Research on UAV path planning obstacle avoidance algorithm based on improved artificial potential field method

Qi BinKai, Li Mingqiu*, Yang Yang, Wang XiYang

College of Electronic and Information engineering Changchun University of Science and Technology Changchun, China
2314836044@qq.com

Abstract: In this paper, we study the path planning obstacle avoidance problem of UAV based on improved artificial potential field method (APF). By introducing dynamic adjustment coefficients, the gravitational force and repulsive force functions in the traditional APF are improved to make the obstacle avoidance safety factor higher and the final path smoother; for the target unreachability problem, a new attractive potential field is built in the gravitational force function to balance the changes of the traditional attractive force and repulsive force; a longitudinal random factor is used to solve the problem of getting into local minima. Through simulation comparison with other methods, this method can solve the path planning obstacle avoidance problem of UAV more efficiently.

1. Introduction

In recent decades, with the booming development of UAV technology, it has been made to be used in military and civilian fields on a large scale. In this context, UAV autonomous flight technology has been widely discussed and researched by scholars at home and abroad, and has gradually become a research hotspot in UAV at home and abroad. Autonomous mission execution is an inevitable trend for the future development of UAV, and path planning is one of the key technologies to improve the autonomous flight capability of UAV to ensure flight safety [1].

Many explorations have been carried out on path planning and many research methods have been invented. From the initial grid method [2], A* algorithm and its improved algorithm to the artificial potential field (APF) method, neural network algorithm [3] and some intelligent algorithms [4]. The APF method is favored in the static and dynamic path planning of UAVs because of its mathematical mechanism, simple calculation, and ability to meet the requirements of real-time control. However, it is easy to fall into the local optimum and fail to reach the target, as well as local oscillation and other defects. Scholars at home and abroad have also proposed many innovative improvements to this[5]. Among them, most of the responses to local minimums and unreachable targets are improvements to the repulsion function[6].

The structure of this paper is as follows: Part II introduces the principle of traditional APF and some of its defects; Part III focuses on the UAV path planning obstacle avoidance algorithm based on the improved artificial potential field method; Part IV simulates and compares some methods mentioned in the literature with the algorithm of this paper; Part V summarizes the work and points out the limitations and future work of this paper.
2. Traditional artificial potential field and defects

2.1. Traditional artificial potential field model

A virtual potential field is established in the UAV operating space, and the total potential energy of the potential field is composed of gravity and repulsive potential energy. Gravity and repulsive force are obtained by calculating the negative gradient of gravity and repulsive potential energy acting on the UAV. Their combined force pulls the drone toward the target while avoiding obstacles. The force is shown in Figure 1.

\[
\text{Figure 1. UAV force diagram} \quad \text{Figure 2. Target unreachable}
\]

Assume that the UAV is in two-dimensional travel space, ignore its mass and size, and treat it as a mass point. Set the coordinates of UAV’s current position as \( X = (x, y)^T \). The target point coordinates are set to \( X_\text{t} = (x_\text{t}, y_\text{t})^T \). The obstacle coordinates are \( X_{o,i} = (x_{o,i}, y_{o,i})^T \) among them \( X_{o,i} \) are the coordinates of each obstacle.

2.2. Traditional gravitational function

Gravitational potential field function of the target point on the UAV is:

\[
U_{\text{att}}(X) = \frac{1}{2} k_{\text{att}} d^2(x, x_\text{g})
\]

(1)

Where \( k_{\text{att}} \) is the positive proportional position gain coefficient, the \( d(x, x_\text{g}) = \|x_\text{g} - x\| \) indicates the Euclidean distance between the current position of the UAV and the target point.

From this, its attractiveness is:

\[
F_{\text{att}}(X) = -\nabla U_{\text{att}}(X) = -k_{\text{att}} d(x, x_\text{g}) \nabla d(x, x_\text{g})
\]

(2)

Among them \( \nabla d(x, x_\text{g}) = \frac{x - x_\text{g}}{d(x, x_\text{g})} \). The size of the attractive force decreases with the decrease of \( d(x, x_\text{g}) \). When the UAV reaches the target point, the gravitational force is zero.

