Unmanned Vehicle Route Planning Based on Improved Artificial Potential Field Method

Min Zha¹, Zhiwen Wang², Jing Feng¹ and Xinliang Cao¹

¹Control theory and control engineering, Guangxi University of Science and Technology, Guangxi, Liuzhou, 545006, China
²Computer Science and Communication Engineering, Guangxi University of Science and Technology, Guangxi, Liuzhou, 545006, China

Abstract. Aiming at the defect of target unreachable and local minimum in the unmanned path planning by traditional artificial potential field method, an improved artificial potential field method is proposed in this paper. By rotating the repulsive force by a certain angle, the unmanned vehicle jumps out of the local minimum point, and adopts the safety distance and the adjustment factor in the repulsive field to solve the problem of the target unreachability, and also ensures the safety of unmanned vehicles during obstacle avoidance. The experimental results show that the improved artificial potential field method can better achieve the safe obstacle avoidance of driverless vehicles and effectively plan the optimal target path.

1. Introduction
Path planning is a core technology in the field of driverless vehicle research. It refers to the planning of a collision-free route from the starting point to the target point according to the driving environment information detected by a variety of sensors to optimize the path. Path planning mainly consists of two steps: building environmental maps containing obstacle areas and free areas, and selecting an appropriate path search algorithm in environmental maps to search feasible paths in real time and quickly [1]. Path planning results play a role in vehicle navigation. It guides the vehicle from the current position to the target position. At present, there are many path planning algorithms used in unmanned driving, such as genetic algorithm, particle swarm optimization, A* algorithm, RRT algorithm and artificial potential field algorithm. Among them, the artificial potential field method is widely used in robot navigation and collision avoidance because of its advantages of small computation, smooth path planning and easy real-time control.

Artificial potential field method was proposed by Khatib in 1986. The basic idea is to assume that there is a virtual force field in the driving road, the target point produces gravity on the main vehicle, and the obstacle repulses the main vehicle. Under the combined control of gravity and repulsion, it moves from the high potential field to the low potential field, and finally reaches the target position. However, the traditional artificial potential field method in complex scenes is prone to fall into local minimum and target unreachable problems. To solve these problems, scholars at home and abroad have carried out corresponding improvement research. Reference [3-4] by adding the distance between the vehicle and the target to the repulsive field function of the artificial potential field method, the repulsive force and gravity of the vehicle are zero only when it reaches the target point. The improved artificial potential field method can plan a safe obstacle avoidance path for the vehicle in the static
environment. Literature [5-6] uses the intermediate target point selected on the side of the obstacle to
guide the robot instead of the real target point, so that the robot can get rid of the local minimum point.
In reference [7], RRT algorithm is introduced to compensate for the shortcomings of traditional
artificial potential field method which is easy to form local optimal solution. By introducing repulsion
coefficients, adjusting factors and repulsion field model of road boundary, the virtual local target
points are set up in reference [8-9], and an improved path planning model is established, which
effectively realizes the collision avoidance local path of intelligent vehicles. Reference [10] Aiming at
the problem of oscillation in trap area and narrow channel when traditional artificial potential field
method is used, the improved artificial potential field method is combined with chaotic optimization
algorithm. Experiments show that this method has superior practicability and efficiency. Literature [11]
optimizes the attractive and repulsive fields and proposes a potential field filling strategy that allows
mobile robots to find a better, collision-free target path.

In this paper, the basic principle of traditional artificial potential field method is introduced, and
analyzes the reason why traditional artificial potential field method falls into local minimum and target
unreachability in path planning. Then the problem of target unreachability is solved by introducing
safety distance and adjusting factor, and the safety performance of unmanned vehicle is improved at
the same time. By rotating the repulsion force at a certain angle, the driverless vehicle can jump out of
the local minimum point. Finally, the effectiveness of the improved algorithm is validated in the
MATLAB simulation environment.

2. Artificial Potential Field Method

2.1. Traditional Artificial Potential Field Model
Assuming that the motion space of an unmanned vehicle is a two-dimensional plane and has a certain
abstract potential energy in the two-dimensional space, the negative gradient direction of the potential
energy points to the direction of the motion of the unmanned vehicle, thus the abstract force can guide
the unmanned vehicle to bypass the obstacles in the road, move towards the target and finally reach
the target point. The basic idea of traditional artificial potential field method is to simulate the motion
of the controlled object in space as a force movement of a particle in the virtual force field. The target
point will attract the controlled object, while the obstacle point produced by the obstacle point or
threat area will have a repellent effect on the controlled object [12]. Finally, under the combined action
of gravitational potential field and repulsive potential field, the controlled object moves towards the
target point and reaches the end point. In the process of driving an unmanned vehicle, a virtual
potential field is firstly established in the space where the unmanned vehicle runs on the road. The
potential energy of the potential field is composed of gravitational potential energy and repulsive
potential energy. The gravitational and repulsive forces obtained by calculating the negative gradient
of gravitational potential energy and repulsive potential energy are superimposed respectively. The
resultant force leads the unmanned vehicle to move towards the target while avoiding obstacles. The
force diagram is shown in Figure 1.

