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Path Planning Algorithm for Quadrotor Unmanned Aerial Vehicles Based on Improved Artificial Potential Field

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ABSTRACT

When the traditional artificial potential field method solves the path problem of quadrotor unmanned aerial vehicles path planning. There are target unreachable problems and local optimal defects. This paper proposes an improved artificial potential field method. The whole obstacle is divided into Far obstacle and short-range obstacle using the distance between unmanned aerial vehicles and obstacle. And different repulsive force functions are established respectively. The target unreachable problems and local optimal defects can be solved by a change of repulsive of obstacle to unmanned aerial vehicles in the 2D artificial potential field algorithm. A hierarchical algorithm is proposed to design a path planning algorithm based on A* algorithm and artificial potential field method. Artificial potential field method is used to perform global path planning. Local path planning is performed using A* algorithm and guide the quadrotor UAV, thereby solving the problem of local minimum and target unreachable in 3d artificial potential field algorithm. The simulation results show that the modified algorithm can effectively accomplish path planning mission of quadrotor unmanned aerial vehicles and have a good optimization performance.

1. Introduction

Relative to Fixed wing unmanned aerial vehicles, quadrotor unmanned aerial vehicles have the advantages of small volume, good stealthiness, fast reaction and can vertically take off and land. It also can execute special tasks in the complicate environment. Quadrotor unmanned aerial vehicles has been widely used in the field of emergency service and disaster relief, aerial photography, geological survey, environmental assessment and conduit patrolling[1]. The control method of unmanned aerial vehicles belongs to manual tele-control. Quadrotor unmanned aerial vehicles operator need to have higher flight control skills and psychological quality. So intelligent path planning of quadrotor unmanned aerial vehicles is very important in order to reduce or eliminate the task failure by operator errors and ensure the quadrotor unmanned aerial vehicles can accomplish task well [2-4]. The path planning is refer to the optimal trajectory of quadrotor unmanned aerial vehicles can be found and on-line planning can be achieved , According to constraints of the properties of quadrotor unmanned aerial vehicles, environmental threat and mission in the little manual intervention and without artificial intervention[5-7].

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The current UAV route planning has the following problems[8].

Airway system constraints are too simplified. At present, the consideration of the UAV dynamic constraints is too simple, resulting in the flight path that is often determined by the dynamic constraints and is actually not flyable. In addition, the dimensionality reduction of the threatened field makes the planned route difficult to use, especially for the route planning where low-altitude penetration is necessary.

Timeliness requirements. For the undetermined battlefield environment, real-time planning or local planning is required, but the current problem is that the calculation time is too long to meet the requirement of evading threats for a few hours, or the model is considered too simple, resulting in actual flight threats greater than planned threats.

The future development direction and research focus of UAV planning are mainly:

Three-dimensional low-altitude penetration. Taking into account the UAV dynamic constraints and threat environment constraints, ensure the timeliness of the algorithm to meet the requirements of UAV low-altitude penetration.

Real-time route planning. For unidentified threat fields, drones must carry out online route planning to avoid risks, realize the evaluation of the battlefield situation in an undetermined environment, and effectively use various kinds of information to fuse the sensory information. Achieve autonomous route planning.

The good path planning algorithms have traditional classical algorithms and modern intelligent algorithms[9]. The traditional classical algorithms include mathematical programming method, dynamic programming, newton method and gradient method. The modern intelligent algorithms includes heuristic optimal searching, artificial neural network, genetic algorithms, simulated annealing, expert system algorithm, swarm intelligence algorithm, artificial potential field, A* algorithm, RRT algorithm, etc[10]-[12]. Among them, the artificial potential field method stands out from many track planning algorithms with the advantages of low computational complexity, smooth track, and strong real-time performance. However, it also has the disadvantages of local minimum and unreachable targets. Therefore, based on the analysis of the basic theory of traditional artificial potential field method and its advantages and disadvantages, this paper proposes an improved artificial potential field algorithm to improve track planning reliability[15-17].

2. Track planning modeling

2.1 Establishment of a cost function

In most cases, drones perform specific reconnaissance and surveillance flight missions. If there are no special circumstances, they fly according to the predetermined path. If a threat is found within the detection range, the flight path is re-planned with the current point as the starting point, and real-time detection of the threat is guaranteed[13]. Without colliding with the threat, plan a feasible flight path in real time to return to the scheduled path to continue the mission. The objective function can be expressed as

$$\max F = \frac{v}{c}$$

where v is the value for booking path, c is the route cost.

