Improved RRT-Connect Algorithm for Urban low-altitude UAV Route Planning

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Abstract: Path length and computation time in path planning seriously affect the safety and efficiency of urban low-altitude UAV flight. This paper improves RRT-connect Algorithm for path planning, the search step length, parent node selection and branch orientation selection are optimized to reduce the path length and algorithm time. Starting from the shortest parent node of the two trees, track search is carried out in the Middle Direction, the search step length is changed according to the field of view, the search step length is cut down quickly through the open field, and the search step length in narrow space is reduced, at the same time, the growth direction of the main branch of the search tree is controlled by the angle to reduce the probability of the UAV turning sharply. Simulation experiments show that the proposed algorithm has better time and space advantages and convergence than the current popular algorithm, the comparison results show that the optimized Algorithm RRT-connect is superior to the current flow Algorithms RTT-extend and Lazy-RTT in terms of the time consumption of short-time fast search and the length of path generation.

1. Introduction

Unmanned Aerial Vehicle (UAV) is widely used in urban logistics distribution. Mainly because of its small size, low cost, high efficiency and other advantages. Route Planning is always a difficult problem in the short distance of UAV. At present, the main research content of UAV route planning is optimized path search algorithm\textsuperscript{[1]}. The traditional Dijkstra and a * Algorithm mainly solves the accuracy of route planning in time and part\textsuperscript{[2]}, but it is time consuming and not suitable for application in 3D. The artificial field potential method is easy to fall into local optimization, ant colony algorithm has the characteristics of global optimization, but the convergence time is long and the convergence speed is slow\textsuperscript{[3]}. With the continuous change of city layout, 3d modeling can not be applied to UAV path planning, so a modeling algorithm is needed.

RRT Algorithm is a probability-based random search algorithm. Because of its randomness, long search time, and the path is not optimal, it needs to be optimized\textsuperscript{[4]}. The algorithms RRT-connect, RRT-extend and Lazy-RRT are proposed from the aspects of convergence speed and computation amount\textsuperscript{[5-7]}. Although they have resolved the problem of low search precision, they still have some deficiencies in the smooth path and the length of the path. This paper presents an improved RRT-connect algorithm for fast route planning based on two-way Tree theory, in which starting point and target point are the parent nodes, two trees are generated to the middle, the parent node is selected and the step is searched, the connect algorithm is improved to improve the convergence speed of path planning, reduce the path distance and improve the search efficiency.
2. Improved RTT-connet Algorithm

RRT-connet has some disadvantages, such as fixed step value and numerous directional branches and leaves. This paper starts with the time and distance of RRT-connet. The starting point, the end point and the obstacle are initialized, and the coordinates of the starting point and the end point are added to the random tree so that when the two trees grow, they have a direction and can reduce the computation of useless work, starting from the initial point, a random point \( x \) is generated to find the point on Tree1 with the smallest euclidean distance from \( x \), marked as \( x \), and the direction is pointing to \( X \), if \( X \) does not meet the obstacle constraint in C space, the point is discarded to regenerate the random point. If \( X \) does, the growing branches and endpoints are injected into the the tree[8].

![Figure 1 RRT-connect double tree stochastic search growth process](image)

Then we calculate the point on Tree2 with the smallest euclidean distance \( x \) and mark it as \( x \), the direction is that the point points to \( x \), then grow a certain step in this direction to get \( x \), and if collision detection is used, \( x \) is injected into TREE2. At the same time, we start the greedy strategy subroutine, continue to grow in the \( x \) direction until it encounters an obstacle or until the nearest distance between the two trees is less than the threshold value, if the distance between two trees is less than the connection threshold, the connection point information is returned and the path search is finished.

