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The Three-dimention Path Planning of UAV Based on Improved Artificial Potential Field in Dynamic Environment

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***Abstract*—In order to solve problem of path planning for Unmanned Aerial Vehicle (UAV) in dynamic environment, a three-dimensional (3D) path planning algorithm of UAV which based on improved artificial potential field is proposed in this paper. First, the problem of target unreachable in path planning is solved through the improvement of artificial potential field function. Then the improved algorithm can avoid UAV going into local pole and shock area by setting potential field guide point. Finally a path optimization method is proposed to optimize the generate path. Simulation results show that the path planning algorithm can ensure UAV to real-time path replanning in dynamic environment and generate a smooth path, it proves the feasibility and effectiveness of the improved algorithm.**

Keywords- UAV; artificial potential field; 3D path planning; path optimization

I. INTRODUCTION

Path planning is to find the optimal flight path from start point to the target point under the consideration of flying time, fuel consumption, battlefield threats, and geographical environment to make UAV avoid threats successfully and strike the goal precisely [1]. As a key part of UAV mission planning system, path planning is not only effective means of improving UAV operational effectiveness and implementation of long-range precision strike but also a technology security of UAV realizing the independent control and intelligent flight. Therefore UAV path planning has become a hot topic in the study of scholars at home and abroad[2]. Based on the idea of hierarchical planning. Paper [3] proposed a path planning method based on the Voronoi diagram and improved genetic algorithm and planned the global optimal path finally; paper [4] proposed the improved A* algorithm and applied it to solve problem of avoiding threat in unknown environment; paper [5] proposed a 3D penetration path planning method based on particle swarm optimization, it reduced search space and improved efficiency of planning; According to the distribution of different threats, paper [6] put forward a path planning method based on the combination method of sparse A * search algorithm preliminary planning and artificial potential field, to achieve UAV dynamic obstacle avoidance and so on. At present, it should be pointed out that path planning research of given known information and static environment relatively mature, while the study of a 3D path planning is less and in dynamic condition is much less too. In existing path planning algorithm, artificial potential field is widely used in robot dynamic path planning because of its advantages such as quick response speed, a small amount of calculation and real-time precision higher, but it's easy to bring problems, such as generates local pole, phenomenon of track shock, and target unreachable when the target and obstacles are close. According to the defects of the artificial potential field, this paper improved the algorithm, and applied it to UAV 3D path planning problem in dynamic environment, and optimization the generated path in order to make sure UAV online path planning, complete the flight mission successfully.

II. ESTABLISHMENT OF PLANNING SPACE

The terrain is not only plays an important part of the flight environment, but also premise of path planning. In recent years, with the development of simulation technology, there are a lot of digital map simulation methods of path planning. Regarding peak barrier as obstacles, using improved artificial potential field to planning initial path and replanning path based on the update environment information. The mathematical description of peak model is shown as follow:

$$\begin{cases} x = r * \cos t + x_0 \\ y = r * \sin t + y_0 \\ z = \dfrac{h}{2}\left(\cos\left(\sqrt{\left(x - x_0\right)^2 + \left(y - y_0\right)^2} \,/\, k \right) + 1 \right) \end{cases} \tag{1}$$

Its physical meaning is: (x_0, y_0) is the bottom of the circle, $k\pi$ is the bottom radius, h is the height of peak model. Peaks model can get through initialize the assignment of x_0, y_0, k, h .

III. DESCRIPTION OF ARTIFICIAL POTENTIAL FIELD

Artificial potential field first proposed by Khatib[7], its basic idea is constructing the gravitational field F_{att} around the target and repulsive force field F_{rep} around the obstacles. reflecting the information about obstacles, distribution of targets and its location to the potential field value, searching

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safe path according to the falling direction of potential function, it has the advantages of small calculation and real-time and so on[8]. Set p in the search space, so the potential function in gravitational field, repulsive force field and composite force field are respectively.