As for the route cost according to the analysis of the influencing factors of the route planning, it includes the threat cost c_t and the fuel consumption cost c_0. The treat cost and fuel consumption cost are summed by a certain weight, the threat cost weight is w_t, and the fuel consumption cost weight is w_0, and $w_t + w_0 = 1$. The route cost is

$$c = w_t * c_t + w_o * c_o$$

The objective function of the route can be expressed as

$$\max F = \frac{v}{c} = \frac{v}{w_t * c_t + w_o * c_o}$$

2.2 Restrictions

Dynamic constraints also need to be considered during the actual flight of the UAV, mainly including the following aspects[14]:

(1)Maximum and minimum flying height of drone. It limits the flying height of the drone on the planned route, and different constraints can be used for different types of mission routes. The maximum flight altitude is usually expressed in altitude, which is generally lower than the actual upper limit of the drone to ensure that the drone can reach this flying height. The minimum flying height is usually expressed as the relative height to the ground, because when the drone passed the enemy defense zone, it usually needs to use the terrain to block to reduce the probability of being detected by the detector. The relative altitude follows the terrain. However, flying too low often increases the risk of the aircraft colliding with the ground, so the relative height above the ground should be greater than or equal to a given height to ensure flight safety. Assuming that the flight height of the planned route is H, the minimum flight height is $H_{\min}$, and the maximum flight height is $H_{\max}$, the constraint can be expressed as: $H_{\min} \le H \le H_{\max}$

(2) The maximum range of the drone. It limits the total length of the planned route to be less than or equal to a preset maximum distance. It mainly depends on the fuel carried by the UAV and the flight speed and flight time allowed to complete the flight and combat missions. Suppose the planned route of the drone is composed of $\{ l_i \,|\, i = 1, 2, \cdots, n \}$, and the maximum allowable total length of the route is $L_{\max}$, then the constraint can be written as:

$$\sum_i \| l_i \| \le L_{\max}$$

(3) Maximum fuel consumption. Since the fuel carried by the drone before take-off is fixed, in order to ensure that the aircraft can return enough fuel after performing the mission, it is required to consider the total fuel consumption allowed as a factor in the route planning.

(4) Maximum and minimum flight speed. In general, the speed of the UAV can only be maintained in a limited interval on a certain flight path, it depends on the aircraft's power system, and is also related to a specific environment, space position and mission, such as low and high altitude, or cruising. During flight and penetration attacks, different flight speed ranges should be set for the UAV. If the actual flight speed of the drone is *v*, the minimum allowed flight speed is $v_{\min}$, the maximum flight speed is $v_{\max}$, and $v_{\min}$ should be greater than the minimum flight speed of the drone,

v_{max} should be less than the maximum flight speed of the drone speed, the constraint is expressed as: $v_{min} \le v \le v_{max}$.

(5) The longest line of sight of the drone. This parameter determines the longest distance that the drone can detect an unknown threat when flying on a scheduled trajectory. If the drone has a longest far sight distance, the path planning time will be more abundant. If the drones has the shortest distance, it will have higher requirements for its maneuverability, to prevent it from being too lead to plan the path after the unknown threat is found collision with threats.

(6) UAV minimum route length. It define the shortest distance that should be maintained between the waypoints during the route planning, and reflects the shortest distance that the drone must maintain direct flight before starting to change the flight attitude. This limitation not only depends on the maneuverability of the aircraft, but is also often linked to the navigation requirements of the aircraft. For example, when the aircraft is flying at a long distance, it is generally hoped that it can maintain a straight flight for a distance when entering and exiting waypoints to reduce navigation errors.

(7) Maximum turning angle of drone. It restricts the drone from flying along a certain flight path to flying along the next flight path, the change of he heading angle can only be within a certain range, so as to avoid frequent turning of the UAV in roundabout travel, the constraint condition generally depends on the aircraft maneuverability and flight mission characteristics. Because the quadrotor can hover, it is not restricted by the turning angle and turning radius, so the constraints of the turning angle and turning radius of the quadrotor are not considered in this article.

(8) Target entry direction. It restricts the aircraft from approaching the target at a specific angle or a specific angle interval to ensure that the aircraft can launch an assault on the weakest position of the enemy’s defense or from the direction in which the maximum combat effect is expected.

