# The Online Path Planning Method of UAV Autonomous Inspection in Distribution Network

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**Abstract.** In this paper, the problem of online path planning for autonomous inspection of distribution network lines by UAV is studied. Because the distribution lines are mostly distributed around cities, counties and mountainous areas, the lines and their surrounding environment are uncertain and dynamic. These factors will affect the safety of UAV inspection, making the off-line pre-planned path for UAV unavailable. This paper designs an improved iteration random tree algorithm (IRRT) algorithm, which can quickly plan the path of UAV in dynamic environment.

## 1 Introduction

Due to the characteristics of light weight, convenient operation and less requirements for take-off and landing site, small unmanned aerial vehicle (UAV), especially quad-rotor UAV, has been widely used in all walks of life, in which UAV plays an increasingly important role in the power industry. With the rapid development of transmission lines in China, line inspection is faced with the problems of high intensity, long cycle and bad environment of some lines. Therefore, in recent years, new technologies such as unmanned aerial vehicle (UAV) have been actively introduced to the power grid. For the distribution network lines around urban and rural areas, UAV inspection is becoming a trend, but the complex distribution network lines and the dense buildings near the lines pose new challenges to the safety of UAV automatic inspection.

This paper mainly studies the online path planning problem of autonomous inspection of distribution network lines by UAV. Distribution lines are mostly distributed around cities, counties and mountainous areas. Lines and their surrounding environment are important application scenarios of UAV. However, the rapid increase in the number of flying UAVs and the dynamic changes of the surrounding environment of distribution network lines will affect the safe and efficient operation of UAV inspection, making the off-line routes planned in advance for UAVs unusable. In order to avoid collision with obstacles, multi rotor UAV must have the ability of online obstacle avoidance and path re-planning. Therefore, this paper designs an online path planning method for UAV autonomous inspection in the distribution network environment, which can make it respond to various dynamic changes in the inspection process quickly and effectively. It is of great significance to improve the autonomous inspection ability of UAV.

The low altitude environment of distribution network lines has the characteristics of narrow space, dense and irregular obstacles, so UAVs need to avoid obstacles when flying in low altitude environment. In reference [1], urban building obstacles are simplified as polygonal prism, cuboid and elliptic cylinder with different heights. The equations representing the shape characteristics of obstacles are given, and a fast path planning method for small UAV in urban wind field environment is proposed. In reference [2], all kinds of obstacles are represented by grid, and the obstacle information is stored in the digital map. A new guidance law with low computational complexity is proposed, which can accurately track the flight path of UAV when the wind speed is up to 50%. For known obstacles, it only needs to detect whether the UAV is surrounded by the space where the obstacles are located [3, 4]. For unknown obstacles, it is necessary to detect and predict them in advance [5]. In reference [6], a map is established based on Gaussian process to detect unknown dense environment. A fast-exploring random tree path planner based on Gaussian process occupancy graph is proposed, which can generate a path containing collision probability information to achieve obstacle avoidance.

The characteristics of narrow space and dense obstacles in low altitude environment of distribution network line put forward higher requirements for the efficiency of UAV path online planning, otherwise it will reduce the inspection efficiency and flight safety of UAV, resulting in serious consequences. In reference [3], aiming at the problem of On-line Obstacle Avoidance Path Planning of quadrotor UAV in urban environment, the commonly used improved algorithms of fast expanding random tree and artificial potential field are studied respectively. In reference [7], a fast path planning method for small UAV in urban environment is proposed. The approximate optimal path is constructed by the combination of helix and straight line. In reference [4],

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aiming at the challenge of urban low altitude dense irregular environment to UAV flight safety, a path planning algorithm based on local backtracking breadth first and fast extended random tree was proposed. In reference [8], a synchronous bidirectional A* search algorithm is proposed, which realizes the synchronous forward search and backward search of bidirectional A* algorithm. Firstly, based on the basic principle of Laguerre diagram, several proposed flight paths between two buildings are found, and then the safest Laguerre path is found as the flight path by analysing the safety degree of each path.

