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The Research of RRT Route Planning Algorithm for UAV that Based on Kinematic Equation

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Abstract

To solve the problem that the traditional rapidly-exploring random tree(RRT) algorithm can not be directly applied to the path planning of Unmanned Aerial Vehicle(UAV), add the UAV turning angle constraint to the planning algorithm in the process of random point were produced, it make the path meet the capable of flying; For the problem that we could not determine the random point about the rapidly-exploring random tree(RRT) algorithm, this paper provide a improvement algorithm which combined aircraft kinematics equation, and use this algorithm to the three dimensional(3D) path planning . The simulation result proved that this algorithm could avoid the threat effectively, and the accuracy of planning is more precise, so the path planned by the algorithm proposed in this paper is more accorded the requirements of actual planning path.

Keywords: *path planning; aircraft kinematics equation; RRT algorithm; three dimensional*

1. Introduction

With the development of science and technology, unmanned aerial vehicles play an important role in modern warfare. Combat planners pay much attention on route planning technology as an important means to improve operational effectiveness for UAV.

On the premise that we consider UAV arrival time, fuel consumption, threat, flight region and other elements, planed a most satisfactory path. The present of route planning algorithm include A* algorithm [1-3], Ant colony optimization algorithm [4-6], rapidly exploring random tree (RRT) [7-13] and so on.

RRT algorithm is widely concerned because of its fast. Literature [14] used RRT algorithm and it considered the constraint of UAV motivation, but it can not solve the problem of selecting random point difficultly. Literature [15] introduced the Dijkstra algorithm improved RRT algorithm, planed an optical path, but the time is so long and it still did not solve the problem. To solve the above problems, this paper provided an improvement algorithm, which combine aircraft kinematics equation and were used to the UAV path planning. The formulation result proved that this algorithm can avoid the threat effectively, the accuracy of planning is more precise, and the path planned is more accorded the requirements of actual planning path.

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$RRT - CONNECT\ (x_{init}, x_{goal})$

$T_a.init(init),\ T_b.init(goal)$

$for\ k = 1\ to\ k$

$x_{rand} = Random\_state()$

$if\ not\ (Extend\ (T_a, x_{rand}))\ then$

$if\ not\ (Extend\ (T_b, x_{new}))\ then$

$return$

$CONNECT\ (T, x)$

$repeat$

$s = Extend\ (T, x)$

$until\ not\ (s = advanced)$

$return\ s$

2. The Basic Theory of Algorithm

2.1. The Basic Theory of RRT Algorithm

RRT was proposed as a plan planning firstly by the LaVall [16], it can search the high dimensional region according to selected nodes randomly in the configuration space. The main idea of the RRT algorithm is not reduced the distance gradually and quickly between the tree and the point until reaching the expected distance. The process of expanding RRT requires a metric function, random sampling algorithm and collision detection algorithm in configuration space.

T is a tree , x_{rand} is a random point, x_{free} is a free regions that have no obstacles x_{init} is the start point , x_{goal} is the end point . $Area\ (x)$ is the sub region with the x as the center.

(1)The start point x_{init} was added to T as a init node of T ;

(2)Selecting a random node x_{rand} in x_{free} ;

(3)Find a node x_{near} to x_{rand} in T , and put it on x_{near} ;

(4)Compare x_{near} , x_{rand} with UAV to compute the node x_{temp} which is possible to x_{rand} closely;

(5)If the x_{temp} is in the x_{free} , x_{temp} is a node of RRT, that is $x_{new} = x_{temp}$, then we add x_{new} to T ; otherwise, x_{temp} is discarded;

(6)Generating random nodes, repeat steps (3) - (5) until $x_{new} = x_{temp}$ or $x_{new} \in Area\ (x_{goal})$;

(7)Find a optical path from the x_{init} to x_{goal} .