(9) Route concealment. The concealment of the route means safety for the aircraft. Although most unmanned aerial vehicles are designed with a variety of stealth technologies, they are still likely to be discovered in the face of various enemy detection systems, so plan a good concealed flight. Usually restrict the route to keep away from the threat source, or make the aircraft fly at low altitude to take advantage of terrain clutter and reflected ground clutter to reduce the probability of discovery, or when you have to pass through the threatened area with the smallest probability of discovery or damage by.

3. Basic principles of artificial potential field algorithm

The artificial potential fields path planning is virtual force method proposed by Khatib. Its basic idea is to design the movement of the drone in the surrounding environment as an abstract artificial gravitational field. The target point generates gravity to the drone, and the obstacles generate repulsion to the drone. Finally the motion of the drone is controlled by finding the resultant force[18] .

3.1 Two-dimensional artificial potential field algorithm

The main problem solved by the two-dimensional artificial potential field algorithm is the two-dimensional trajectory planning of the quadrotor UAV.

According to the principle pf artificial field of view, the target gravity function is established, as shown below

$$U_G(p) = \frac{1}{2}k(p - p_G)^2$$

where, $U_G\left(p\right)$ is the gravitational field of p, and k is the gravitational field coefficient, and p_G is the target point position.

Establish obstacle repulsion function as shown below

$$U_O(p) = \begin{cases} \frac{1}{2}\eta\left(\frac{1}{\rho} - \frac{1}{\rho_0}\right), & \rho \le \rho_0 \\ 0, & \rho > \rho_0 \end{cases}$$

where, $U_0\left(p\right)$ is the repulsive field of p ,η is the repulsive force field coefficient, ρ is the shortest distance from the quadrotor to the obstacle, and ρ_0 is the threshold.

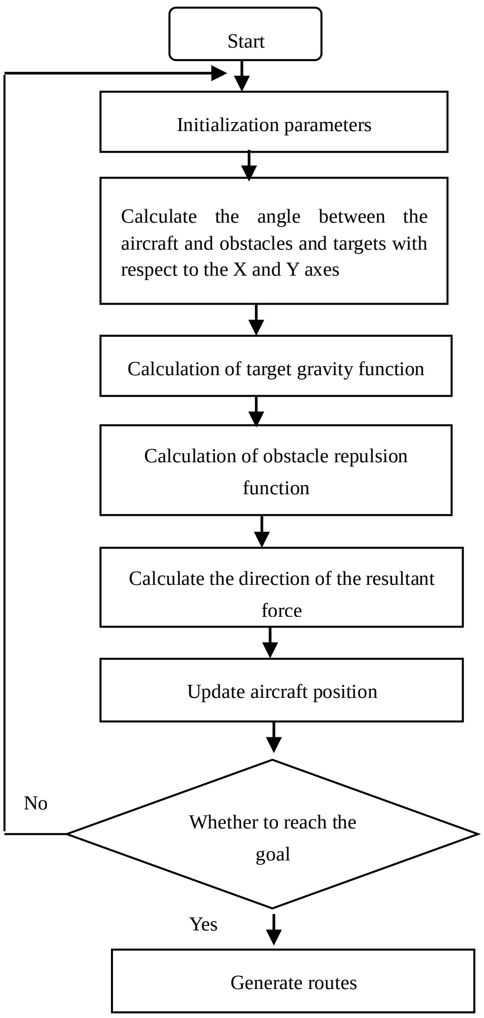

Fig.1.functional block diagram of two-dimensional artificial potential field algorithm

The expression of the combined force of the quadrotor drone in the potential energy field is:

$$F(p) = F_G(p) + \sum_{i=1}^{n} F_{Oi}(p)$$
$$= -\nabla U_G(p) + \sum_{i=1}^{n} (-\nabla U_{Oi}(p))$$

where, $F_G(p)$ is the gravitational force generated by the gravitational field at the ρ point of the drone, which is the negative gradient of the gravitational field, $F_{oi}(p)$ is the repulsive force of the i-th obstacle at P point, and is the negative gradient of the repulsive field at P point.

By calculating the distance and angle information of the position of the drone and the location of the obstacle target, and substituting it into the gravitational function and the repulsion function, the resultant force formula is used to obtain the direction of the resultant force on the position. Advance the unit step in the direction of the resultant force to get the next position of the drone, and then cycle until the target position is reached, and plan the track of the quadrotor in real time. The principle flow chart of two-dimensional artificial potential field algorithm trajectory planning is shown in figure 1.