## 2 Fast search random tree algorithm

The application of sampling-based path planning algorithm in the field of UAV path planning is increasing. It can not only solve the problem of time complexity caused by high-dimensional environment, but also solve the problem of local minimum. The core of RRT and PRM algorithms are efficient data structures such as graph and tree, which are widely used in complex constraints such as dynamic constraints, time performance constraints and high-dimensional unfamiliar environment.

Fast search random tree algorithm (RRT) was proposed by Lavall in 1998. It is a method based on random sampling to generate path. Compared with the traditional path planning method, it is not limited by the space dimension, so it is widely used in UAV and manipulator. Compared with PRM algorithm, RRT algorithm constructs a random search tree by random sampling, which saves the time and memory space required by PRM algorithm to construct the route map. RRT algorithm in unfamiliar high-dimensional environment can quickly guide the blank area, quickly find a feasible path. The core of RRT algorithm is tree derivation in data structure, so there is no need to deal with the established environment model before the path planning, The main method is to take the starting point ($X_{start}$) as the root node, get the random point ($X_{rand}$) through random sampling in configuration space ($C$), and then find the leaf node ($X_{nearest}$) closest to the point $X_{rand}$ from the current random tree. If there is no collision between points $X_{nearest}$ and $X_{rand}$, then $X_{rand}$ is added as a new leaf node $X_{new}$, In this loop, the search is directed to the unknown blank area until the leaf node contains the target point ($X_{goal}$) or is in the area where the target point is located, then the search is completed and a random search tree is generated. Then, from the target point ($X_{goal}$) to find a collision free path from the starting point ($X_{start}$) to the target point ($X_{goal}$) through a series of sampling points. The expansion process of RRT algorithm is shown in the figure. Starting from $X_{start}$, $X_{rand}$ is obtained continuously through sampling. If there is no collision, it is added to the random tree as $X_{new}$.

Table 1 shows the pseudo code of traditional RRT algorithm, The *ExtendRRT* function in Algorithm1 refers to expanding with a certain step size (*Stepsize*),Find the nearest leaf node $X_{nearest}$ of $X_{rand}$ in the current random tree, If the distance between them is greater than the step size, a new $X_{new}$ is obtained according to formula (1), That is, $X_{new}$ is on the extension line of $X_{nearest}$ and $X_{rand}$, otherwise $X_{rand}$ will be added to the random tree as $X_{new}$.

