Intelligent Path Planning Algorithm for UAV Group Based on Machine Learning

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Abstract. Aiming at the minimum and local minimum problems existing in the artificial potential field algorithm for obstacle avoidance of UAV, a new path planning method is proposed by using the improved artificial potential field algorithm. Different from the current artificial potential field method, this model starts from the interaction between two aircraft. On the basis of obstacle repulsion, the repulsion force between UAV is increased, and the pre-centroid of the cluster is defined as another source of gravity. The analysis of the algorithm shows that this method can effectively prevent the UAV from falling into the local minimum and enhance the control and obstacle avoidance ability of the UAV cluster. Based on the UAV control model, the path planning design is given and the simulation experiment is carried out. The experimental results show that the UAV cluster control based on this model has better obstacle avoidance performance and target tracking ability.

Keywords: UAV, path planning, improved artificial potential field, formation flight

1. Introduction

With the development and application of science and technology in the world, the performance development of UAV is becoming more and more comprehensive. In recent years, UAV is playing a more and more important role in both military and civilian fields, and its development potential has been gradually tapped [2]. UAV with the ability to carry out missions independently is the inevitable trend of future development. Path planning is the key technology to ensure the autonomous flight of UAV and improve the survivability and safety index [3].

UAV path planning is a comprehensive consideration of UAV in the environment with obstacles or threats, with a certain control algorithm to find a collision-free path from the starting position to the target position, comprehensively considering the obstacle target guidance [4].

When performing tasks on a single UAV, the survival rate is low, the mission failure rate is high, and the reconnaissance efficiency is low, so it is necessary to control the UAV cluster. At present, the control of UAV cluster is mostly based on the master-slave relationship control of long aircraft-wingman, which solves the problem of cooperative control of UAV cluster to some extent, but this method reduces the flexibility of each UAV and limits the performance of individual UAV. Based on the improved artificial potential field, a control method suitable for drones is proposed in this paper. In this method, the repulsive force function is used as the repulsive force of the obstacle to the UAV, which solves the
problem that the UAV cannot reach the target point because of the large repulsive force of the obstacle near the target point. The concept of pre-centroid is newly added, which has a corresponding gravitational force on UAV, which solves the problem that UAV is trapped in local minimum.

2. UAV path Planning based on artificial potential Field method

2.1. Overview of artificial potential field

The artificial potential field method is originally proposed by Khatib [12] to solve the path planning problem. The method of path planning is to design the work of the robot in the environment as a kind of abstract artificial gravitational field, the target point provides gravity to the movement of the UAV [13], and the obstacle provides the repulsive force to the moving UAV. Finally, through the resultant force to achieve the purpose of controlling the UAV to avoid obstacles [14]. The advantage of this method is that the planned path is relatively smooth and avoids the danger caused by UAV stall caused by large angle turning; one disadvantage is that it is easy to fall into the minimum point [15], and when there is a large obstacle around the target point, the repulsion force of the obstacle is greater than the target gravity, and the UAV cannot reach the target point.

2.2. Definition of pre-centroid of UAV group

![Figure 1. Schematic diagram of pre-centroid](image)

In order to solve the shortcomings of the artificial potential field method, a new gravity source, the pre-centroid, is defined in this paper (as shown in figure 1). The front centroid is the point at which the centroid position of the UAV group is fixed in the direction of the target point. When there is no obstacle in front of the UAV and the target gravity and obstacle repulsion are equal, the pre-centroid is used as another source of gravity of the UAV group. The gravity source acts on the unmanned organic gravity, which breaks the force balance of the UAV and makes the UAV maneuver toward the target point.

The normalized direction of the gravity of the target point to the front point is taken as the target direction for the advance of the front centroid, that is,

$$\mathbf{P}_f = \frac{\mathbf{F}_{at}}{|\mathbf{F}_{at}|}$$  \hspace{1cm} (1)

The formula for calculating the pre-centroid is

$$(x_0, y_0) = (\bar{x}, \bar{y}) + L\mathbf{P}_f$$  \hspace{1cm} (2)

Among them, $\mathbf{P}_f$ is the direction vector of the front centroid to the target point; $(x_0, y_0)$ is the coordinate position of the pre-centroid; $(\bar{x}, \bar{y})$ is the centroid of the UAV group; and L is the unit step size, which can be adjusted according to the size of the obstacle. In the process of UAV flight, the front centroid can pass through the obstacle, and it also has a gravitational effect on the UAV in the obstacle.
2.3. Repulsion function definition

The purpose of the obstacle repulsion field is to produce repulsion to the flight of the UAV and to make the UAV make the obstacle avoidance action at the right time. Because of the definition of repulsive force in the improved artificial potential field function, the gravity of the UAV is not strong enough when it reaches the target point, which makes the UAV wander near the target point and cannot reach the target point. Therefore, on the basis of the original repulsion, the influence factor of the distance from the target point is increased, and a new repulsion function is constructed:

\[ F_{re} = K_e \left( \frac{1}{\rho_{obs}} - \frac{1}{\rho_0} \right) e^{-\frac{\lambda}{\rho_{obs}}} P_{oe} \rho_{obs} \leq \rho_0 \]

\[ F_{re}=0 \rho_{obs} > \rho_0 \]

Among them, \( K_e \) is the constant of the repulsive force gain of the obstacle, \( \rho_{obs} \) is the distance between the UAV and the obstacle, \( \rho_0 \) is the range of the repulsive force acting on the obstacle, \( \lambda \) is the constant that can be adjusted according to the obstacle and \( \rho_{max} \), and \( P_{oe} \) is the unit vector, and the direction is directed from the obstacle to the UAV.