3. 2 The three-dimensional artificial potential field algorithm

The three-dimensional artificial potential field algorithm is improved on the basis of the two-dimensional algorithm, adding height information, changing the gravity function and repulsion function, and solving the three-dimensional path planning problem of the quadrotor UAV.

The three-dimensional artificial potential field algorithm is based on the two-dimensional artificial potential field algorithm to define the gravitation function and repulsion function. In order to simplify the calculation, the three-dimensional space is divided into two planes, the horizontal plane and the vertical plane, and the resulting trajectory planning is synthesized to achieve the three-dimensional space trajectory planning of the quadrotor UAV.

First define the three-dimensional gravitational function as

Level

$$U_{G1}(p) = \frac{1}{2} k_1 (p - p_G)^2$$

Plumb

$$U_{G2}(p) = \frac{1}{2} k_2 (p - p_G)^2$$

In the formula, $U_{G1}(P)$ and $U_{G2}(P)$ are the gravitational fields of point p in the horizontal plane and the vertical plane, k_1 and k_2 are the gravitational field coefficients of the corresponding plane, and P_G is the position of the target point.

Secondly, the three-dimensional repulsion function is defined as Level

$$U_{O1}(p) = \begin{cases} \frac{1}{2}\eta_1\left(\frac{1}{\rho} - \frac{1}{\rho_0}\right), & \rho \le \rho_0 \\ 0, & \rho > \rho_0 \end{cases}$$

Plumb

$$U_{O2} = \begin{cases} \frac{1}{2}\eta_2\left(\frac{1}{\rho} - \frac{1}{\rho_0}\right), & \rho \le \rho_0 \\ 0, & \rho > \rho_0 \end{cases}$$

In the formula, $U_{o1}(P)$ and $U_{o2}(P)$ are the repulsion fields of point P in the horizontal plane and the vertical plane, η_1 and η_2 are the repulsion field coefficients of the corresponding plane, ρ is the shortest distance from the quadcopter to the obstacle, ρ_0 is a threshold.

Finally, the force of the drone in the horizontal plane and the vertical plane are calculated separately, and the direction of the resultant force of the drone *n* the each plane is calculation. The calculation formula is as follows:

$$F(p) = F_G(p) + \sum_{i=1}^{n} F_{Oi}(p)$$
$$= -\nabla U_G(p) + \sum_{i=1}^{n} (-\nabla U_{Oi}(p))$$

After obtaining the direction of the resultant force, according to the principle of the algorithm, advance the unit step along the direction of the resultant force in each plane, update the position of the aircraft, and obtain the coordinates of the flight path points. The coordinate information in the two planes is generated according to the corresponding relationship to generate three-dimensional position coordinates, so as to realize the three-dimensional space path planning of the quadcopter.

3. 3 Characteristics of artificial potential field algorithm

Compared with other traditional algorithms, the artificial potential field can not only reflect the topology of the planning environment, but also have lower operation complexity, fewer, calculation steps, smooth planning trajectories and good real-time performance compared with global planning. Man-machine orbit planning. However, the artificial potential field algorithm has the following two situations in long-term practical application, which limits the application scenarios of the planning algorithm, affects the planning efficiency of the artificial potential field method, and causes the system to fail to complete path planning.

1）because he traditional artificial potential field method uses virtual force to control the movement of he UAV, when two obstacles are close, the problem that the UAV cannot pass through the narrow channel may occur. In addition, if the drone, obstacle and target point are on the same straight line, the drone can only be moved repeatedly in a straight line under force control, but cannot reach the target. If the obstacle is located near the target point, the repulsive force may be greater than the attractive force, causing the target to be the unreachable.

2）When the drone has not reached the target point but resultant force is zero, it will fall into a local minimum point and stop moving.

The schematic diagram of path planning failuer of artificial potential field algorithm is shown in figure 2.

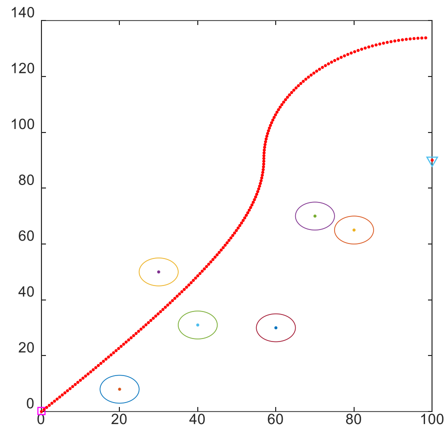

Fig. 2. Schematic diagram of path planning failure of artificial potential field algorithm

4. Improvement of artificial potential field

Aiming at the problems of local minimum value and unreachable goal of artificial potential field algorithm, two-dimensional and three-dimensional artificial potential field algorithms are proposed to improve the reliability of trajectory planning

4.1 improvement of two-dimensional artificial potential field algorithm

By changing the repulsive force of obstacles to the drone to solve the local minimum and target unreachable

(1) According to the distance between the drone and the obstacle, divide the obstacle into long-distance obstacles and short-distance obstacles, and establish different repulsion function.

