Route Planning for Unmanned Aerial Vehicle Based on Rolling RRT in Unknown Environment

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***Abstract*—For the problem of unmanned aerial vehicle route planning in unknown environment, a rolling rapidly-exploring random tree algorithm is proposed. According to the current environment information, the local route planning is carried out in the rolling window. Unmanned aerial vehicle flight in accordance with the planning results. At the same time, the new environment information is detected and the next stage of the route is generated. This process is repeated, until the unmanned aerial vehicle reaches the target position. The implementation method of the rolling rapidly-exploring random tree algorithm is discussed in detail, including the rolling window design, the local target setting, random node selection, route pruning and smoothing and so on. A new random node selection strategy is proposed, which can guide the rapidly-exploring random tree grows rapidly to the boundary of the rolling window. Finally, the simulation results show that the proposed method can meet the demand of online route planning in unknown environment.**

Keywords—Route planning; Rapidly-exploring Random Tree; Unmanned Aerial Vehicle; Rolling optimization

I. INTRODUCTION

Route planning is an important part of the unmanned aerial vehicle (UAV) mission planning system. Nowadays, the application of the UAV is more and more extensive. There are many uncertain factors in the task environment of UAV, or the UAV is flying in a completely unknown environment [1]. At this time, the off-line route planning method is no longer applicable. The online route planning method can be used to generate a feasible route based on real-time detection of environmental information [2, 3].

Rapidly-exploring Random Tree (RRT) algorithm is an efficient path planning method, which can quickly find the feasible solution in complex environment [4]. The existing research shows that the RRT algorithm has better optimization performance than the mixed integer linear programming [5], A* algorithm [6], and other algorithms [7, 8]. Different from the planning method based on Voronoi diagram, the RRT algorithm does not need to partition the task area in advance, and RRT is easier to deal with all kinds of shape threats, including dynamic threats, which is more conducive to the application in the complex task environment. Different from the MILP method, the computational complexity of RRT algorithm does not change significantly with the increase of threats, which can be adapted to a variety of special requirements of the computational constraints. So RRT algorithm can be widely used in UAV route planning, robot motion planning, etc [9,10].

In this paper, a rolling RRT algorithm is proposed to carry out the online route planning for UAV in unknown environment. The remainder of paper is organized as follows. Section 2 introduces the problem of online route planning of UAV. Subsequently, in section 3, it gives a brief introduction of the principle of RRT algorithm, expounds the realization mechanism of rolling RRT algorithm, including the rolling window design, local target setting, random node selection, path pruning and smoothing, then the steps of the rolling RRT algorithm are given. In section 4, the simulation experiment is carried out and the section 5 is conclusion.

II. PROBLEM DESCRIPTION

The UAV route is composed of a series of nodes. The order of the nodes corresponds to the order of arrival of the UAV. $q(x_k, y_k)$ indicates the k-th node position of the UAV, the route from the initial point through n nodes to the target point can be expressed as:

$$Route = \{q(x_1, y_1), \cdots, q(x_k, y_k), \cdots, q(x_n, y_n)\} \tag{1}$$

UAV can only detect the environmental information in current rolling window, and build a local environment map. Instead of generating the whole route at a time, the rolling planning method generates several route segments in the local area. UAV flight along the generated route, meanwhile the next stage of route planning is carried out according to the real-time detection of the environment.

Rolling window indicates the current detection range of the UAV, is also the range of the local route planning. The rolling window is expressed as $Win(q_R(t))$. $q_R(t)$ is the center position of the rolling window, and R is the radius of the rolling window.

$$Win(q_R(t)) = \{p \mid p \in C, d(p, q_R(t)) \le R\} \tag{2}$$

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III. ROLLING RRT ALGORITHM

A. Principles of RRT Algorithm

Assumes that C is the search space. C_{free} denotes the feasible region, C_{obs} denotes the obstacle region. C_{free} and C_{obs} are subset of C, which satisfies $C = C_{free} \bigcup C_{obs}$, $C_{free} \bigcap C_{obs} = \varnothing$. $q_{init} \in C_{free}$ and $q_{target} \in C_{free}$ represent the initial position and target position.