$$U_{att}(p) = \frac{1}{2}\xi\rho_g^2(p) \tag{2}$$

$$U_{rep}(p) = \begin{cases} \frac{1}{2}\eta(\frac{1}{\rho(p)} - \frac{1}{\rho_o})^2, & \rho(p) \le \rho_o \\ 0, & \rho(p) > \rho_o \end{cases} \tag{3}$$

$$U_{tatal} = \sum U_{rep} + \sum U_{att} \tag{4}$$

Where ξ , η are gain coefficients of attraction and repulsion, ρ_o is the influence distance of threat, $\rho_g(p)$, $\rho(p)$ are distance of p relative to target and threat respectively, gravity function and repulsive force function equation are:

$$F_{att}(p) = -\xi\rho_g(p) \tag{5}$$

$$F_{rep}(p) = \begin{cases} -\eta(\frac{1}{\rho(p)} - \frac{1}{\rho_o})(\frac{1}{\rho(p)})^2 \frac{\partial\rho(p)}{\partial X}, & \rho(p) \le \rho_o \\ 0, & \rho(p) > \rho_o \end{cases} \tag{6}$$

$$F_{total} = \sum F_{att} + \sum F_{rep} \tag{7}$$

According to the (5) - (7), potential field force of every point can be calculated in the environment, and moves from the starting point to ending point under the guidance of resultant force.

Artificial potential field can find a path to the goal by an efficient way, but it has limitations. When there is an obstacle around target point, UAV is also close to the obstacle along with closing to the target, at this time repulsive force will be far greater than gravity so that target is not a global minimum point, therefore target unreachable. When the resultant force is zero, potential field local poles will appear, abstract force formed on all of the obstacles and the target at these points is zero, and UAV can't continue to search. When obstacles distribution is denser, path will also appear complicated shock faults even if the UAV does not fall into the local pole [9]. To solve above problems, the traditional artificial potential field be improved.

IV. Dynamic Path Planning of UAV Based on Improved Artificial Potential Field

A. Problem of Target Unreachable

Artificial potential field function is improved on account of the particularity and limitation of the application of artificial potential field in UAV path planning. The equation is written as:

$$U_{att}(p) = \frac{1}{2}\xi\rho^2(p, p_{goal}) \tag{8}$$

$$U_{rep}(p) = \begin{cases} \frac{1}{2}\eta(\frac{1}{\rho(p, p_{obs})} - \frac{1}{\rho_o})^2 \rho^n(p, p_{goal}), & \rho(p_{obs}, p) \le \rho_o \\ 0, & \rho(p_{obs}, p) \le \rho_o \end{cases} \tag{9}$$

ξ and η are gain factors of gravitation and repulsion respectively, ρ_0 is the influence range of threaten, p, p_{goal}, p_{obs} means the position of UAV, target and obstacle respectively. n is a positive constant, $\rho(p, p_{goal})$ and $\rho(p, p_{obs})$ mean the distance between UAV and the target and obstacle respectively. The distance $\rho(p, p_{goal})$ between UAV and target is integrated into the repulsive force field, it will guarantee that the repulsion become small while the distance between path point searched and the target, and target is the global minimum if and only if $p = p_{goal}$ when obstacles near target, then target unreachable will be not appear due to the oversize repulsion. The repulsion function is shown:

$$F_{rep}(p) = -\nabla U_{rep}(p) = F_{rep1}n_{OR} + F_{rep2}n_{RG} \tag{10}$$

$$F_{rep1} = \eta(\frac{1}{\rho(p, p_{obs})} - \frac{1}{\rho_o})\frac{\rho^n(p, p_{goal})}{\rho^2(p, p_{obs})}, \quad F_{rep2} = \frac{n}{2}\eta(\frac{1}{\rho(p, p_{obs})} - \frac{1}{\rho_o})^2 \rho^{n-1}(p, p_{goal})$$

$n_{OR} = \nabla\rho(p, p_{obs})$ and $n_{RG} = -\nabla\rho(p, p_{goal})$ are unit vectors, means the distance between UAV and the target and obstacle respectively, when UAV approaches the target, the repulsion of the obstacle nearby target become zero, UAV fly to target under the action of gravitation. This method maybe not solves the problem of target unreachable completely, but it is reasonable and applicative for the practical UAV path planning.

B. Method for Local Poles

The defect of artificial potential field is next step is searched by a single resultant force compressed by all information, then other valuable information of local obstacle is abandoned, so the target is unreachable while UAV obstacles avoidance. guided points is set in this paper that give UAV a potential field force with random direction, and guide UAV keep searching. The guided point is set either beforehand while off-line programming or random selection while replann. This method would also solve the problem of path shocking caused by concentrated distribution of obstacles. The UAV searches target and avoid shock area because shock point replaced by the guided point.