The obstacle repulsion function is

$$Y_r(i) = m \times (\frac{1}{r} - \frac{1}{\rho_0}) \times \frac{1}{R} \times R_a$$

$$Y_a(i) = m \times (\frac{1}{r} - \frac{1}{\rho_0}) \times r_a$$

where, $Y_r(i), Y_a(i)$ are the two components of the obstacle's repulsive force decomposition to the target, m is the repulsion coefficient, r is the distance between the path point and the obstacle, ρ_0 is the distance affected by the obstacle, R is the square of the distance between the path point and the obstacle, R_a is the square of the distance between the path point and the target, and r_a is the distance between the path point and the target.

For short-range obstacles, the repulsive force is

$$Y_{rx}(i) = -Y_r(i) \times \cos\theta$$
$$Y_{ry}(i) = Y_r(i) \times \sin\theta$$
$$Y_{ax}(i) = Y_a(i) \times \cos\varphi$$
$$Y_{ay}(i) = Y_a(i) \times \sin\varphi$$

where, $Y_{rx}(i), Y_{ry}(i), Y_{ax}(i)$ and $Y_{ay}(i)$ are respectively the vectors of the $Y_r(i)$ and $Y_a(i)$ components on the x and y axes, θ is the angle between the path point and the obstacle, φ is the angle between the path point and the target.

For long distance obstacle, the repulsive force is

$$Y_{rx}(i) = Y_r(i) \times \cos\theta$$
$$Y_{ry}(i) = -Y_r(i) \times \sin\theta$$
$$Y_{ax}(i) = Y_a(i) \times \cos\varphi$$
$$Y_{ay}(i) = Y_a(i) \times \sin\varphi$$

where, $Y_{rx}(i), Y_{ry}(i), Y_{ax}(i)$ and $Y_{ay}(i)$ are respectively the vectors of the $Y_r(i)$ and $Y_a(i)$ components on the x and y axes, θ is the angle between the path point and the obstacle, φ is the angle between the path point and the target.

(2) The direction of the repulsive force of the drone subject to obstacles is specified to meet the obstacles where the abscissa of the drone is greater than the abscissa of the obstacle, for obstacles that meet the drone's abscissa less than the abscissa of the obstacle, the direction of the repulsive force along the two-point line points to the positive direction of the ordinate.

4.2 Simulation verification of improved two-dimensional artificial potential field algorithm

Drones will face many threats in the course of their missions, including obstacles on the route, anti-aircraft missiles and radar detection threats from the enemy. In order to better apply the artificial potential field algorithm to UAV trajectory planning, the following assumptions are proposed.

Hypothesis 1: in the two-dimensional space, since the defense of firepower and radar equipment is omnidirectional, threats such as obstacle, radar, and ground firepower are approximated by a circle. The geometric center and radius are used as the main parameters of the threat. The threat can penetrate and superimpose. The space threat is regarded as a repulsive body, which generates repulsive force against the UAV to avoid obstacles.

Hypothesis 2: in two-dimensional space, the UAV is represented by a circle, the center of mass is the center of the circle, the largest feature size is the diameter, and the distance between the drone and the threat of target point is the center of mass distance. The particles are processed.

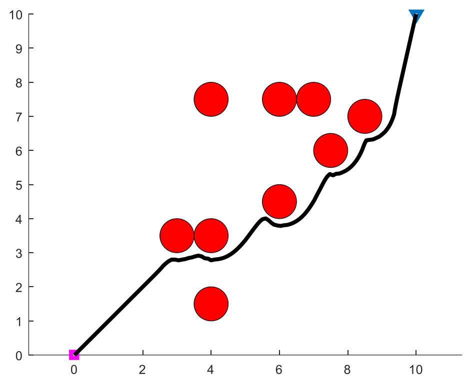

Fig. 3. The path planned by the improved two-dimensional artificial potential field method in an unknown environment (1)

