2011 International Conference on Computer Science and Information Technology (ICCSIT 2011)
IPCSIT vol. 51 (2012) © (2012) IACSIT Press, Singapore
DOI: 10.7763/IPCSIT.2012.V51.104

Real-time Path Planning In Completely Unknown Environment for UAV

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Abstract. In completely unknown environment, UAVs require real-time independent path planning capacity. To solve this problem, this paper presents a new method based on rolling window, adopting the multi-steps searching pattern. In local path planning schema, using the people's way of thinking of exploring paths, and combining with the multi-steps strategy to seek the local optimization target, consider it as path node. The novelty of our algorithm, unlikely the previously proposed methods, it works on continuous domain. The discretion domain which provides alternative nodes, the way of generating node dynamically as required in this paper we use. According to the intersection situation of planning window and obstacles to select planning section, reduced the search area. This algorithm provably converge to a given target point and produce a series of safe waypoints.

Keywords: Unknown Completely Environment, Rolling Window, Path Planning

1. Introduction

Technological advances push from all aspects of the society development. In modern war and military exercises, UAVs received great attention, become the focus of national military research. Aircraft path planning refers to finding the target from the starting point and meets certain performance index of optimal flight path with specific constraints [1]. Existing algorithms to solve route planning problems are many, they are mainly based on the premise of environmental information is known, before the UAVs took off, off-line planning algorithm map out an optimal path as a reference to guide the UAVs track. The environment of the modern battlefield is changing rapidly, in these cases, UAV have to cross unknown environmental areas, this demand UAV own a certain self-path planning capabilities to planning out a better path with local area information and some details in its memory to ensure missions are accomplished. Grid of spatial planning will generate candidate path node, this is a widely used method. The author of literature [2] and [3] makes grid of the planning space and every step of the search path nodes are known, the node selection method has certain limitations and physical constraints cannot be better solved.

In completely unknown environment for route planning, basing on a rolling window, this paper applies local path planning method and generate path node in the planning window in order to get the global path. The structure of the text: Section I introduces the flight environment, the physical characteristics of UAVs, and definition of terms used in the paper; Section II describes the algorithm ideas, presents the basic idea of the algorithm and specific implementation methods; Section III demonstrates the experimental results and analysis and evaluation of the characteristics of the algorithm.

2. Introduction

2.1. Physical characteristics of UAV

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In order to make the UAVs can track the out-planning path to fly physically; selection of next point has to be given full consideration with UAV's flight performance. Due to the relative small size of UAV in proportion to the overall planning of space, it is better to establish equations of motion of aircraft on the ground.

$$\theta_{k+1}=\theta_k+\theta_0\Delta \tag{1}$$

$$x_{k+1} = x_k + S_0 \cos(\theta_{k+1}) \tag{2}$$

$$y_{k+1}=y_k+S_0 \sin(\theta_{k+1}) \tag{3}$$

. θ_k represents the current UAV's flight path in level flight; θ_{k+1} represent the next moment when the UAV flight path in level flight azimuth; θ_0 is the smallest unit of change when the aircraft heading angle changes. Δ stands for the size of the course changing. S_0 is the step size of path planning. $A(x_k, y_k)$ and $B(x_{k+1}, y_{k+1})$ respectively refer to the current track point and the next track point coordinates [4].

2.2. Mathematical Description

When an UAV flies at a fixed altitude, its path planning can be seen as similar to path planning problem in two- dimensional plane. For any given two-dimensional plane , in which randomly distribute kinds of obstacles *Obi* ($i = 1, 2, 3 ... n$) in size. UVA's mission is seeking the point from a given starting point *S* to the target point *G* with shortest flight path. In fact, in real-time UAV flight, the shortest path is very difficult to find, so we try to get the best track in reality. In this study, environment information is unknown when UAV execute missions, only the starting position point, the target location point and the boundary information are present. In this case, UAV can achieve navigation and find target point by its sensors receiving local environmental information and finished path information.

A given planning two-dimensional plane is a continuous area there is no clear choice of discrete points, so UAV in path-searching have to determine the next destination point dynamically by path searching rules. After a series of choices, a point set $\{w_k \mid k = 1, 2 ... n\}$ is produced. In the formula, $w_1 = S$, $w_n = G$, the curve connecting these points is the required solution of the problem. Assuming from w_k to w_{k+1} track costs is Ck, the length of the best path is $c=\sum_{k=1}^{k=n} c_k$. In researching course, obstacles are considered impenetrable, and the resulted threat may not be included in the cost of track costs. The smaller the obtained track costs, the smoother the resulted path, and this problem have a good solution.