2.3. Traditional repulsion function

The repulsive potential field function of the obstacle to the UAV is expressed as:

\[
U_{\text{rep,i}}(X) = \begin{cases} 
\frac{1}{2} k_{\text{rep}} \left( \frac{1}{d_i(x, x_{o,i})} - \frac{1}{d_0} \right)^2, & \text{if } d_i(x, x_{o,i}) \leq d_0 \\
0, & \text{if } d_i(x, x_{o,i}) > d_0
\end{cases}
\]

(3)

Here represents the repulsive potential field of each single obstacle in \( U_{\text{rep,i}}(X) \), \( k_{\text{rep}} \) is proportional to the positive gain coefficient, \( d_0 \) is the influence range of obstacles, and \( d_i(x, x_{o,i}) \) is the distance from the drone to the closest point in each obstacle.

The repulsive force is the negative gradient of the repulsive potential function, the formula is as follows:

\[
F_{\text{rep,i}}(X) = -\nabla U_{\text{rep,i}}(X)
\]

(4)
\[ F_{\text{rep},i}(X) = \begin{cases} \frac{k_{\text{rep}}}{d_i(x,x_{o,i})} - \frac{1}{d_0} \frac{1}{d_i(x,x_{o,i})^2} \nabla d_i(x,x_{o,i}) & , \text{if } d_i(x,x_{o,i}) \leq d_0 \\ 0 & , \text{if } d_i(x,x_{o,i}) > d_0 \end{cases} \]  

Among them \( \nabla d_i(x,x_{o,i}) = \frac{x-x_{o,i}}{d(x,x_{o,i})} \). The repulsive force increases with the decrease of \( d_i(x,x_{o,i}) \). Then the total potential energy function and resultant force of UAV is:

\[ U(X) = U_{\text{attr}}(X) + \sum_{i=1}^{n} U_{\text{rep},i}(X) \]  

\[ F(X) = F_{\text{att}}(X) + \sum_{i=1}^{n} F_{\text{rep},i}(X) \]

### 2.4. Defects of traditional APF

**2.4.1. Target unreachable**

When there is an obstacle near the target point, when the UAV is not close to the target point, the repulsive force of the obstacle to the UAV may be much greater than the attraction of the target point to the UAV, resulting in the direction of the resultant force always pointing away from the target point. In this case, the global minimum of the total potential field is not at the target position, so that the UAV cannot reach the target. The specific situation is shown in Figure 2:

**2.4.2. Local minimum**

When the UAV reaches some special positions, the resultant force will be zero. At this time, the attractive force and repulsive force of the UAV are collinear and their directions are opposite, and the magnitudes are almost equal. At this time, the UAV is balanced by the force and stops at the same place. UAV is trapped in the local minimum area. Figure 3 lists three possible situations: a, b and c:

![Figure 3. Situation (a)](image)

![Figure 3. Situation (b)](image)

![Figure 3. Situation (c)](image)

### 3. Improved artificial potential field method

**3.1. Improvements to traditional gravitation and repulsion functions**

For UAV obstacle avoidance, the range of influence of repulsion and the size of gravity and repulsion, a new gravitational and repulsive potential field function is proposed. The improvement strategy is to add a dynamic factor coefficient to the traditional APF function, so that the UAV can avoid the above situation without affecting the overall performance and make the route more smooth and stable to reach the target point.

To construct a new gravitational potential field function for the gravitational source is:

\[ U_{\text{attr}}(X) = \frac{1}{2} \alpha k_{\text{att}} d^2(x,x_{\text{g}}) \]
\[ \alpha = \begin{cases} \frac{1}{2} \left[ \sin \left( \frac{d_i(x,x_o,i) - R_0}{d_0} \cdot \left( \frac{\pi}{2} - 1 \right) \right) + 1 \right], & d_i(x,x_o,i) < R_0 \\ 0, & R_0 \leq d_i(x,x_o,i) < d_0 \\ 1, & d_i(x,x_o,i) \geq d_0 \end{cases} \] (9)

