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# The comparison of four UAV path planning algorithms based on geometry search algorithm

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***Abstract*—The comparative study of four practical three-dimensional (3D) path planning algorithm based on geometry search is proceeded in this paper, the four algorithms include Dijkstra algorithm, Floyd algorithm, A* algorithm and Ant colony algorithm. In four algorithms, the working environments of Unmanned Aerial Vehicle (UAV) are all modeled using grid map method and UAV three-dimensional paths are all obtained by amending two-dimensional paths with the terrain following algorithm. In addition, a perpendicular approach is used to choose the key path node during UAV path planning. In this paper, online real-time path planning abilities of the four algorithms are compared from the two aspects of the run time and the path length. Simulation results show that the four algorithms can all handle fixed threats and sudden threats, and their planning time are short; but synthetically considering the run time, complexity and path length of the four algorithms, Dijkstra algorithm is in turn better than Floyd algorithm, A* algorithm and Ant colony algorithm.**

***Keywords- UAV; Path planning; Dijkstra algorithm; Floyd algorithm; A* algorithm; Ant colony algorithm***

## I. INTRODUCTION

Path planning of UAV refers to looking for an optimal movement route of a moving object from the starting point to the target point under certain constraints, the optimal movement route, namely path, meet some performance index and some constraints [1]. Path planning is usually processing into two kinds of questions: one is the optimal control problem; the second is the space search problem. And the corresponding planning algorithm can also be divided into optimization algorithm based on control theory and the search algorithm based on geometry [2]. The optimization algorithms based on cybernetics need to consider aircraft motion dynamics constraints; and the search algorithms based on geometry look the path planning as search space problem, don't need to consider the aircraft motion dynamics constraints. Because there exist many types of UAVs, such as fixed wing aircraft and rotary aircraft which movement dynamics constraints are different, path planning algorithms of various UAVs based on the control theory are different from each other; and because the aircraft motion dynamics constraints are not considered by the search algorithm based on geometry, a path planning algorithm is suitable for all kinds of UAV. In conclusion, the applicability of the path planning algorithm based on geometry is stronger.

Generally, search algorithms based on geometry can be divided into certainty search algorithm and random search algorithm. Search behavior of the certainty search algorithm can be foreseen and repeated, and the optimal path conforming to a performance index can be obtained; however, search behavior of the random search algorithm cannot be foreseen for adopting random probability factor, and the optimal path cannot be guaranteed, only a satisfactory path is obtained [2]. Usually, the certainty search algorithm include shortest path algorithm and dynamic programming algorithm and so on, and methods based on the shortest path mainly include Dijkstra algorithm, Floyd algorithm and A* algorithm. The common random search algorithms include Genetic algorithm, particle swarm algorithm, Ant colony algorithm which are intelligent optimization algorithms [1, 3]. In addition, path planning algorithm can be divided into grid map method, roadmap method and artificial potential field method according to the literature [4].

In this paper, the working environments of UAV in four algorithms are all modeled based on grid map method; and the comparative study of Dijkstra algorithm, Floyd algorithm, A* algorithm and Ant colony algorithm is proceeded, the comparative work mainly compare running time and the path length of the four algorithms to check whether every algorithm meet the real-time demand and shortest path demand; To facilitate Dijkstra algorithm and Floyd algorithm used in UAV path planning, a perpendicular approach is used to choose the key path node during UAV path planning referring to the literature [5]; in addition, a terrain following algorithm is proposed to amend two-dimensional paths, and then to obtain three-dimensional paths.

## II. GRID MAP METHOD AND PERPENDICULAR APPROACH

### *A. Grid map method*

Grid map method is to divide the working environment of UAV into the regular and uniform grids. According to whether there is obstacle in grids, each grid can be judged that which one of two states are they in. The grid without obstacle is called the free grid; otherwise the grid is called the obstacle grid. UAV path planning problem is actually to

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find a shortest path from the starting grid to the target grid by bypassing obstacle grid.

### B. *perpendicular approach*

More convenient to understand the perpendicular approach, actual simulation environment is taken as an example to explain in detail the route selection rules this paper. The schematic diagram of choosing the key path node in using Dijkstra algorithm and Floyd algorithm to plan path is shown in Figure 1.