$T = x_{init}$

$while\ (x_{new} \neq x_{goal} \parallel x_{new}\ Area\ (x_{goal}))\ do$

$x_{rand} = Rand\ (T, x_{free})$

$x_{nearest} = Nearest\ (T, x_{rand})$

$x_{temp} = New\_Node\ (x_{near}, x_{rand}, U)$

$if\ (Collision\ (x_{temp}) = False)\ then\ do$

$x_{new} = x_{temp}$

$T.Add\_Node\ (x_{new})$

$T.Add\_Edge\ (x_{near}, x_{new})$

$end\ while$

$\mathrm{Re}\ turn\ T$

2.2. The Basic Theory of RRT- Connect Algorithm

RRT-Connect was developed on the basis of the RRT algorithm. It produced two trees in the initial point and the target point T_a and T_b [17], in the process of the each iteration expansion, The two trees not extended the other recent node, it generating new nodes as the same time until the two tree was connected. The end of this algorithm and the path was completed,

3. The Application of Improved RRT Algorithm in the UAV Path Planning

The problem of path planning in unknown environment was the process which was visual domain approximated to the goal point gradually in actually and looks for the path repeatedly. According to the current position of the UAV and the track evaluation standard determined the target point, then determined the feasible path [18].

The leaf nodes is to meet the constraint of random offset point in the RRT-connect, if the planning horizon domain had not obstacle, random point was selected as the target point according to a certain probability. If the planning horizon domain had obstacle, leaf nodes was selected by using the method of random point.

The selection mechanisms of random points are as follows:

If the planning horizon domain had not obstacle, random point was selected as the target point.

If the planning horizon domain had obstacle, random point was selected according to second ways.

A UAV current position is x_i, the visual domain R can be regarded as a circle which radius is r.

The one way:

If there were no obstacles in the horizon, the select of random points as follow figure.

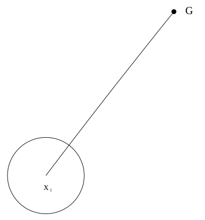

Figure 1. Select Random Point in the Free Barrier Space

G is target point.

The second way:

If there were obstacles in the horizon, the select of random points as follow figure.

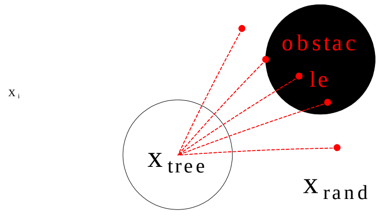

Figure 2. Select Random Point in the Barrier Space

x_{tree} is a node in the tree. The red points represents x_{rand}, and the black circle is obstacle. The red line is route.

If there were obstacles in the horizon, the volume of UAV was smaller than the whole planning area relatively, so the UAV could be simplified to a particle of aircraft. [19].According to the assumptions of the planning problem, the aircraft kinematics equations were simplified and were built on the ground fixed coordinate line.

$$\theta_{k+1} = \theta_k + \theta_0 \Delta \quad (3.1)$$

$$x_{k+1} = x_k + s_0 \cos(\theta_{k+1}) \quad (3.2)$$

$$y_{k+1} = y_k + s_0 \sin(\theta_{k+1}) \quad (3.3)$$

The formula: θ_k represent the current track range in level flight, θ_{k+1} represent track range in level flight in the next moment; θ_0 was the smallest unit of angle variation when the course changes; Δ was numerical course variation; s_0 was the step of route planning; $A(x_k, y_k)$ was the current waypoint coordinate, $B(x_{k+1}, y_{k+1})$ was the next waypoint coordinate.

$$s_0 = v \times t \quad (3.4)$$

v Represents current speed, t represents time.

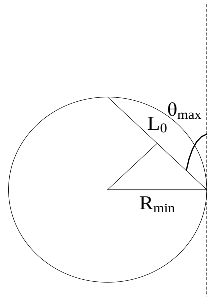

Figure 3. The Way of Expending Point

The vehicle had to meet the flight requirements in actual. The calculation formula of minimum turning radius of UAV as follow:

$$R_{min} = v_{min}^2 / \sqrt{n_v^2 - 1} \quad (3.5)$$

The formula: v_{min} was the minimum flight speed of UAV, $n_{y\max}$ was the maximum normal overload .According to the minimum turning radius and the step of route planning, we could calculated the maximum angle when the course was changed.

$$\theta_{max} = \arcsin(s_0 / 2(R_{min})) \quad (3.6)$$

The calculation of the maximum turning angle diagram is shown in figure 4.