**Table 1.** Traditional RRT algorithm.

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Algorithm1 traditional RRT algorithm ($X_{start}$ 1 is the initial state, $X_{goal}$ is the target state, $C_{free}$ is the free space region)
function RRT ($X_{start} \in C_{free}$, $X_{goal} \in C_{free}$)
    while RRT pathsize or searchtime do // Find the path within a certain period of time
        $X_{rand} \leftarrow RandomSample(C_{free})$
        $X_{nearest} \leftarrow Nearest(RRTree, X_{rand})$
        $ExtendRRT(RRTree, X_{nearest}, X_{rand})$
        if $CheckNo\det oGoal(X_{new}, X_{goal})$ then
            return RRTree
        end if
    end while
end function
function $ExtendRRT(RRTree, X_{nearest}, X_{rand})$
    $X_{new} \leftarrow New\_State(X_{nearest}, X_{rand}, Stepsize)$
    if $ObstacleFree(X_{nearest}, X_{new})$ then
        $RRTree.addnode(X_{new})$
    end if
end function
```

$$X_{new} = X_{nearest} + Stepsize * \frac{(X_{rand} - X_{nearest})}{\| X_{rand} - X_{nearest} \|} \tag{1}$$

Where $\| X_{rand} - X_{nearest} \|$ is the norm and represents the Euclidean distance between them, the vector $(X_{rand} - X_{nearest})$ is unitized and multiplied by the step size, and then $X_{nearest}$ is added to get a new sampling point.

## 3 Problem modelling

to simplify the complexity of the problem, the surrounding low altitude environment of the whole distribution network line is divided into several small cubes with the same size, as shown in Figure 1.

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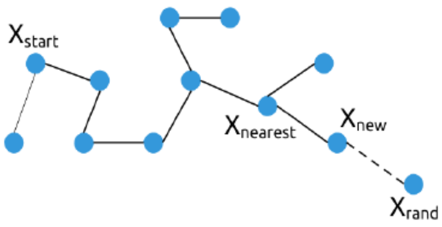

**Figure 1.** The extension process of RRT algorithm.

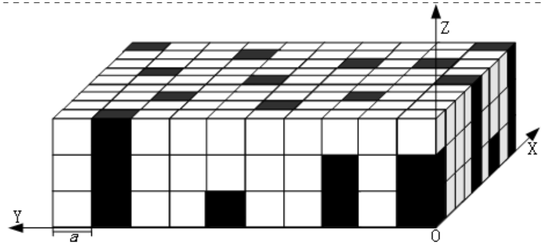

**Figure 2.** The surrounding environment of distribution network lines after discretization.

In Figure 2, $a$ is the side length of the small cube, and the black square represents the space occupied by obstacles of different heights. In order to avoid collision with obstacles, UAVs can only fly in white space. In addition, referring to the practice of setting discrete waypoints in civil aviation air traffic control system, the waypoints of UAV are also set in discrete form, and can only be selected from the vertices of small white cube in Figure 1, and it is stipulated that UAV can only fly in a straight line between two adjacent waypoints. The UAV can select one side, one face diagonal or one body diagonal of the cube as the next leg.

The path planning must meet the dynamic performance constraints of multi rotor UAV, otherwise, UAV cannot fly according to the planned track. The main dynamic performance constraints of multi rotor UAV are as follows.

(1) Maximum flight distance constraint $L_{\max}$ : The battery capacity of multi rotor UAV is limited, and the flight distance is limited by power. For flight safety, the farthest flight distance should be set. If the flight path of UAV is composed of track segments $\{l_i \mid i=1,2,...,n\}$ , the constraint can be expressed as:

$$\sum_{i=1}^{n} \| l_i \| \le L_{\max} \tag{2}$$

Among them, $\| l_i \|$ is the first flight distance, $L_{\max}$ is the farthest flight distance.

(2) Flight altitude constraint $H$: When the UAV flies normally, it is constrained by its own performance and height limit area, and there is a maximum flight height. At the same time, the flight height should not be too low, so as to avoid increasing the probability of collision with ground obstacles. Therefore, the flight height of the UAV is within a certain range.

$$H_{\min} \le H_i \le H_{\max} \tag{3}$$

Among them, $H_{\min}$ is the minimum flight altitude, $H_i$ is the altitude of the first track point, $H_{\max}$ is the maximum flight altitude.

(3) Minimum direct flight distance constraint $L_{\min}$ : In order to ensure the flight safety of UAV, the UAV must maintain a certain direct flight distance before adjusting its posture. When the direct flight distance is less than a certain value, the risk probability of UAV will increase. The minimum direct flight distance constraint can be expressed as:

$$\| l_i \| \ge L_{\min} \tag{4}$$

Among them, $\| l_i \|$ represents the flight distance of the third straight line, $L_{\min}$ indicates the shortest direct flight distance.

(4) Waypoint constraints: Let the number of waypoints be $N_{\max}$ , Then the following constraints must be satisfied to ensure the safe flight of UAV. All waypoints must keep a certain distance from the obstacles.

$$\sqrt{(x_j-\bar{x})^2+(y_j-\bar{y})+(z_i-\bar{z})^2} \ge a \tag{5}$$

Among which, $j=1,2,...,N_{\max}$ Indicates the number of the waypoint, $(\bar{x},\bar{y},\bar{z})$ is a point arbitrarily selected from the space occupied by an obstacle. It is stipulated that the distance between UAV and building should not be less than the side length of small cube. UAV must be able to reach the designated target point.

$$\sqrt{(x_{N_{\max}}-x_{star})^2+(y_{N_{\max}}-y_{star})^2+(z_{N_{\max}}-z_{star})^2}=0 \tag{6}$$

Among which $(x_{star}, y_{star}, z_{star})$ is the location of the target point.

Since the multi rotor UAV can hover, it is not constrained by the turning angle and turning radius, so the report does not consider the constraints of the turning angle and turning radius of the UAV.

Objective function: the UAV online path planning model takes the minimum flight distance and the number of waypoints as the objective function, as shown in equation (6).

$$J_{path}=\min\{\sum^{n} l_i+\alpha(N_{\max}-1)\} \tag{7}$$

## 4 IRRT algorithm

But RRT algorithm is especially suitable for solving path planning problems under complex constraints, such as kinematic constraints and time constraints, and in high-dimensional unfamiliar environment, so it is still widely used in the field of robot. In order to solve the randomness of RRT algorithm and make it suitable for path planning in dynamic environment, this paper proposes an improved RRT algorithm. The basic RRT algorithm does not need to pre-process the environment model before path planning. It is directly random sampling in the space to increase the leaf nodes until the target point, and then reverse searching from the target point to the starting point to find a collision free path. However, because RRT algorithm is random sampling in the space, although the algorithm is efficient and not affected by the spatial dimension, the results are not satisfactory the randomness of the route to the destination is very large. Even if the same starting point and target point are used, the quality of the generated final route is different.

**Table 2.** IRRT algorithm.

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Algorithm2 The IRRT algorithm（$X_{start}$ is the initial state，$X_{goal}$ is the target state，$C_{free}$ is a free space area）
function IRRT $(X_{start} \in C_{free}, X_{goal} \in C_{free})$
    $Init(iter)$
    $RRTree \leftarrow RRT(X_{start}, X_{goal})$
    $RRTreeOfoptimization \leftarrow RRTree$
    while $iter != 0$ do
        $RRTree1 \leftarrow RRT(X_{start}, X_{goal})$
        if $Compare(RRTreeOfoptimization, RRTree1)$ then
            $RRTreeOfoptimization \leftarrow RRTree1$
        end if
        $——iter$
    end while
    if $X_{goal}$ is Notbigchange then
        $Local\ REPLAN(RRTreeOfoptimization)$
    else
        $RRT(X_{start}, X_{newgoal})$
    end if
end function
function $Local\ REPLAN(RRTreeOfoptimization)$
    $node \leftarrow RRTreeOfoptimization.node_0$
    while $node != T\arg etnode$ do
        $Checkcollision(node)$
        if $node$ is Collision then
            $delete(node, node.children)$
            $ExtendRRTreeoptimization(node.parent)$
        end if
        $nextnode$;
    end while
end function
```