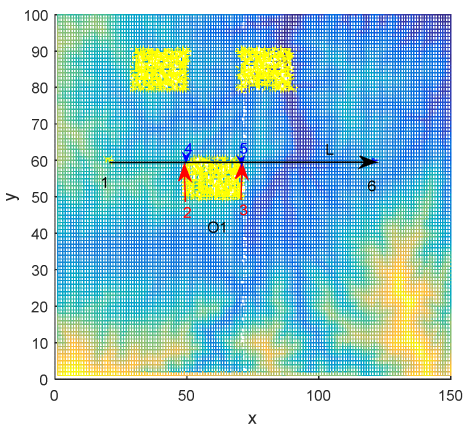


Figure 1. The schematic diagram of choosing the key path node by the perpendicular approach

The procedure of choosing the key path node by the perpendicular approach is given as

Step 1 Find the obstacles passing the wire that connect the starting point and the target point;

Step 2 Do the perpendiculars to on the obstacles, record the intersections of perpendiculars and obstacles edges, and number the intersections respectively, as shown in Figure 1, the intersections are $\{1 \quad 2 \quad 3 \quad 4 \quad 5 \quad 6\}$;

Step 3 select grid point of free grid near intersections as the key path node required by Dijkstra algorithm and Floyd algorithm.

## III. INTRODUCTION TO THE FOUR KINDS OF ALGORITHMS

### A. *Dijkstra algorithm*

Dijkstra algorithm is a mature classical shortest path of single source algorithm, it is used for calculating the shortest path from one node to all other nodes in non-negative weights graph. The basic idea is to divide all of the nodes in the weighted graph into two groups, and the first group includes the nodes with the shortest path determined which are expressed by $S$, while the second group includes nodes with the shortest path to be determined which are expressed by $U$; then add the nodes in $U$ into $S$ one by one according to the order of the increasing length of path, until all the vertices are added to the $S$, Dijkstra algorithm is ended [3]. It is need to be noticed that initially, $S$ only include one starting point $v$, and in the process of adding the nodes in $U$ into $S$, the shortest path length from the source point $v$ to each vertex in $S$ is always not greater than the path length from the source point $v$ to each vertex in $U$.

### B. *Floyd algorithm*

Floyd algorithm is a shortest path of multi-source algorithm which can solve the shortest path between any two points in weights graph which can be a negative weights graph. The core of Floyd algorithm is to check whether there is a vertex which makes the distance from $u$ to $w$ and then to $v$ is shorter than the known path of vertices $u$ and $v$. If there exist the vertex, then update the distance of $u$ and $v$ with the distance from $u$ to $w$ and then to $v$; otherwise, the distance of $u$ and $v$ keep its original value.

### C. *A* algorithm*

A* algorithm is a classical algorithm which commonly used in engineering, and is often used in UAV two-dimensional (2D) path planning. The basic idea is firstly to calculate the cost of all nodes that can be reached from the current position node and evaluate the point that has been searched through the heuristic information, and then choose the node with the minimum cost as the new expanding node; secondly to repeat the above procedure until one of the expanding node is target point.

### D. *Ant colony algorithm*

The basic principle of ant colony algorithm can be expressed as follows

Step 1 Initialize pheromone matrix of the grid map;

Step 2 Form a viable path from the starting point to the target point ants according to the state transition rules for every ant, and then obtain the optimal path by comparing the objective functions of all ants' viable paths;

Step 3 Adjust pheromone matrix of the grid map according to certain pheromones adjustment rule;

Step 4 Repeat step2 and step 3 until the global optimal path is obtained.

## IV. THE PRINCIPLE OF TERRAIN FOLLOWING

Terrain following is to change the path of adjacent path point planed by the four algorithms to a new path according to the topographic relief. The detailed implementation steps are expressed as follows.

Step 1 Write the linear equation of adjacent path points $P_1(x_1 \quad y_1 \quad z)$ and $P_2(x_2 \quad y_2 \quad z_2)$ according to the linear equation between the two points in space, and calculate the $z$ coordinate value corresponding to the every $x$ coordinate value between two adjacent path points.

Step 2 compare $z$ coordinate value between flight path and the space surrounded by the $x$ coordinate value and $y$ coordinate value of path point $P_1(x_1 \quad y_1 \quad z)$ and $P_2(x_2 \quad y_2 \quad z_2)$ corresponding to the same $x$ coordinates, and obtain the maximum $z$ coordinate value of all point which lie in the surrounded space and its $z$ coordinate value is larger than $z$ coordinate value of flight path. Further, record the exact coordinate values and the quantity of these points. Assume the variable recording the quantity of these



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points is called as oversum, and assume the initial value of variable oversum is 1.