C. UAV Path Planning Based on Improved Artificial Potential Field Method

The key problem of UAV path planning is how to find the path points which meet constraint conditions. UAV plans path from starting point, its flight direction of next step is affects by resultant force F . Set a certain UAV location coordinates is (x_c, y_c, z_c) , F can be decomposed into three axes direction component are F_x , F_y and F_z . The coordinate axis force determine the direction of the step length, finally it determine the position coordinate of the UAV next time. Selecting the largest absolute value record as $F_{\max}$ among

F_x , F_y and F_z .The following formula determine the three coordinate axes step-length:

$$k = L / F_{\max} = L_x / F_x = L_y / F_y = L_z / F_z \tag{11}$$

L is UAV path planning step-length, coordinates calculation formula of next path point (x_n, y_n, z_n) is:

$$\begin{cases} x_n = x_c + L_x \\ y_n = y_c + L_y \\ z_n = z_c + L_z \end{cases} \tag{12}$$

Be attentive, after obtaining the path point it need to judge whether path point enters into obstacles or threatened area. If enters, it means the path point is unreasonable, irrational path point need to discard, then choose a new path point. Through search process of path points above, it gets a series of the path points, then add the target point, these points are connected by line segments, it generates a path which acquired by artificial potential field

D. Path Optimization

Path acquired by artificial potential field is not the optimal path, accurate to say, it is more like a kind of overall trend, so we need to optimize the path. Optimization procedure has three steps:

- The points close to obstacles or threatened area boundary is not reasonable because the restricted of UAV scale and the flight safety coefficient, the points should be abandoned;
- Starting from the second path point, seeking their intermediate point between front and rear point, and judging intermediate point whether it close to obstacle area or in the obstacle area, if so, use the same method to study the third point, If not, the intermediate point replaces the second path point.

This is one time optimization procedure, the path is still not the real optimal path. To get a better path, you need to optimal of dozens or even hundreds of times using the above method.

V. SIMULATION

A. Static Path Planning

Build flight environment based on part Ⅱ B, Initialized information of the peak model is:

$k = [1.6, 1.8, 2.1, 1.2, 2.6, 2.1, 1.5, 1.7]$;

$h = [7, 6, 7, 4, 10, 7, 4, 5]$;

$x_0 = [10, 10, 24, 35, 32, 41, 50, 52]$;

$y_0 = [12, 25, 45, 15, 29, 44, 38, 52]$; With the formula (1), the initialized terrain will be formed. The start point and target point of UAV is $(0,0,0)$ and $(60,60,0)$, safe flight height $H = 4$, scope of repulsion $d_{rep} = 4$, radius of landing $R_{goal} = 20$, planning step $L = 0.5$, initial path planned by traditional artificial potential field showed in Fig.1, planned by improved artificial potential field is showed in Fig.2.

It is observed from figure1 and figure2, shock appears in initial path planned by traditional artificial potential field when UAV near biggest obstacles, but the shock can be eliminated in initial path planned by improved artificial potential field, The simulation proved the effectiveness of the improved algorithm. The optimized initial path is formed by optimization procedure is showed in Fig.3. It is observed from the Fig.3, a smooth path can be got after 100 times optimization, the path is better than that before the optimization.