First, q_{init} is selected as the root node. q_{target} is selected as the random node q_{rand} with the probability p_g, or choosing q_{rand} from C_{free} with the probability $1-p_g$. The nearest node from the tree to q_{rand} is selected as the near node q_{near}. Then, a candidate new node q_{new} is obtained by extending the distance ε with the direction from q_{near} to q_{rand}. In the extension process, judging whether the pathway is conflict with the known obstacle region, if there is no confliction, then q_{new} is accepted as a part of the tree, else reject this q_{new} and renew one. With the constant extension, the construction of tree is complete if any of nodes in the tree is close enough to the target position. From the closest node with the target position, to search theirs parent node step by step. Then a feasible path is obtained from the initial position to the target position.

B. The design of rolling planning

The rolling route planning is designed based on the idea of predictive control, and its basic framework has three components.

- Environmental information detection. Using airborne sensing equipment, UAV obtains the environment information and evaluates the impact of threats, and then local environmental model is established.
- Local planning. The local environment model is constructed as a rolling window. A local target is set in the rolling window, which is the mapping of the final target. Local route planning in the rolling window is carried out according to the local target.
- Information correction. UAV flight in the known local environment, while detecting the new information. This new information is used to supplement and improve the original environmental model, and prepare for the next stage of planning.

Through the above three steps, the rolling route planning has realized the closed loop mechanism. By constantly exploring the environment, the ability to deal with the uncertainty and emergencies is enhanced. In the unknown environment, the framework of rolling planning is shown in Fig.1.

Rolling RRT algorithm is combined with the basic framework of rolling planning and RRT algorithm. The RRT algorithm is used as the route planning method in the rolling window. In the design of rolling RRT algorithm, the selection of the root node, the mapping of the target position in the rolling window, the selection of random node and the criterion of the termination are mainly involved.

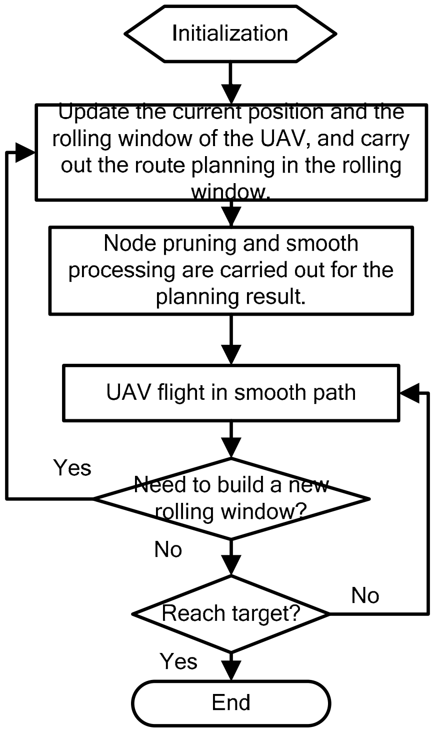


Fig. 1. The framework of rolling planning in unknown environment

Since UAV cannot be suspended in the air, this needs to start the next window's route planning before UAV reach the boundary of current window. The last node of the current window is selected as the center of the next window. The choice of local target needs to consider local environment in current window and the final target location. In general, the local target is selected from the boundary of the rolling window. As the mapping of the final target location, the role of the local target in the RRT is mainly related to the selection of random nodes.

In Fig. 2, (x_c, y_c) is the center position of the current rolling window. The dotted line indicates the boundary of the rolling window, and R is the radius. Connecting the final target (x_g, y_g) and (x_c, y_c), the intersection of window circle denote as (x_{t0}, y_{t0}).

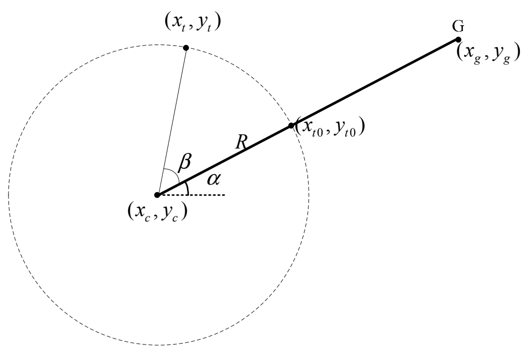


Fig. 2. Random node selection in rolling window

(x_{t0}, y_{t0}) is selected as the q_{rand} with the probability p_g, and the other location on the boundary is chosen as q_{rand} with the probability $1-p_g$. The closer point with (x_{t0}, y_{t0}), the greater probability of being selected as q_{rand}.