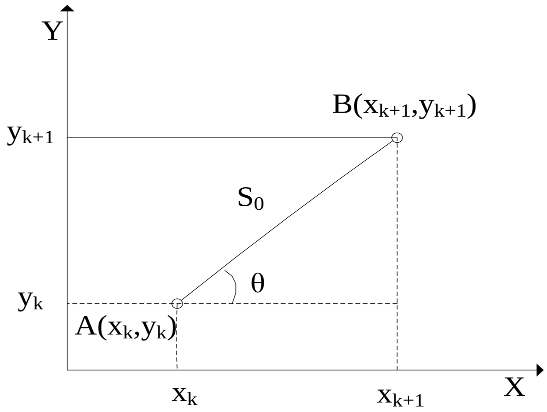

Figure 4. Calculated the Maximum Turning Angle

The maximum angle was going to divide into N equal parts when the course was changed, the range of Δ was
$(-\theta_{\max}, (-2/n)\theta_{\max}, (-1/n)\theta_{\max}, 0, (1/n)\theta_{\max}, (2/n)\theta_{\max}, ... \theta_{\max})$

The process of the algorithm:

$Initialize \quad tree \quad T.init \quad and \quad T.goal$
$for \quad i = 1:k \quad do$
$p_{rand} = rand()$
$if \quad p_{rand} > p$
$x_{rand} = RandomState()$
$if \quad x_{rand} \in \theta$
$\quad Extend(T.init, x_{rand})$
$\quad x_{new} = (x_{k+1}, y_{k+1})$
$else$
$\quad Break;$
$if \quad Connect(x_{new}, x_{goal})$
$\quad Break;$
end
$if \quad p_{rand} < p$
$x_{rand} = Random(T.goal)$
$x_{new} = Extend(T.init, x_{rand})$
$if \quad Connect(x_{new}, x_{goal})$
$\quad Break;$
end
$Update \quad p$

4. Simulation and Results

In order to verify that the improved the improved RRT algorithm is more optical for plan planning in two-dimension, we compared it with the A* algorithm, RRT algorithm and RRT-Connect algorithm using matlab programming tools, The aircraft latitude and longitude is 100 * 100; the vehicle speed is 12m/s,the normal overload is 2.5g. In following diagram, blue circles represent obstacles, and blue lines represent the UAV final path and red lines represent the tree.