Step 3 Judge whether the path need to be modified according to the value of variable oversum, if the value of variable oversum is greater than or equal to 2, then the path is needed to modify. Specially, a new path between path point $P_1(x_1 \quad y_1 \quad z)$ and path point $P_2(x_2 \quad y_2 \quad z_2)$ is obtained by adding the surrounded space point founded above to the path planning among adjacent path points $P_1(x_1 \quad y_1 \quad z)$ and $P_2(x_2 \quad y_2 \quad z_2)$. If the value of variable oversum is still 1, then the path doesn't need to be modified.

## V. SIMULATION RESULT

To test online real-time path planning abilities of the four algorithms described in this paper, path planning abilities under the following two conditions are verified. Firstly, path planning effect of four algorithms are verified under the threat of three fixed obstacles, secondly, path planning effect are verified when adding a sudden threat, where, there are also two condition according to the position where the sudden threat is added to the working environment of UAV. One sudden threat is added near the starting point, and the other is added near the target point. In the process of path planning, four algorithms firstly plan the path under the threat of three fixed obstacles, meanwhile, they scan the obstacles ahead and reorganize path when a sudden threat is founded. In addition, in order to well demonstrate the advantages of terrain following proposed in this paper in path planning, the path planning figures of A* algorithm with terrain following and without terrain following are given.

The path planning figure of four algorithms under three fixed terrain obstacles condition is shown in Figure 2; the path planning figure of four algorithms when adding a sudden threat near the starting point is shown in Figure 3; the path planning figure of four algorithms when adding a sudden threat near the target point is shown in Figure 4. In Figures 2-4, the red path line represents path planning result of A* algorithm; the blue path line represents that of Dijkstra algorithm; the green path line represents that of Floyd algorithm; the black path line represents that of ant colony algorithm.

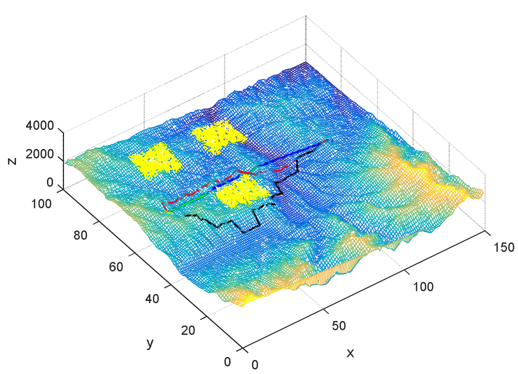


Figure 2. The path planning figure of four algorithms under three fixed terrain obstacles condition

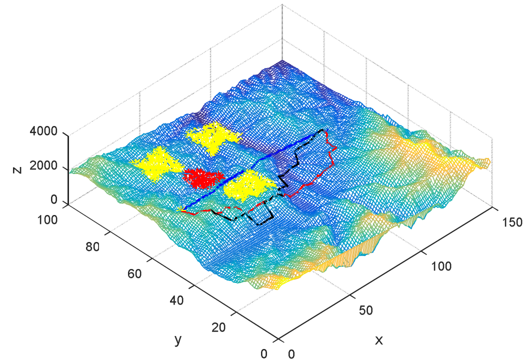


Figure 3. The path planning figure of four algorithms when adding a sudden threat near the starting point

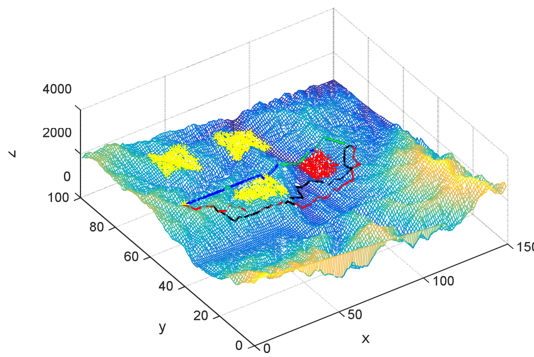


Figure 4. The path planning figure of four algorithms when adding a sudden threat near the target point

As can be seen from the Figures 2-4, under the above three situations, the path lines planned by the Dijkstra algorithm and Floyd algorithm completely overlap; the quantity of long straight path lines in the path lines planned by the Dijkstra algorithm and Floyd algorithm are more than those planned by the A* algorithm and ant colony algorithm; all of four algorithms described in this paper can handle fixed and sudden threats. The reason for the phenomenon that Dijkstra and Floyd algorithms have the same path lines is that the key path nodes of Dijkstra algorithm and Floyd algorithm obtained by perpendicular approach are the same, both algorithms can plan out the optimal path, and the optimal path are the same. It can be seen from the phenomenon that the quantity of long straight path lines in the path lines planned by the Dijkstra algorithm and Floyd algorithm are more than those planned by the A* algorithm and ant colony algorithm, the paths planned by the Dijkstra algorithm and Floyd algorithm are shorter than those planned by the A* algorithm and Ant colony algorithm.

when adding a sudden threat near the target point, the path planning figure without terrain follow of A* algorithm is shown in Figure 5, and the path planning figure with terrain follow of A* algorithm is shown in Figure 6.