The repulsion potential field function is improved to:

\[ U_{\text{rep},i}(X) = \begin{cases} \frac{1}{2} \beta k_{\text{rep}} \left( \frac{1}{d_i(x,x_o,i)} - \frac{1}{d_0} \right)^2, & \text{if } d_i(x,x_o,i) \leq 2d_0 \\ 0, & \text{if } d_i(x,x_o,i) > 2d_0 \\ 1, & d_i(x,x_o,i) \leq d_0 \\ 0, & d_i(x,x_o,i) > d_0 + R_0 \end{cases} \] (10)

\[ \beta = \begin{cases} \frac{1}{2} \cos \left( \frac{d_i(x,x_o,i) - R_0}{d_0} \cdot \pi \right), & d_0 \leq d_i(x,x_o,i) < R_0 + d_0 \\ 0, & d_i(x,x_o,i) \geq R_0 + d_0 \end{cases} \] (11)

where \( R_0 \) denotes the radius of the obstacle, \( \alpha \) and \( \beta \) is the dynamic adjustment factor we added. Its size is related to \( d_i(x,x_o,i) \). From the improved gravitational potential field, \( \alpha \) is 1 when \( d_i(x,x_o,i) \) is large, according to the conventional gravitational function; when \( R_0 \leq d_i(x,x_o,i) < d_0 \), the UAV is in the gravitational transition zone, The gravitational action on the UAV decreases faster due to the change of \( \alpha \), and the speed direction and size of the UAV are more easily changed, making obstacle avoidance easier. For the new repulsion function, when \( d_i(x,x_o,i) \) is large, the UAV is in the repulsion-free zone; when \( d_0 \leq d_i(x,x_o,i) < R_0 + d_0 \), the UAV is in the repulsion transition zone. It can be seen that it has a wider range of influence than the traditional repulsion, and UAV has more changes in speed direction. Time, and due to the existence of \( \beta \), the linear increase of the repulsive force will also make the obstacle avoidance path smoother; When \( d_i(x,x_o,i) \leq d_0 \), act according to the traditional repulsive force. The specific potential field action area is shown in Figure 4 as follows:

3.2. Improvement of unreachable goals

This paper proposes a new form of improved gravitational function to solve the unreachable target. The specific improvement of the gravity function is as follows:

\[ U_{\text{att}}(X) = \frac{1}{2} \alpha k_{\text{att}} d^2(x,x_g) + \frac{1}{2} \alpha k_{\text{att}} \left[ \left( \frac{1}{\varepsilon} \right)^2 - \left( \frac{1}{\varepsilon + d(x,x_g)} \right)^2 \right] \] (12)

The formula (12) can be simplified to:

\[ U_{\text{att}}(X) = \frac{1}{2} \alpha k_{\text{att}} \left[ d^2(x,x_g) + \left( \frac{1}{\varepsilon} \right)^2 - \left( \frac{1}{\varepsilon + d(x,x_g)} \right)^2 \right] \] (13)

Among them is the positive parameter of \( \varepsilon \), and the selection only needs to satisfy \( \varepsilon < d(x_o,j,x_g) \), and \( x_{o,j} \) represents the coordinates of the obstacle that affects the UAV to reach the target point. When \( d(x,x_g) = 0 \), it means that the UAV reaches the target point, and the gravity is also 0 at this time;
when the UAV is far away from the target point, \( U_{\text{att}}(X) = \frac{1}{\varepsilon + d(x, x_g)} \approx 0 \), then:

\[
U_{\text{att}}(X) = \frac{1}{2} \alpha k_{\text{att}} \left[ d^2(x, x_g) + \left( \frac{1}{\varepsilon} \right)^2 \right] \quad (14)
\]

Compared with the traditional gravitational function, the improved new attraction potential is stronger; when the UAV encounters the target unreachable problem, due to the addition of a part of the gravitational potential field, the combined force of the UAV will make it move toward the target and finally reach the target.

3.3. Improvement of local minimum problem
This paper introduces a longitudinal random factor \( \tau \) to solve the local minimum problem mentioned above. It can be seen from Figure 3 that the gravitational force of the target point on the UAV and the repulsive force of the obstacle reach a balance and are 180° each other. Due to the addition of the longitudinal random factor, a new gravitational force breaks the balance relationship and makes the UAV move toward the target. The specific improvement method is shown in Figure 5.