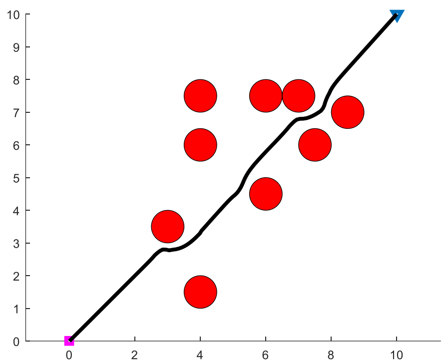

Fig. 4. The path planned by the improved two-dimensional artificial potential field method in an unknown environment (2)

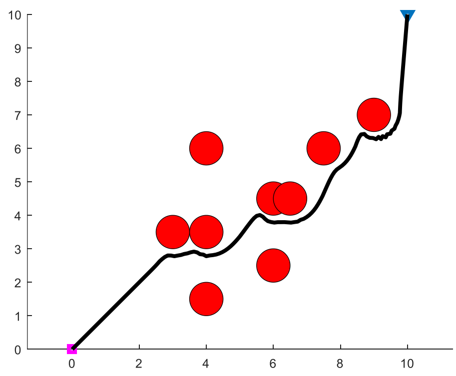

Fig. 5. The path planned by the improved two-dimensional artificial potential field method in an unknown environment (3)

In order to verify the performance of the improved artificial potential field algorithm proposed in this paper, matlab programming was used. The size of the execution area of the drone is 120×120, the starting point coordinates of the drone is (1,0), target point coordinates is (100,100). The obstacles in the flight area are randomly generated.

The simulation results of the path planned for the quadrotor UAV in an unknown environment based on the improved two-dimensional artificial potential field algorithm are shown in figures 3、4 and 5. The experimental results show that the improved two-dimensional artificial potential field algorithm has obstacle in an unknown environment where objects are densely distributed, the path can be well planned, the planning trajectory is smooth, and the real-time performance is good, which verifies the correctness and effectiveness of the algorithm.

4.3 improvement of three-dimensional artificial potential field algorithm

The problem of the local minimum value and target unreachability in the three-dimensional artificial potential field algorithm is in the final analysis because the local minimum value and the repulsive force of the UAV due to obstacle repulsion and target gravity cause the target to be unreachable. Therefore, when the artificial potential field algorithm is caught in the problem of local minimum and target unreachability, the A* algorithm is used to make the quadrotor UAV trajectory jump out of the extreme point, and then realize the UAV trajectory through the artificial potential field algorithm.

1.A* algorithm

The A* algorithm is a heuristic search algorithm widely used in path planning. It comprehensively evaluates the generation value of each node, and compares these generation values, and selects the node with less value as the expansion node, and then continues to expand the next node with this node until the target point is selected as the expansion node generate the path with the least value from the starting point to the target point[19-20].

2. Two-dimensional A* algorithm

The A* algorithm obtains the minimum path by comparing the algebraic value of each node. The cost function is established as follows:

$$f_{(n)} = g_{(n)} + h_{(n)}$$

where n is the node to be expanded, $f(n)$ is the evaluation function of the node to be expanded, $g(n)$ is the true cost from the starting point to the current node n, and $h(n)$ is the heuristic function, indicating that from the current node n to the target node cost estimated cost from the starting point to the target point.

When using the A* algorithm to expand the next node, all the alternative nodes with the smallest values $f(n)$ are inserted into the possible path list. It is proved that as long as the value of the heuristic function $h(n)$ is not greater than the real generation value from node n to the target node, and there are feasible solutions in the search space, then the A* algorithm must be able to find the optimal solution.

The A* algorithm mainly uses two tables to perform the expansion of the node and the selection of the optimal node when performing the search. These are the open table and close table, respectively. The function of the open table is to save the expansion nodes encountered in the search process, and at the same time to sort these nodes according to the size of the generation value. The function of the close table is to save the scalable nodes with the smallest generation value in the open table. These nodes may be the components of the optimal path.

The main process of applying the A* algorithm to the two-dimensional space drone track planning is as follows:

(1)Set map information: establish two-dimensional map information and set the map range、targets、obstacles and starting point of the aircraft

(2)Generate closed table: insert all obstacles into the closed table

(3)Start node setting: set the aircraft starting point as the first node and insert it into the open and closed tables

(4)Inheritance list generation: based on the start node, generate an inheritance list and mark $h(n)$, $g(n)$ and $f(n)$ parameter information

(5)Determine whether open has the same coordinates as the inherited list coordinates: if it exists, update the parent node and insert the new element into the open table and go to step(6)，if not, go to step(6)

(6)Determine whether the open table is empty, if it is empty, determine whether the parent node is the target point, if it is ,then output the path, if it is not the target point, then output "the target path has not been reached", if it is not empty, then select the open table insert the element with the smallest $f(n)$ value into closed, and update the parent node information, add the new element to the open table, and determine whether the parent node is the target point. If it is, output the path; if it is not, also loop (5) (6) steps until the output path.