$$\beta = randn \cdot \pi \tag{3}$$

$$\begin{cases} x_t = R \cdot \cos(\alpha+\beta) \\ y_t = R \cdot \sin(\alpha+\beta) \end{cases} \tag{4}$$

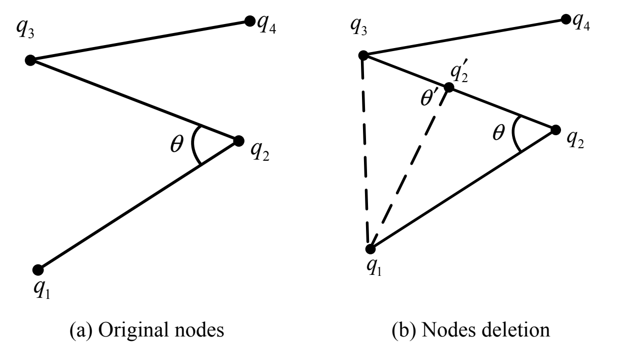
To generate a random angle $-180^\circ < \beta < 180^\circ$, which follows the normal distribution. Taking the (x_{t0}, y_{t0}) as the center, the deflection angle is β, the random node coordinates (x_t, y_t) can be obtained by the (4). If the q_{rand} is located in a threat area, it will be discarded and regenerated.

C. Route Pruning and Smoothing

RRT algorithm has the high computational efficiency, but the resulting route is not optimal. It is necessary to use certain strategy to remove redundant nodes on the route. To this end, a simple and efficient path pruning and smoothing method is designed.

Fig.3(a) shows four consecutive nodes on the route. The sequence is $q_1 \to q_2 \to q_3 \to q_4$. First calculating the turning angle θ of the adjacent nodes $\widehat{q_1q_2q_3}$, and according to the θ to do different processing:

- $120^\circ < \theta < 180^\circ$: in the neighborhood of node q_2,the route is relative straight, and unnecessary to carry out the route pruning operation;
- $0^\circ < \theta < 120^\circ$: The route is tortuous in the before and after q_2.It is necessary to carry out the pruning;



(a) Original nodes (b) Nodes deletion

Fig. 3. Sketch map of route pruning

If it is necessary to pruning, first judging whether exist threat in the straight line $\overline{q_1q_3}$, which connect the node q_1 and q_3. If there is no threat, the node q_2 will be abandoned, and setting the $\overline{q_1q_3}$ as the new route segment; else q'_2 is defined as the midpoint of $\overline{q_2q_3}$, and add $\overline{q_1q'_2}$ as the part of the route if there no threat between q_1 and q'_2; else retain the q_2.

After route pruning, the connection between adjacent nodes is still a broken line. In this paper, the Bezier curve is used to smooth the route.

D. Algorithm Steps

Based on the analysis of the above, the rolling RRT algorithm in unknown environment is described below:

step 1) Algorithm initialization;
step 2) Random node selection strategy is used to obtain q_{rand};
step 3) According to the nearest principle, the q_{near} is selected, and ε is extended to obtain the candidate new node q_{new};
step 4) Whether q_{new} is conflict with known threats? If conflict, then turn to step 2);
step 5) Accept q_{new} as the new node. Route reaches the border of rolling window? if not reach, then turn to step 2);
step 6) Using reverse search to obtain the route in the rolling window;
step 7) Route pruning and smoothing.

IV. Simulation

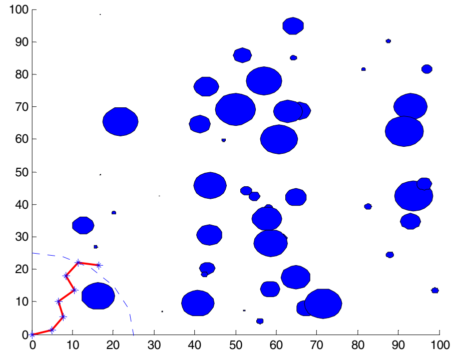
There are 50 threat areas in the task environment. The rolling window radius is 25. The UAV initial position coordinate is $(0,0)$, and the target position coordinate is $(100,100)$. The parameters of RRT is set as $\varepsilon = 5$, $p_g = 0.5$. The CPU of computer is Intel dual core 2.1GHz, memory is 2G. Algorithm is simulated in MATLAB.