3. Algorithm improvement

3.1. search step improvement

At the moment, urban buildings are oddly shaped and uneven, creating a serious problem with the smoothness of the drone's flight path. In this paper, the search step value of RRT-connet Algorithm is improved, and the search step value of RRT-connet Algorithm is extended under the condition of wide field of vision and small curvature of flight path, the search step value of RRT-connet Algorithm is extended under the condition of narrow field of vision and large curvature of flight path, the search step value of the minifying algorithm. The Adaptive Step rule is Adaptive Step = \( N \) Stepsta, where Step is the standard Step and \( n \) takes the following values, The value of \( N \) is related to visual field distance (FD) and standard flight distance (SFD)

\[
N = \begin{cases} 
0.5 & \text{if } FD \leq 0.5 \cdot SFD \\
1 & \text{if } 2 \cdot SFD > FD > 0.5 \cdot SFD \\
2 & \text{if } FD \geq 2 \cdot SFD 
\end{cases}
\]

3.2. grandfather node clipping

In order to prevent the path of the UAV from being too long and increase the efficiency of searching, the grandfather and the parent nodes of the new node are merged into a new set, and the distance from
the new node to the parent node and the parent node is compared, after the collision test between the newly generated node and the ancestor node, the best ancestor node is connected to the new node as a new branch of the search tree, and its growth process is shown in figure 2.

![Figure 2 Pruning principle of search tree](image)

3.3. search tree smooth optimization
In order to reduce the probability of the UAV sharp turn, the path planning of the route as smooth as possible. In this paper, the direction of branches and leaves is always controlled in the process of searching for branches and leaves. The angle between the newly formed branch and the existing branch is judged. When the angle is acute, the growth of the branch turning is unfavorable to the smooth path, so it should be cut, the results show that the new branches grow in the same direction as the original branches, and the secondary branches are retained. When two trees are connected to each other, the whole new path is interpolated to smooth the path. Search Tree Branch direction consistent growth clipping principle as shown in figure 3.

![Figure 3 Search tree branch direction consistent growth clipping principle](image)

3.4. Algorithm Design for RTT-connect Algorithm
This paper in the search path length, search tree direction to improve the Algorithm, the specific flow as shown in figure 4.
4. Simulation Verification

In order to verify the superiority of the proposed algorithm in UAV path planning, under the same conditions, Matlab2020 is used as a platform to set up a complex obstacle 3D environment, and the improved RTT-connect, RTT-extend and lazy-RTT Algorithms, compare the computation time with the path length. As can be seen from figure 5, the improved RTT-connect Algorithm has a shorter path length than RTT-extend Algorithm and lazy-RTT Algorithm in 3D, which is helpful to reduce the energy consumption of uavs.
Compared with the data in the table, the improved RRT-connnect outperforms the current flow Algorithms RRT-extend and Lazy-RTT in terms of algorithm time consumption and path length, and the improved RRT-connnect has the characteristics of adjustable dynamic step size, in the high-rise city, the adaptive step length can meet the need of switching between wide open space and narrow space, and the path length and calculation time can be adjusted reasonably. It can satisfy the demand of space-time adjustability of Urban low-altitude path planning, and the algorithm has good generality.

| Algorithm | RRT-connect | RRT-extend | Lazy-RRT |
|-----------|-------------|------------|----------|
| Planning time/s | 3.01 | 5.04 | 9.06 |
| dynamic step/m | 2.25-9.0 | 4.5 | 4.5 |
| iteration / time | 145 | 222 | 271 |
| search/point | 117 | 121 | 125 |
| path/point | 72 | 95 | 97 |
| length/m | 324 | 427 | 436.5 |

5. Summary Discussion
Aiming at the problems of fixed path planning step and long path planning time in urban low-altitude uav logistics distribution, this paper perfects RRT-connnect Algorithm, the Algorithm is improved in step length selection, path length and path branch and leaf direction clipping. The results of experiment show that the improved algorithm has better advantages in path length and planning time compared with the current popular algorithm, the Algorithm presented in this paper has good generality in low altitude path planning of complex cities.

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