3. Three-dimensional A* algorithm

Like the artificial potential field 3D A* algorithm, the 3D A* algorithm is based on the improvement of the 2D algorithm, adding height information, expanding the 2D search space into a 3D search space and establishing a 3D Threat model, so as to realize the 3D path of the A* algorithm planning.

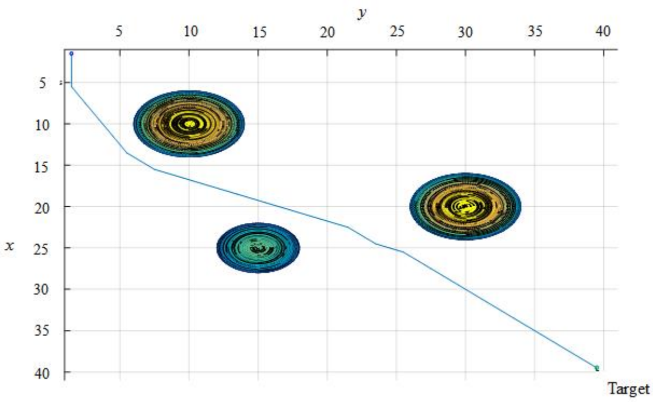

Fig. 6. schematic diagram of three-dimensional A* algorithm planning path

5. The characteristics of A* algorithm

The A* search algorithm is simpler than other search algorithms. According to the heuristic function to guide the search toward the target node, the search degree and the number of nodes in the search area can be reduced. The planned path is short and the fuel consumption is low. However, the real-time performance is low. There is a broken line segment in the path, which requires high mobility of the drone, the schematic diagram of three-dimensional A* algorithm planning path is shown in figure 6.

After comparative analysis, the planning time of the A* algorithm is limited by the size of the map, which is suitable for small map trajectory planning. The planning trajectory is suitable for re-planning of small-scale trajectory in flight. However, due to the roundness of the planned trajectory, it has the disadvantage of low practicality and needs to be improved. The track planning algorithm of the artificial potential field has a high degree of smoothness, but there are defects of local optimality and unreachable goals. Therefore, A* algorithm and artificial potential field algorithm have complementary advantages.

5. Improvement of three-dimensional artificial potential field algorithm

By analyzing the artificial potential field algorithm and the A* algorithm, it can be seen that the A* algorithm can solve the problem that the artificial potential field algorithm falls into the local minimum value of the target unreachable. Therefore, the three-dimensional artificial potential field algorithm is improved to improve the three-dimensional artificial potential field algorithm. In the field algorithm route planning, the A* algorithm is introduced. When the artificial potential field algorithm falls into the problem of local minimum and target unreachability, the A* algorithm is used to make the quadrotor UAV route jump out of the extreme point, thereby realizing unmanned quadrotor aircraft trajectory planning.

The execution steps are as follows:

First of all, the four-rotor UAV plans the trajectory according to the artificial potential field algorithm. During flight, it detects whether it reaches the target point in real time. If it reaches the target point, the algorithm exits; if it does not reach the target point, it detects whether it falls into a local minimum and the target is unreachable problem. If yes, go to step 2.

Secondly, When the planned path of the artificial field algorithm is caught in the problem of local minima and target unreachability, the A* algorithm is called to re-plan a new trajectory to make the quadrotor drone jump out of the extreme point.

Finally, the four- rotor UAV flies according to the newly planned track and detects whether it reaches the target point in real time. If it reaches the target point, it jumps to step 1, if it does not reach the target point, it jumps to step 2.

4.4 simulation verification of improved three-dimensional artificial potential field algorithm

Like the two-dimensional space, in the three-dimensional space, the threats of obstacles, radar detection and fire strikes are combined. With the characteristics of each threat, the following assumptions are proposed.

Hypothesis 1: In three-dimensional space, the obstacle, radar, and ground fire seal threats are approximated by hemispheres. The geometric center and radius are the main parameters of the threat. The threat can penetrate and superimpose. The space threat is regarded as a repulsive body, which generates repulsion against the drone avoid the threat.