Fig. 4 is the rolling route planning process. Blue areas are threats, but before taking off, these threat areas are unknown for UAV. The radius of the first rolling window is shown with the dotted line in Fig.4(a). In the first rolling window, RRT algorithm generates a route composed of 7 nodes, after pruning and smoothing, 5 nodes are retained, as shown in Fig.4(b). Through pruning and smoothing, unnecessary nodes are discarded, and unnecessary direction changes are reduced. The flatness of the route becomes better and the voyage becomes short. Fig.4(c) and Fig.4(d) respectively is the planning result by RRT algorithm in the sixth rolling window.

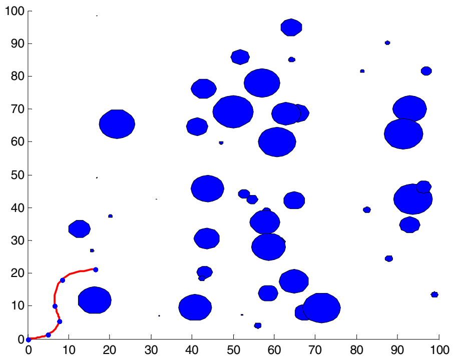
Route planning time and the number of nodes in each rolling window are shown in Table I. Rolling RRT algorithm can get a feasible path in several ten milliseconds, which is able to meet the requirements of real time.

TABLE I. SIMULATION DATA OF ROLLING RRT

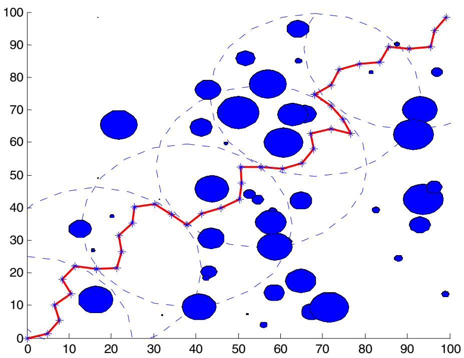
Windows	1	2	3	4	5	6
Time(ms)	39.3	17.8	24.4	17.8	12.7	13.2
Nodes	10	12	7	11	9	8



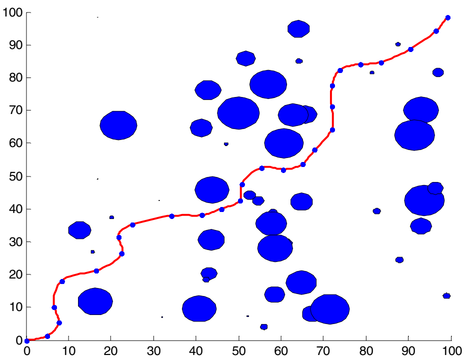
(a) The first rolling window



(b) Smooth after first rolling window



(c)The sixth rolling window



(d) Smooth after sixth rolling window

Fig. 4. Simulation results of rolling RRT

V. CONCLUSION

To solve the problem of UAV route planning in unknown environment, a rolling RRT algorithm is proposed in this paper. Each time, local route is generated only in the detection range. UAV flight in accordance with local route in current rolling window, at the same time, route planning for the next stage is carried out. The implementation method of the rolling RRT algorithm is discussed in detail, including the rolling window design, the local target setting, random node selection, and so on. A redundant nodes pruning method is designed, and the Bezier curve is used to smooth the route. The simulation results show that the proposed method can meet the requirements of online planning in unknown environment, and obtain satisfactory results.

The unique feature of this paper is to propose a new rolling RRT algorithm, and design a new random node selection strategy. On the one hand, the rolling window can be guided to the final target position through the local target position. On the other hand, the RRT can be extended to the border of the rolling window quickly. Compared with other methods, the proposed method has the advantages of simple structure, easy to implement, small amount of calculation, and is especially suitable for online planning problems with high real-time requirement.

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