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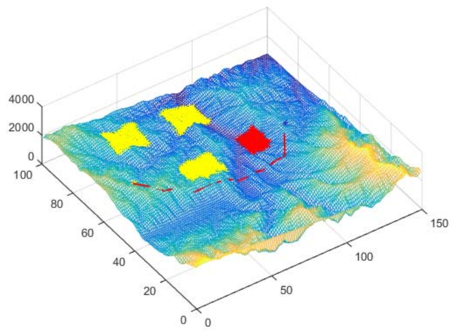


Figure 5. The path planning figure without terrain follow of A* algorithm

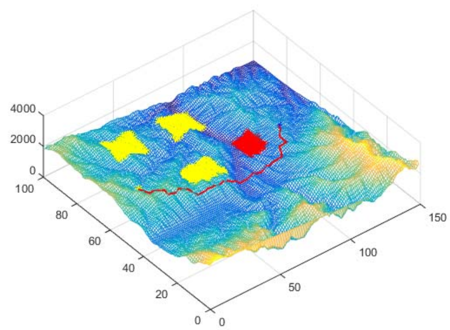


Figure 6. The path planning figure with terrain follow of A* algorithm

It can be seen by comparing Figure 5 with Figure 6, the 3D path planning with terrain following can well follow topographic relief and complete the path planning of UAV. In order to further compare the run time and path length of four algorithms based on geometry search algorithm, the path planning time of four algorithms is given in Table 1, 3D path length of four algorithms under three obstacle conditions is given in Table 2.

TABLE I. THE PATH PLANNING TIME OF FOUR ALGORITHMS

| Algorithm | number of experiments | Average run time for three situations(s) | Average run time for three situations(s) |
|---|---|---|---|
| Dijkstra | 25 | 3.029996 | 1.01 |
| Floyd | 25 | 3.06997 | 1.0233 |
| Ant | 25 | 3.383045 | 1.1277 |
| A* | 25 | 3.278161 | 1.0927 |

TABLE II. 3D PATH LENGTH OF FOUR ALGORITHMS UNDER THREE OBSTACLE CONDITIONS

| Algorithm | Three fixed terrain obstacles condition | With a sudden threat near the starting point | With a sudden threat near the target point |
|---|---|---|---|
| Dijkstra | 1046.6 | 1046.6 | 2605.5 |
| Floyd | 1046.6 | 1046.6 | 2605.5 |
| Ant | 3869.1 | 3869.1 | 4146.6 |
| A* | 4023.5 | 3878.1 | 3878.1 |

It can be seen from the run time shown in Table 1, average run time of four algorithms are below 1.2s, real-time performance is good; the run time of Dijkstra algorithm is shortest, and is in turn less than that of Floyd algorithm, less than that of A* algorithm, less than that of ant colony algorithm. As can be seen from 3D path length of four algorithms under three obstacle conditions given in Table 2, the path lengths of Dijkstra and Floyd algorithms are the same, and under three obstacle conditions, they are both far less than A* algorithm and ant colony algorithm.

synthetically considering the run time, complexity and path length of the four algorithms, Dijkstra algorithm is in turn better than Floyd algorithm, A* algorithm and Ant colony algorithm. In addition, the four algorithms can all handle fixed threats and sudden threats, and their planning times are short, therefore, four algorithms can all be used to complete online real-time path planning.

## VI. CONCLUSION

Online real-time path planning abilities of four algorithms based on geometry search are compared in this paper, the four algorithms include Dijkstra algorithm, Floyd algorithm, A* algorithm and Ant colony algorithm. Simulation results show that the four algorithms can all handle fixed threats and sudden threats, and their planning time are short; therefore, four algorithms can all be used to complete online real-time path planning. But synthetically considering the run time, complexity and path length of the four algorithms, Dijkstra algorithm is in turn better than Floyd algorithm, A* algorithm and Ant colony algorithm. The advantages of terrain following proposed in this paper can be seen from the path planning figures of A* algorithm with terrain following and without terrain following.

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