![Figure 1. Schematic diagram of unmanned vehicles](image-url)
Assume that the unmanned vehicle is in a two-dimensional driving space, ignoring the size and quality of the car, and regard it as a mass point, setting the current position coordinate of the unmanned vehicle \( X=(x, y) \), obstacle coordinate \( X_o=(x_o, y_o) \), the target point coordinate \( X_t=(x_t, y_t) \), the virtual potential field is defined by the formula (1).

\[
U(X) = U_{gra}(X) + U_{rep}(X)
\]

Among them, the gravitational potential energy is \( U_{gra}(X) \) and the repulsive potential energy is \( U_{rep}(X) \). Therefore, the resultant force of the driverless vehicle in the potential field is

\[
F(X) = F_{gra}(X) + F_{rep}(X)
\]

Among them, \( F_{gra}(X) \) is gravity and \( F_{rep}(X) \) is repulsion.

2.2. Gravitational Function
The gravitational potential field function of the target point to the unmanned vehicle is

\[
U_{gra}(X) = \frac{1}{2} \alpha \rho_t^2
\]

Among them, \( \alpha \) is the gravitational gain coefficient, and \( \rho_t \) is the distance between the controlled object and the target point.

\[
\rho_t = ||X - X_t|| = \sqrt{(x - x_t)^2 + (y - y_t)^2}
\]

The negative gradient of the gravitational field of the controlled object is

\[
F_{gra}(X) = -\nabla U_{gra}(X) = -\alpha \rho_t
\]

It can be seen from the above formula that the gravitational force is inversely proportional to the distance between the unmanned vehicle and the target point. When the unmanned vehicle moves towards the target point, the potential energy suffered decreases and the gravitational force increases. When the potential energy decreases to zero, the unmanned vehicle reaches the target point.

2.3. Repulsion Function
The repulsive potential field function of obstacle to unmanned vehicle is

\[
U_{rep}(X) = \begin{cases} 
\frac{1}{2} \beta \left( \frac{1}{\rho(X, X_o)} - \frac{1}{\rho_o} \right)^2, & \rho(X, X_o) \leq \rho_o \\
0, & \rho(X, X_o) > \rho_o 
\end{cases}
\]

Among them, \( \beta \) is the repulsive gain coefficient, \( \rho(X, X_o) \) is the distance between the controlled object and the obstacle, and \( \rho_o \) is the maximum influence distance of the obstacle.

Then the repulsive force of the controlled object is the negative gradient of the repulsive force field is

\[
F_{rep}(X) = -\nabla U_{rep}(X) = \begin{cases} 
\beta \left( \frac{1}{\rho(X, X_o)} - \frac{1}{\rho_o} \right) \frac{1}{\rho(X, X_o)^2} \frac{\partial \rho(X, X_o)}{\partial \rho} , & \rho(X, X_o) \leq \rho_o \\
0, & \rho(X, X_o) > \rho_o 
\end{cases}
\]

It can be seen from the above formula that the repulsion force is related to the distance between the unmanned vehicle and the obstacle. When the controlled object is not within the distance of the obstacle, the repulsion force is zero. On the contrary, when the controlled object is within the distance of the obstacle, the repulsion force is proportional to the distance between the two. The closer the controlled object is to the obstacle, the greater the repulsion force will be, so that the controlled object will be controlled. Objects move away from obstacles.

2.4. Defects of Traditional Artificial Potential Field Method
Compared with other traditional algorithms, the artificial potential field method not only reflects the topological structure of the planning environment, but also has lower computational complexity, less computational steps, smooth planning trajectory and good real-time performance compared with global planning. However, the traditional artificial potential field method still has some shortcomings. When there are obstacles near the target point, with the driverless vehicle approaching the target point continuously, the repulsion force of the obstacle to the vehicle may be far greater than the attraction of the target point to the vehicle, which makes the vehicle wander around the target point and causes the...
problem of unreachable target. When the repulsion force and gravitation of the driverless vehicle are opposite in the same direction, the resultant force of the driverless vehicle in the artificial potential field is zero, and the driverless vehicle falls into the local optimal solution, thus it can’t reach the target point.