The figure shows that \( F_{\text{att}}(X) = F_{\text{rep}}(X) \). At this time, we establish the x-y axis, and we know the angle \( \alpha \) between the gravity and the x axis. Let the new gravity and the x axis be the angle \( \delta \), where the new gravity is:

\[
F_{\text{att, new}}(X) = F_{\text{att}}x \hat{i} + \tau \cdot F_{\text{att}}y \hat{j}
\quad (15)
\]

And the angle \( \delta \) between the new gravity and the x-axis is:

\[
\delta = \arctan \left( \frac{F_{\text{att, new}}y}{F_{\text{att, new}}x} \right) = \arctan(\tau \tan \alpha)
\quad (16)
\]

Then \( \tau = \frac{\tan \delta}{\tan \alpha} \). Then the new gravitational expression is:

\[
F_{\text{att, new}}(X) = F_{\text{att}}x \hat{i} + \frac{\tan \delta}{\tan \alpha} \cdot F_{\text{att}}y \hat{j}
\quad (17)
\]

Since we \( \alpha \) is known, the size of the longitudinal random factor \( \tau \) is only related to the angle \( \delta \), and it needs to satisfy:

\[
\frac{\pi}{2} > \delta > \alpha \geq 0
\quad (18)
\]

4. Improved artificial potential field method
In order to evaluate the performance of the algorithm, simulations were performed under different environment settings. In addition, in order to highlight our work, we compared the current results with the method in [6]. Firstly, a 120 \( \times \) 120 two-dimensional model data map and hazard environment data are established, the gravitational constant is chosen as \( k_{\text{att}} = 30 \), the repulsive constant is \( k_{\text{rep}} = 45 \), the radius of the obstacle is \( R_0 = 5.5 \), the influence range is \( d_0 = 10 \), the \( \varepsilon = 10 \), and the angle \( \alpha = 45^\circ \).

4.1. Scenario 1
scenario 1 is a comparison of the traditional APF function with the path planning simulation diagram after adding the dynamic random factor. As shown in Figure 6(a), when the UAV moves from the starting point to the target point under the action of the traditional APF, it encounters obstacles. Due to the excessive gravity and speed, it cannot avoid the obstacles in the end. It is very large, exceeding the ability of repulsive force changes; when dynamic random factors are added, the influence range of obstacles becomes larger, and the UAV successfully avoids obstacles and reaches the end under the action of repulsive force and gravitational transition zone. Explain that the method proposed by us is feasible.
4.2. Scenario 2
Scenario 2 is aimed at the problem of unreachable targets. We compare the method in [6] with the method in this paper in the same environment. From the comparison of Figure 7 (a) and (b), it can be seen that because the method in this paper expands the influence range of the repulsive force, the path of (b) is smoother, and the distance traveled by (b) is significantly less than that of (a), UAV running time is relatively less. As far as picture (a) is concerned, the UAV almost hits the obstacle due to the too fast speed, and its path is steeper due to the excessive repulsion. Although they all reach the target point in the end, the comparison between the two pictures shows that the method in this paper is obvious Better.

4.3. Scenario 2
Scenario 3 discusses the local minimum problem, and also compares the method of [6] with the method of this paper in the same environment. Figure 8 (a) uses the method of improving the repulsion function. It can be seen that when the UAV encounters a local minimum, the ability to get rid of is deviated, and because it is very close to the obstacle and is affected by the strong repulsion, it basically deviates. The original trajectory direction causes the UAV to take more time and path to make its final movement direction point to the target. It can be seen from Figure 8(b) that when the UAV encounters a local minimum, it passes through the obstacle and adjusts the direction of movement under the action of the longitudinal random factor, which greatly shortens the time and the movement route. Therefore, the method used in this article is more excellent.

5. Conclusion
This paper improves the shortcomings of traditional APF and applies the solution to UAV path
planning. First, by adding dynamic factor coefficients to gravity and repulsive potential energy, the influence range of repulsive force is expanded, and gravity and repulsive force will change with the distance between the UAV and the obstacle; by establishing a new gravitational potential field on the gravitational function to balance the changes of gravitational and repulsive forces, the problem of unable to reach the goal was finally overcome. Consider that when the UAV is in the local optimum, the longitudinal random factor is added to the gravity to change the direction of the resultant force to get rid of the local optimum. Finally, a comparison simulation experiment with the method in literature [6] proves that the method in this paper is more excellent.

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