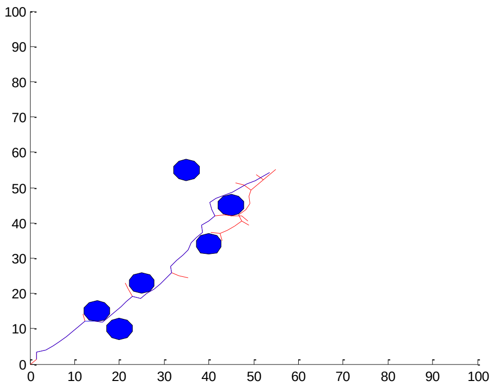

Figure 5. A* Algorithm in the Two-dimension Barrier Space

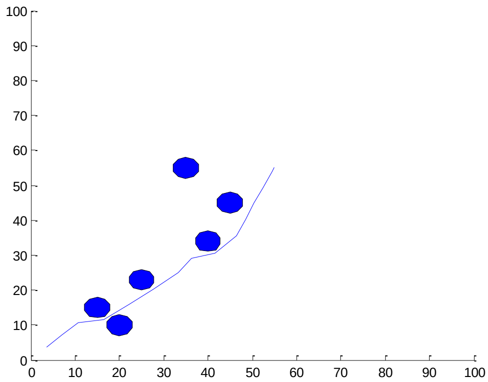

Figure 6.RRT Algorithm in the Two-dimension Barrier Space

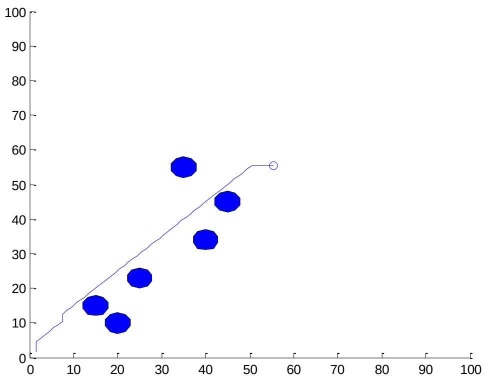

Figure 7. RRT-Connect Algorithm in the Two-dimension Barrier Space

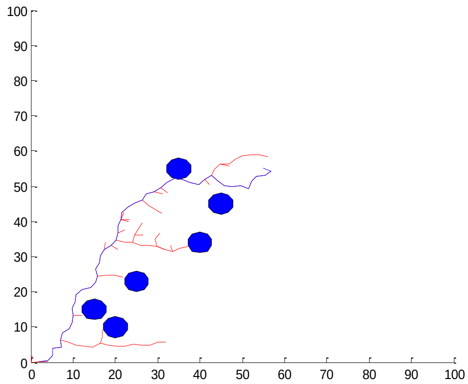

Figure 8.The Improved RRT Algorithm in the Two-dimension Barrier Space

In order to verify the feasibility and effectiveness of the improved RRT algorithm in three-dimension environment, programming tool is matlab and Simulation tests. The aircraft latitude and longitude is 100*100. The vehicle speed is 12m/s, the normal overload is 2.5g. In following diagram, blue circles represent obstacles, and blue lines represent the UAV final path. * represents the starting point, the destination point and red represent the tree search.

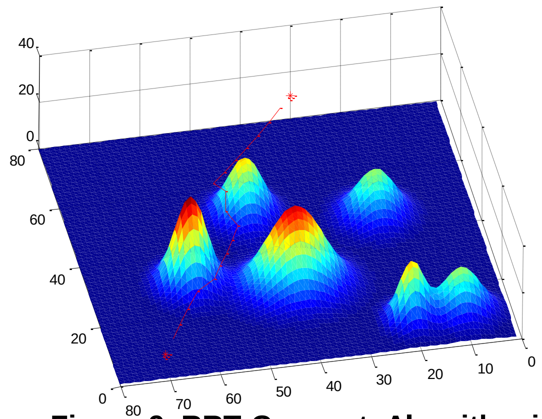

Figure 9. RRT-Connect Algorithm in the Three-dimension Barrier Space

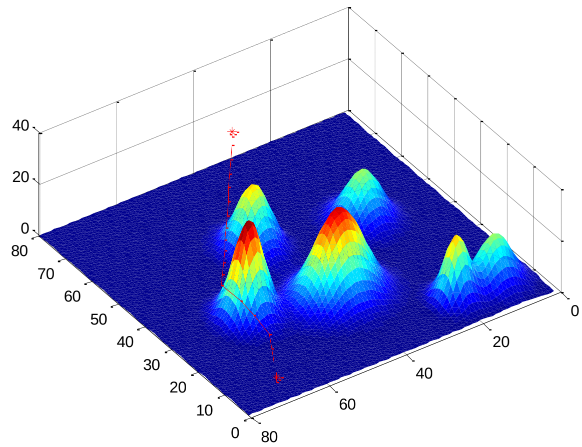

Figure 10. The Improved RRT Algorithm in in the Three-dimension Barrier Space

The experimental data as follow form:

Table 1. The Comparison of Path Planning Algorithm Performance in Two-dimension Environment

	A * algorithm	Basic RRT	RRT-Connect	The improved RRT
Average Planning Time	24.1100	0.25000	0.12500	0.04100
Summarize Points	861	109	72	75
Effective Node	60	50	42	75
Track Length	120	108	90	83

Table 2. The Comparison of Path Planning Algorithm Performance in Three-dimension Environment

	RRT-Connect	The improved RRT
Average Planning Time	0.12900	0.17000
Summarize Points	34	18
Effective Node	22	18
Track Length	142	127

According to the Table 1, we compared the improved RRT Algorithm with the A* algorithm, it have a fast convergence speed ;We compared the improved RRT Algorithm with the RRT algorithm and RRT-connect algorithm ,it can meet the time requirements of on-line route planning with a less threat in two-dimension.

According to the Table 2, we compared the improved RRT Algorithm with the RRT-connect algorithm, the improved RRT algorithm is more suitable for UAV route planning in three-dimension.

5. Conclusion

This paper provided an improvement algorithm of RRT, which increased the constraint of turning angle and combined aircraft kinematics equation, used this algorithm to the three-dimension path planning. Compared with A* algorithm, the algorithm of this paper has the advantage of running more fast and is suitable for on-line path planning. Compared with the RRT algorithm and RRT-connect algorithm, the algorithm of this paper is more accurate, and the length of the path is shorter, it is more accorded the requirements of actual planning path. Compared the simulation results with the offset RRT algorithm in the three-dimension space, the algorithm of this paper is also has many advantages like the path length is shorter.

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