3. UAV path Planning based on artificial potential Field method

Suppose there are \( n \) UAVs in the specified flight area for marshalling flight, and the position information of the \( i \)th UAV at \( t \) time is \((x_i,y_i)\). The distance between the UAV and the target point \( \rho_{goal} \), is calculated and the gravity \( f_{att} \), of the target point to the UAV is calculated according to the formula:

\[ (\bar{x}, \bar{y}) = \left( \frac{1}{n} \sum_{i=1}^{n} x_i, \frac{1}{n} \sum_{i=1}^{n} y_i \right) \]

The position of the centroid of the UAV \((\bar{x}, \bar{y})\) is obtained, and the position of the pre-centroid, the distance between the UAV and the pre-centroid \( \rho_{pre} \), and the gravity \( f_{ap} \) of the UAV subjected to the pre-centroid are calculated according to the formula (2).

4. Simulation verification

In order to verify the experimental conjecture, MATLAB2014a is used for simulation.
The initial positions of UAV 1, 2, 3 and 4 are set as $(x_1, y_1) = (450,150)$, $(x_2, y_2) = (350,250)$, $(x_3, y_3) = (250,350)$ and $(x_4, y_4) = (150,450)$, respectively. The speed of the UAV is 10, the size of the UAV is set to 10, the gravitational field gain coefficient $K_a$ is 30, and the repulsion field gain coefficient $K_b$ is set to 30. The simulation results shown in figure 2 are obtained.

It can be seen from figure 2 that the UAV can make corresponding obstacle avoidance actions in time when it encounters obstacles in the process of moving towards the target point at a uniform speed, and because the obstacle avoidance paths between the No. 2 UAV and the No. 3 UAV are similar, so that the corresponding repulsion force occurs between the UAV, we can see the avoidance effect of the No. 2 UAV to the No. 3 aircraft in the forward process. After the UAV flew out of the obstacle area, because of the repulsion between the UAV and the gravity of the target point on the UAV, the corresponding flight path was re-planned between the UAV and the UAV.

![Figure 3. Simulation diagram of path planning with obstacles in the target area of 4 UAVs](image)

When the obstacles in the target area of the UAV are added, and the remaining conditions remain unchanged, the initial position of the UAV is set to $(x_1, y_1) = (450,150)$, $(x_2, y_2) = (350,250)$, $(x_3, y_3) = (250,350)$, $(x_4, y_4) = (150,450)$, so that when the formation is in a disordered state, the remaining parameters remain unchanged. The simulation results shown in figure 3 are obtained.

As can be seen from figure 3, before the UAV starts to avoid obstacles, due to the repulsive force between the UAV, the path planning of each UAV has obvious avoidance behavior. Take the No. 5 UAV as an example, before entering the obstacle area, the aircraft takes the path point of the UAV ahead of the sequence number as the current obstacle point, and re-plans the path; after entering the obstacle area, it plans the path based on the repulsion of other drones and obstacles and successfully avoids obstacles. When all the UAV reaches the target area, it can be seen from the figure that due to the improvement of the repulsion function, the influence factor of the distance of the target point is increased, so that the UAV can successfully reach the target area when there are obstacles around the target area.

5. Conclusion

In this paper, aiming at the problem of path planning in UAV formation flight, a UAV path planning method based on improved artificial potential field is proposed. The following conclusions can be seen through experimental simulation.

(1) The main results are as follows: 1) in the process of flight, the UAV is avoided from entering the minimum point, resulting in the failure of obstacle avoidance. In this paper, it is proposed to increase the resultant force between the preform gravity and the repulsion force of the UAV, which can effectively avoid the force balance of the UAV after entering the minimum point.
(2) In the process of formation flying, under the action of the front gravity and the repulsion force between the UAV, it not only ensures the stability of the formation flight, but also ensures the autonomy of the single UAV, and improves the overall robustness. This paper only defines and restricts the virtual force on the UAV, and does not restrict the behavior of the UAV, so it can effectively avoid obstacles when it encounters new obstacles.

(3) After reaching the target point, the repulsion function based on the improved potential field attenuates faster due to the existence of the exponential function, which avoids the situation that the UAV reaches the target point but cannot reach the target point, and effectively enhances the UAV's ability to reach the target point.

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