2.3. Definition

Definition 1: The current position point w_k as the center, UAV's detection range as r, the set $U=\{x_i \mid \|x_i - w_k\| \le r\}$ as the UAV's sensing range.

Definition 2: If the current position point is w_k, the target point is w_n, the vector $\alpha = \overline{w_k w_n}$ as the guide vector.

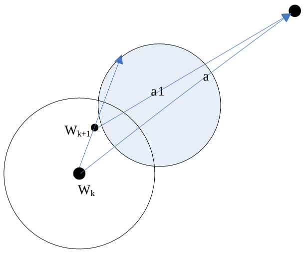
3. Problem Description

3.1. Basic Idea

Path planning consists of global path planning and local path planning. In this paper, we discuss the path planning problem which in completely unknown environment, the UAV can obtain very limited environment information, for this perspective, we can conclude that local path planning is a more reasonable way to resolve this problem. BUG algorithm is a representative one in the path planning algorithms of unknown environment, which is a completely stress type algorithm and demand less storage capacity. If there exit a feasible path between given start point and objective point, this algorithm must can finish the path planning and guarantee the global convergence. The basic idea of the BUG algorithm: the object walks along the main line of M-line which connects the start point and the target point toward to the target, when the object encountered obstacles the method edge tracking was used to bypass the obstacles, then back to the main line and move forward until reach the target point.

3.2. Improved Algorithm

Based on the BUG algorithm and by the human way of thinking finding a path of inspiration in unknown environment, this paper present a new path planning method, the description of this algorithm as follows. If there were no obstacles or there were no barrier in UAV's sensing range along the direction of, the UAV will fly along the direction of, the example of this case is shown in Figure1(b); If there were obstacles along the direction in the UAV's sensing range, we should choose a certain method of obstacle avoidance, the example of this case is shown in Figure1 (a). According to the above two case, it can choose the next position point. When the UAV reaches the next position point, consider it as the current position point, and modify and then take it as the new guide vector. This idea is showed in figure1:



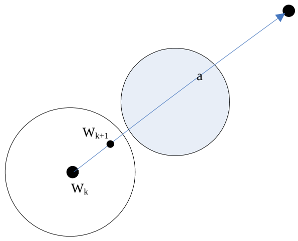


Figure 1 (a)sensing range and obstacles intersect (b)sensing range and obstacles do not intersect

In the UAV's sensing range, if the current flight direction along the direction of , and in this direction there exist obstacles, the UAV should choose less costly to make the flight track direction to avoid obstacle. Figure 3 shows, M and N is obtained from the intersection of U and Obi. If the UAV flight set step is a certain value, then according to the formula (4)

$$x^2 = a^2 + l^2 - 2al\cos\theta \tag{4}$$

a is the length of current α , *l* is UAV's flight set step. *a* and *l* are given values, the range ofθ is [0, π], the values of x increases with theθ values is increasing. Thus, in order to get the optimum track costs, select the direction ofθ smaller to flight. This method is simple and fast, but the physical properties of the UAV constraints, it doesn't the best one. In order to get better solutions, we take multi-step strategy to search in UAV's sensing rang.

Multi-step search method:

In the sensing window, we search the local target point in the circle, the current location of the point as the center and the step of the UAV as the radius. The process of searching the local target point followed the proposed method of path planning: (1) based on the intersection situation of obstacle and sensing window, breaking up the sensing window into different fan-shaped region; (2) select the number of planning sector; (3) through continuous refinement of selected sector, get the n-optimum solution by the optimization.

The solution will be N times repeat the above process, obtained the track segment consist of N sub-track sections.

Route optimization:

After a local planning finished, each sub-node of track path which is worked out by a multi-step optimization will be given a label, they are respectively: w_{s1}, $w_{s2} \ldots w_{sn}$. For any point w_{si}, we connect it with each node between $w_{s(i+1)} \ldots w_{sn}$. If the connection between w_{si} and any point could not cross obstacles, other path nodes between these two points would be cancelled; the path would be changed as w_{s1} w_{si}, w_{sk} w_{sn}, repeatedly, until w_{si} is equal to w_{sn}. In the optimization process, we must combine the physical properties of UAV to meet the minimum turning radius and ensure its normal flight. For previous obtained n paths, we have to optimize each article and select the shortest path as a result of the plan at last.

3.3. Rolling window-based local path planning

In this paper, the path planning problem we discussed for UAV is in unknown completely environment. That is, before the UAV take off, it has very little information about the flight environment, only area boundary and target point position. In this case, UAV navigation system only depend on local information obtained from the sensors. In order to get the global optimum path, take the repeated local optimization planning strategy.