Table 2 is the pseudo code of IRRT algorithm. It refers to the number of $iter$ iterations that is, the random expansion tree $RRTreeOfoptimization$ where the better path is found after $iter$ iterations. When the target point changes greatly, the path planning is carried out again. $Localreplan$ function is a local re programming function, When the stored historical path collides with a dynamic obstacle shown in Figure 3, then delete the colliding node and its children. Then, the parent node $parent$ of this node starts RRT search again until it is connected to the tree where $RRTreeOfoptimization$ function expands the path of the optimal tree, In order to improve planning efficiency, When this function expands the path of the optimal tree, the random sampling points are sampled around the opposite direction of the dynamic obstacle movement, which avoids the large deviation from the optimal path, and also speeds up the re-planning time.

**Figure 3.** Schematic diagram of local re-planning.

## 5 Conclusion

This paper designs an online planning method for UAV patrol path in the distribution network environment. To overcome the shortcomings of random search, such as slow convergence and tortuous planning track of traditional RRT algorithm, this paper proposes an improved IRRT algorithm, which can store the upper cycle tree where the better path is stored in iterative comparison to perform local re-planning. This algorithm not only realizes timely local re-planning in dynamic environment, but also improves the probability of the final path approaching the optimal path. The online planning algorithm makes UAV respond to various dynamic changes in the process of patrol inspection quickly and effectively, which is of great significance to improve the autonomous inspection capability of UAV.

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