3. Improved Artificial Potential Field Method

When the resultant force is zero, the local minimum point is easy to appear, and the driverless vehicle will stop moving. In order to avoid this situation, the resultant force must not be zero, so that the driverless vehicle can reach the target position smoothly. Therefore, the repulsion force is improved by formula (8).

$$ F_{\text{rot}}(X) = \begin{bmatrix} \cos \theta & -\sin \theta \\ \sin \theta & \cos \theta \end{bmatrix} F_{\text{rep}}(X) $$  \hspace{1cm} (8)

Among them, $F_{\text{rot}}(X)$ is the repulsive force obtained after rotation and $\theta$ is the angle of $F_{\text{rep}}(X)$ rotation, which makes the direction of repulsive force change, and then changes the direction of resultant force on the vehicle, jumps out of the situation of falling into the local optimal solution, and continues to move to the target point.

When the vehicle travels within the influence range of obstacles near the target point, the repulsive force may be greater than the gravitational force, which makes the vehicle hovering around the target point and unable to stop moving. Therefore, this paper introduces the distance factor between the target point and the vehicle into the repulsion function, and adds a safe distance within the influence range of the obstacle, which makes the repulsive force of the unmanned vehicle driving within the safe distance of the obstacle greater than the repulsion force before the unmanned distance is added, thus ensuring the safety of the unmanned vehicle in the process of driving.

Formula (9) is used to improve the repulsive potential field function.

$$ U_{\text{rep}}(X) = \begin{cases} \frac{1}{2} \beta \left( \frac{1}{\rho(X,X_o)} - \frac{1}{\rho_o} \right)^2 + \frac{1}{2} \gamma \left( \frac{1}{\rho(X,X_o)} - \frac{1}{\rho_s} \right)^2 e^{\rho_o^2}, & \rho(X,X_o) \leq \rho_s \\ \frac{1}{2} \beta \left( \frac{1}{\rho(X,X_o)} - \frac{1}{\rho_o} \right)^2 e^{\rho_o^2}, & \rho(X,X_o) \leq \rho_o, \rho(X,X_o) > \rho_s \\ 0, & \rho(X,X_o) > \rho_o \end{cases} $$  \hspace{1cm} (9)

Among them, $\gamma$ is the repulsion gain coefficient corresponding to the safe distance, and $\rho_s$ is the added safe distance.

The improved repulsion function is calculated by formula (10).

$$ F_{\text{rep}} = \begin{cases} F_{\text{rep1}} + F_{\text{rep2}}, & \rho(X,X_o) \leq \rho_s \\ F_{\text{rep3}} + F_{\text{rep4}}, & \rho(X,X_o) \leq \rho_o, \rho(X,X_o) > \rho_s \\ 0, & \rho(X,X_o) > \rho_o \end{cases} $$  \hspace{1cm} (10)

Among them, the direction of $F_{\text{rep1}}$ and $F_{\text{rep3}}$ points from obstacles to driverless vehicles, and the direction of $F_{\text{rep2}}$ and $F_{\text{rep4}}$ points from driverless vehicles to target points.

When $\rho(X,X_o) \leq \rho_s$,

$$ \begin{cases} F_{\text{rep1}}(X) = \beta \left( \frac{1}{\rho(X,X_o)} - \frac{1}{\rho_o} \right), & \rho(X,X_o) \leq \rho_s \\ F_{\text{rep2}}(X) = -n \frac{1}{2} \beta \left( \frac{1}{\rho(X,X_o)} - \frac{1}{\rho_o} \right)^2 + \frac{1}{2} \gamma \left( \frac{1}{\rho(X,X_o)} - \frac{1}{\rho_s} \right)^2, & \rho(X,X_o) > \rho_s \end{cases} $$  \hspace{1cm} (11)

When $\rho(X,X_o) \leq \rho_o$ and $\rho(X,X_o) > \rho_s$,

$$ \begin{cases} F_{\text{rep3}}(X) = \beta \left( \frac{1}{\rho(X,X_o)} - \frac{1}{\rho_o} \right) \frac{e^{\rho_o^2}}{\rho(X,X_o)^2} \frac{\partial \rho(X,X_o)}{\partial X} \\ F_{\text{rep4}}(X) = -n \frac{1}{2} \beta \left( \frac{1}{\rho(X,X_o)} - \frac{1}{\rho_o} \right)^2 e^{\rho_o^2} \rho_o^{-1} \frac{\partial \rho_o}{\partial X} \end{cases} $$  \hspace{1cm} (12)

Figure 2 (a) and Figure 2 (b) are repulsive potential energy intensity side diagrams before and after adding safety distance. From the diagrams, it can be seen that the driving space of an unmanned vehicle is the horizontal axis of the side diagrams, and the position coordinates of obstacles are (1.5, 1),
(5, 6), (9, 5.5), respectively. The position coordinates of the target point are (10, 10), and the longitudinal coordinates. The axis represents the repulsive potential energy. It can be seen that the improved repulsive potential energy increases near the obstacle, thus improving the driving safety of driverless vehicles.