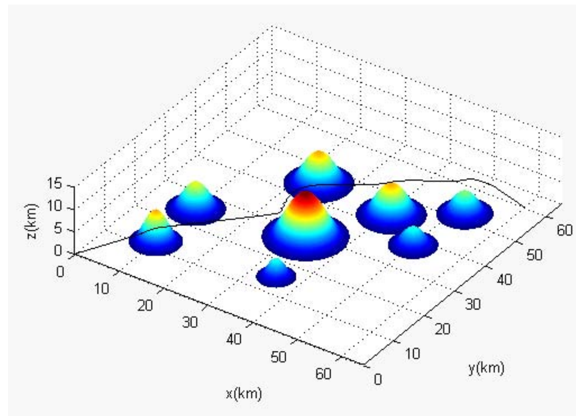

Figure 1. Initial path planned by traditional artificial potential field

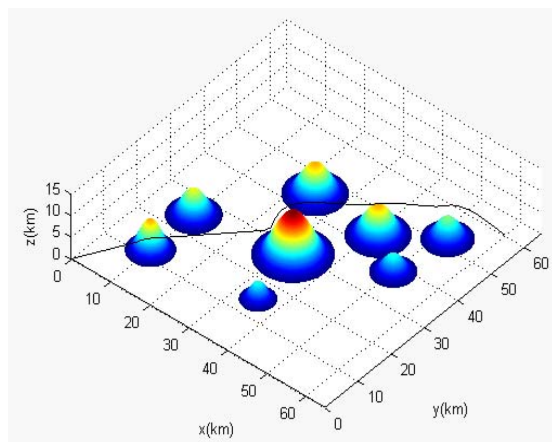

Figure 2. Initial path planned by improved artificial potential field

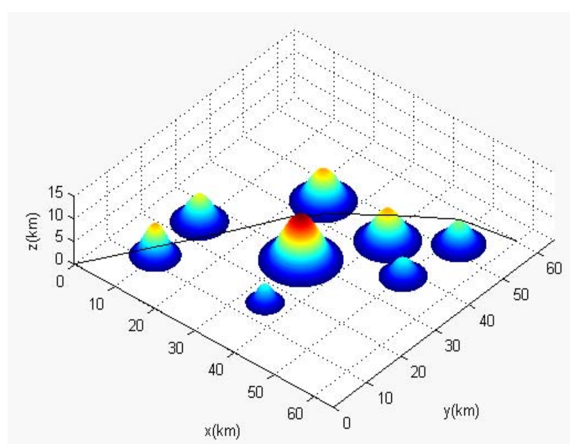

Figure 3. Optimized path

B. Dynamic Path Planning

Suppose when UAV detecting the change of environment at its twenty-eight path point, the information of environment is updating as follow:

$k = [1.6, 1.8, 2.1, 1.2, 2.6, 1.3, 2.3, 1.9]$;

$h = [7, 6, 7, 4, 10, 5, 6, 7]$;

$x_0 = [10, 10, 24, 35, 32, 41, 50, 50]$;

$y_0 = [12, 25, 45, 15, 29, 42, 35, 48]$; at this time UAV updates the parameters to replan path by improved artificial potential field, the comparison chart of optimized initial path and dynamic path is shown in Fig.4- Fig.7, it is observed that the paths which after twenty-nine path point are different, it shows the feasibility and effectiveness of the improved algorithm to replan path online.

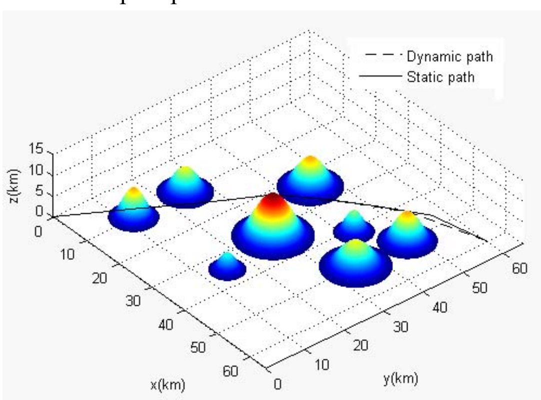

Figure 4. Visual rendering of 3D path

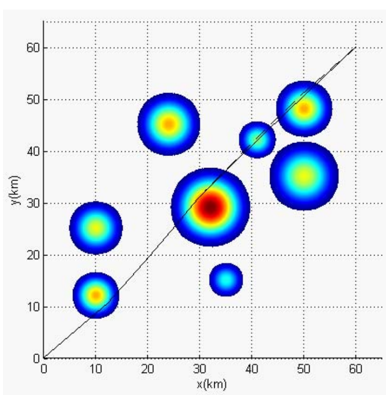

Figure 5. Visual rendering of plane X-Y

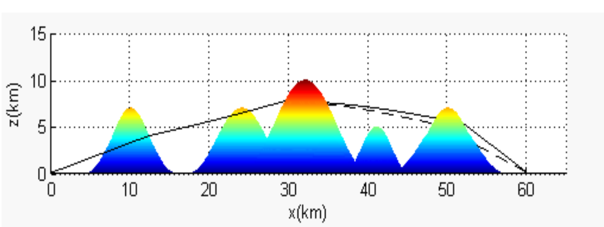

Figure 6. Visual rendering of plane X-Z

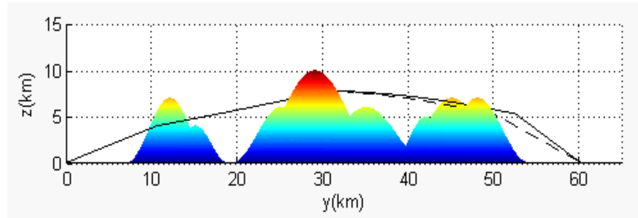

Figure 7. Visual rendering of plane Y-Z

VI. CONCLUSION

A 3D path planning algorithm of UAV based on improved artificial potential field in dynamic environment is proposed. The improved algorithm can avoid UAV going into local pole and shock area by setting potential field guide point and solve the problem of target unreachable by improving potential field function. Simulation results show the feasibility and effectiveness of the improved algorithm.

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