Rolling window-based local path planning method relies on local information in real time to detect, and realize online planning with rolling way. In every rolling step, gets the optimum point in this planning window, then get the global optimum path planning through the rolling of sensing window. The rolling window is the UAV's sensing range, and the planning window is $U_1 = \{x_i \| x_i - w_k \| \le r_1\}$.

4. Experimental Results And Analysis

In order to illustrate and verify the effectiveness of the algorithm, choose a 100km 100km area the size of the rectangular plane but in the experiment we narrow the planning area and use the ratio of 1:100000. The lower left corner of the rectangle is defined as *(0, 0),* defined as the upper-right corner coordinates *(100,100),* and the boundary of the rectangular area also will be determined. Suppose the coordinates of start point *S (10, 10),* the target point *G (80, 70),* area with a circle to represent a threat. To verify the effectiveness of the algorithm, BUG algorithm respectively, and cultural use of the proposed algorithm to solve problem.

4.1. Experiment and Analysis

In a given environment, results basing on the implementation of two algorithms are as figure 2, figure 3 demonstrate. There are no clear differences in the length of the path obtained by these two algorithms, but the improved algorithm is more suitable for planning a path to guide the UAV flight in real time.

Figure 2 shows the result of BUG algorithm. On one hand, in this figure, the curve of the path consists line and arc, there is no any transition curve connect the line and arc. Because the limitation of itself's physical properties, it is hardly to turn any angle for UAVs. Therefore the path curve is not suitable to track. On the other hand, the UAVs can't avoid the obstacle until it close in obstacle. This will increase the threat cost and path length cost.

Figure 3 shows the result of improved BUG algorithm. The path curve is smooth and physical, the curve connected the path node is obtained according the UAVs' physical properties. It will avoid the obstacle once the obstacle entering the rolling window, so it will reduce the collision probability.

Through comparative analysis, found that the algorithm is a feasible and effective, real-time path planning algorithm can satisfy the path planning under limited environment information.

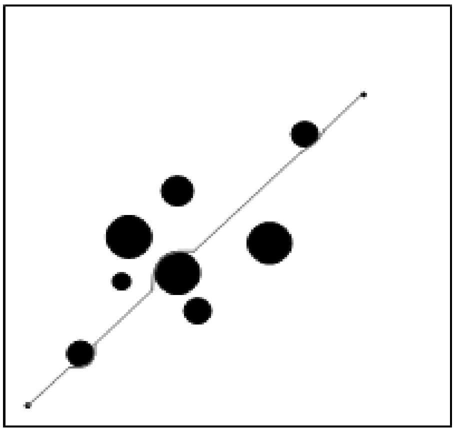


Figure 2 the result of BUG algorithm

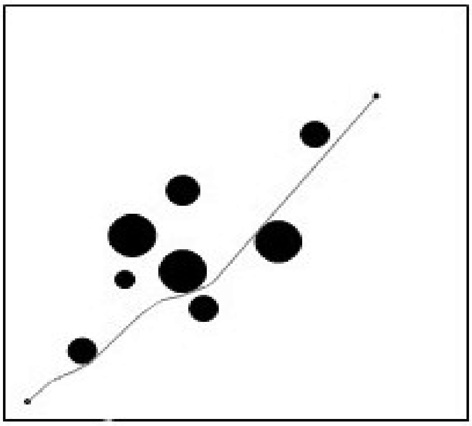


Figure 3 the result of improved BUG algorithm

4.2. Algorithm Advantage

Compare to other path planning algorithm, the thought of improved BUG algorithm this paper presents is easy to follow. Taking the advantage of the guidance of the direction vector, UAVs won't get into blind to choose path and won't get lost.

5. Experimental Results And Analysis

For autonomous UAVs path planning task in completely location environment, we propose a rolling window-based path planning of multi-step search method. Relying on limited environmental information, the idea of human exploration is combined with UAV. With the local implementation of multi-step route optimization strategy, the global path planning is achieved by the rolling window moves forward. There are long enough steps designed to ensure that the UAV has enough time to plan the next stage at the track, largely reducing the time of UAV hovering in the air in for getting future path. This algorithm effectively takes advantages of limited local environment information to achieve real-time autonomous UAV path planning capabilities.

6. Acknowledgements

I express my sincere gratitude to my supervisor, for his instructive suggestions and valuable comments on my research. Besides, I wish to thank my classmates; they helped me search for reference.

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