![Figure 2](image1.png)

**Figure 2.** Strength profile of repulsive potential field before and after improvement

![Figure 3](image2.png)

**Figure 3.** Side view of total potential field strength before and after improvement

4. **Simulation Analysis**

In order to verify the effectiveness of the improved artificial potential field method in the unmanned driving path planning, the traditional artificial potential field method is compared with the improved artificial potential field path planning simulation through MATLAB R2014a, which is trapped in local minimum point and target unreachable, to verify the effectiveness of the improved artificial potential field path planning algorithm.

4.1. **Experimental Steps of Improved Artificial Potential Field Algorithm**

(1) Construct the operating space of the driverless vehicle, determine the position of the starting point and the target point of the driverless vehicle, the gain coefficients of gravity and repulsion, the number of obstacles $n$, the influence distance of obstacles is $\rho_o$, the safe distance is $\rho_s$, and the step length $l$ of driverless vehicles.

(2) The gravitational and repulsive forces are calculated respectively.

(3) Calculate the resultant force.
(4) Whether the driverless vehicle falls into the local minimum when moving to the next position, if so, call step (5), otherwise proceed step (6).

(5) Change the rotation angle of the repulsion force and go back to step (2) to start again.

(6) Whether an unmanned vehicle travels within the influence distance near the target point causes the target to be unreachable. If so, call step (7), otherwise proceed step (8).

(7) The safety distance and the distance between the car and the target point are added to the repulsion function, and then step (2) is restarted.

(8) Whether the driverless vehicle has reaches the target point or not, if so, stop the path planning and draw the path, otherwise go back to step (2) and start again.

4.2. Simulation Results and Analysis

According to the above experimental steps, the artificial potential field method path planning before and after the improvement is simulated on the MATLAB simulation platform. The gravitational gain coefficient is 15, the repulsive gain coefficient is 4, the influence distance of obstacles is 2.5, the safety distance is 1, the driving step length of the car is 0.2, the maximum iteration number is 600, the starting point coordinate of the car is (0,0), and the target point coordinate is (10,10).

Firstly, the path planning of traditional artificial potential field method is simulated. When the driverless vehicle, obstacle and target point are in the same straight line, when the driverless vehicle is close to the target point, the gravity decreases gradually, and the repulsion increases gradually. The driverless vehicle will be balanced at some point and fall into the local minimum point, so it can’t reach the target point, as shown in Figure 4. When there are obstacles at the target point and the driverless vehicle travels within the influence distance of the obstacle, the repulsion force of the unmanned vehicle is greater than the gravitation force, so that the driverless vehicle can’t reach the target point, as shown in Figure 5.

The simulation results of the improved artificial potential field method are shown in Figure 6 and 7. Figure 6 is an improvement of the repulsion rotation angle to make the driverless vehicle jump out of the local minimum point and continue to move to the target point when the driverless vehicle falls into the local minimum point in Figure 4. However, considering the force situation, a smaller repulsive rotation angle will make the direction of the composite force field back to the direction of the unmanned vehicle and the target. The planned local path tends to be far from the target point, and the planning is not reasonable enough. A larger repulsive rotation angle will make the direction of the composite force field closer to the direction of the obstacle, and there is a collision risk. The rotation angle of repulsion is 30 degrees, which is helpful for planning a smooth curve and avoiding collision, as well as for solving the algorithm. Figure 7 is an improvement of the repulsive force of the driverless vehicle by adding adjustment factor and safety distance when the target is unreachable in Figure 5, so that the force of the driverless vehicle is balanced when it reaches the target point.
From the simulation results, it can be seen that the improved algorithm can solve the problem that the driverless vehicle falls into local minimum point and the target is not reachable, and guide the driverless vehicle to the target point. By comparing the traditional distance factor improvement method in Figure 8 with the improved distance factor and the method of increasing the safe distance in this paper, the goal reachable path formed by the improved distance factor and the method of increasing the safe distance is tested. The effectiveness of the improved artificial potential field method is verified.

5. Conclusion
This paper mainly aims at improving the shortcomings of the traditional artificial potential field method. When the driverless vehicle falls into the local minimum point in the course of driving, the direction of resultant force is changed by rotating the repulsion force at a certain angle, which makes the driverless vehicle jump out of the local minimum point and continue to move towards the target point. When an unmanned vehicle travels within the influence range of obstacles near the target point, a new repulsion function is provided by considering the distance between the unmanned vehicle and the target point, and a safe distance is added to ensure the safety of the driverless vehicle in the course of driving. The effectiveness of the improved path planning algorithm is verified by simulation analysis. However, both the traditional artificial potential field method and the improved artificial potential field method are model-driven, which have certain limitations. This also requires us to do further research on the path planning algorithm, constantly improve to meet the requirements of the unmanned vehicle for path planning and obstacle avoidance, and ultimately make the technology of the unmanned vehicle more mature.
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