Hypothesis 2: In three-dimensional space, the UAV is represented by a sphere, the center of mass is the center of the sphere, the largest feature size is the diameter, and the distance between the drone and the threat of target point is the center of mass distance. The particles are processed.

In order to verify the performance of the improved three-dimensional artificial potential field algorithm proposed in this paper, matlab simulation verification was performed. The size of the execution area of the drone is 60×60×60,, the starting point coordinates of the drone is (0,0,0), target point coordinates is (60,58,10). The obstacles in the flight area are randomly generated. The path planned by the improved three-dimensional artificial potential field method in an unknown environment is shown in figure 7.

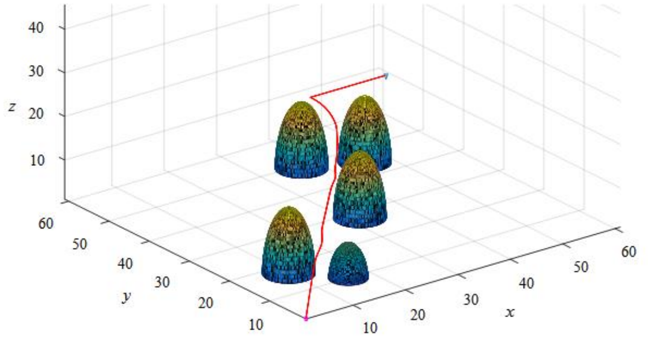

Fig. 7. The path planned by the improved three-dimensional artificial potential field method in an unknown environment

After many verifications, the three-dimensional artificial visual field improved algorithm simulation operation can well plan the UAV trajectory, and the planned route combines the characteristics of the artificial potential field and the A* algorithm, with good real-time and reliability, can well meet the real-time obstacle avoidance needs of drones.

6. Application of trajectory planning algorithm in MAPX

```
        return -1;
}
mwArray mwStart(1,2,mxDOUBLE_CLASS);
mwArray mwGoal(1,2,mxDOUBLE_CLASS);
mwArray mwbarcenter(1,2,mxDOUBLE_CLASS);
mwArray mwradius(1,1,mxDOUBLE_CLASS);
mwArray mwpath;
mwStart.SetData(Start,2);
mwGoal.SetData(Goal,2);
mwbarcenter.SetData(barcenter,2);
mwradius.SetData(&radius,1);
RRT(1,mwpath,mwStart,mwGoal,mwbarcenter,mwradius);
NumofElement=mwpath.NumberofElements();
path1=new double[NumofElement];
mwpath.GetData(path1,NumofElement);
for(int j=0;j<2;j++)
    {
        for(int i=0;i<NumofElement/2;i++)
        {
            path[i][j]=path1[i+(NumofElement/2)*j];
            }
        }
for(int k=0;k<NumofElement/2;k++)
    {
        for(int l=0;l<1;l++)
        {
```

Fig. 8. Visual C++ calling matlab program

MAPX is an ActiveX control product with powerful map analysis function provided to users based on the visual map component. DataMap developed by American MapInfo company. MapX is a programmable control based on ActiveX（OCX）technology. In the visual development environment such as VB、Delphi、PowerBuilder、VC etc, you only need to put the MapX control in the form at the design stage and program it, set properties or call methods or corresponding events, you can achieve data visualization and special analysis, Geographic query, geographic coding and other rich map information system functions.

This section mainly introduces how to call the path planning algorithm simulated in matlab to visual C++, and combine the mapx map function to show the planned path on the map

Create a map in visual c++

Generate matlab function as a dynamic link library, and then call the dynamic link library in C++ by calling the function

Run the called program in visual c++, you can get the generated waypoint information, the draw the waypoint information on the map, and finally show the planned track on the mapx map. The Visual C++ calling matlab program is shown in figure 8.

7. Conclusion

UAV route planning is an important part of UAV flight control. In the paper ,an improved artificial potential field algorithm is proposed to solve the problem of trajectory planning for quadrotor UAV in unknown environment, By changing the repulsive force of obstacles to the drone to solve the local minimum and target unreachable， And introduce A* algorithm to solve the problem of local minimum and target unreachability in three-dimensional artificial potential field algorithm and it is used in two-dimensional mission space. The simulation verification was carried out, and satisfactory results were obtained. It was verified that the improved artificial potential field algorithm can adapt to the requirements of dynamic track planning.

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