple operation, easy to understand, and the path length after fitting is shorter than the original path length. It is suitable for the simple path with fewer included angles. Bessel curve method is a kind of mathematical curve of two-dimensional graph. It can control the trend of curve by using control points. It has good global planning effect, but its local adjustment ability is weak. B-spline curve is a more flexible Bessel curve, which not only has all the characteristics of Bessel curve, but also is more flexible, which can make local correction and adjustment to a certain section of curve path. At the same time, B-spline curve is widely used, which can not only optimize the curve in the two-dimensional plane, but also optimize the curve in the three-dimensional space. Therefore, B-spline curve method is used in this paper to fit the UAV's flight path points in the vertical direction.

4. Simulation Result Analysis

In this paper, the idea of layering is adopted for path planning, and the three-dimensional space model is set as 100×100×100 airspace. Other simulation parameters are set as follows: The start point of path planning is set to (1,1,1); Set the path planning target point to (100,100,70). The result of path planning and the change of optimal individual fitness are shown in Figure 6 and 7.

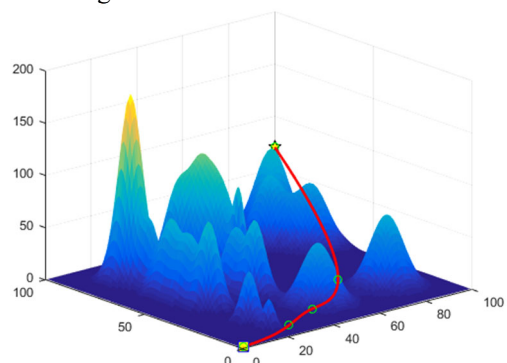


Figure 6. Route planning effect diagram

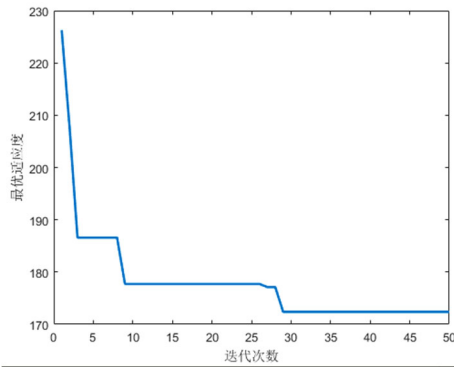


Figure 7. Fitness value change effect diagram

The simulation results show that the hierarchical path planning method can plan the shortest path at a fast convergence rate, and the optimal fitness value is close to the optimal value, which can well meet the task requirements.

5. Conclusion

This paper mainly introduces the layered path planning model of UAV in 3D environment. Firstly, the characteristics and advantages of hierarchical path planning are introduced, and then the modeling method of UAV three-dimensional environment is introduced, and the three-dimensional environment modeling of UAV is completed by three-dimensional elevation diagram method. Then, the hierarchical model: horizontal direction and vertical direction is introduced in detail, and the selection of horizontal direction and vertical direction path node and path optimization are elaborated. Finally, the feasibility and smooth optimization of the planned path are analyzed, and the final simulation results show the practicability and feasibility of the layered path

planning model.

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