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Path planning for unmanned automaton based on improved artificial potential field method

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Abstract. The artificial potential field method (APF), a highly effective navigation technique, is currently utilized extensively in this area due to the rapid development of unmanned automatons. Traditional APF, however, have several shortcomings, including the issue of unreachable object points and the propensity to sink into local minima that prohibit the automaton from moving on. In this paper, a two-part improved APF model is created to address these issues. First, by including additional constraints, the repulsive field model at the stumbling block is enhanced to address the issue that the object point is impassable when too close a distance between the two stumbling blocks. Secondly, a new potential field is introduced to help the automaton walk out of the local minima. Analogue simulation show that the methods mentioned above can solve these problems better and make the route planning of unmanned automatons come true.

Keywords: unmanned robot, artificial potential field, path planning.

1. Introduction

Unmanned automatons are widely used in many real-world situations, including construction, mining, industrial automation, agriculture, etc., as the level of automation rises. A mobile automaton with effective route-planning technology can not only save a lot of time, but also decrease wear and the cost of ownership [1]. Ability of unmanned automatons to carry out duties effectively and precisely depends on route planning, which is an integral component of the technology. The automatons can successfully approach the predetermined point as targets through route planning, improving time utilization.

Unmanned aerial vehicles' (UAV) route planning aims to determine the best and most collision-free route through a cluttered environment while considering geometric, physical, and temporal constraints [2]. Numerous techniques, including the raster decoupling method, probability route graph method, neural network method, APF method, fuzzy logic algorithm, ant colony algorithm, etc., have been suggested to accomplish this end [3]. When it comes to resolving route-planning issues, each of these approaches has strengths of its own. Because of its straightforward structure, straightforward implementation of the underlying control, minimal hardware requirements, and ease of understanding, the APF technique is among them and is widely used. This approach, however, also has several flaws. First off, if there is an obstruction nearby when the automaton is near the point as target, it may unable to get there. In this scenario, the gravity force of the point as target on the automaton may be higher than the repulsive force of the stumbling block, causing the automaton to move away from the point as target and come to a halt at the location where the net force is zero. Second, whenever the automaton is in near proximity to multiple stumbling blocks, it may cause the combined to be zero. In such a situation, local minima point occurs, and the automaton loses momentum near this point, leading to the end inaccessibility problem.

To solve the above shortcomings, many scholars have come up with their solutions. Hongqiang Sang et al. proposed a hybrid route planning algorithm with A* and an APF, which produces the globally optimal route through the heuristic A* algorithm and divides the optimal route into multiple subends, greatly reducing the probability of falling into the local minima [4]; Euiho Kim et al. suggested a hybrid route planning algorithm using locational risk and APF. Euiho Kim et al. presented a hybrid route planning algorithm using potential risk field and APF to generate hybrid orientational flow for unmanned vehicle navigation [5]; Lin Xin et al. advanced a hierarchical decision-based APF algorithm to make reasonable classification decisions based on repulsive coefficients, combined forces, and bias angles of velocity [6]; Ding et al. proposed an APF algorithm based on threat modelling and connectivity analysis, which converts point as targets into multiple sub-point as targets to plan routes through the connectivity of point as targets, starting points, and stumbling blocks [7];Zhao Ming et al. proposed a domain-based improved APF algorithm to help automatons reach the point as target quickly according to the domain potential field by adding an adaptive domain potential field [8]; Zhang et al. offered an APF algorithm with additional control force to jump out the local minimal value point, so that the automaton moves parallel to the edge of the stumbling block toward the nearest vertex to achieve route planning [9]. All these methods have obtained good results in route planning based on the APF method and solved some problems of the traditional APF method.

To solve the two issues stated above, an unmanned automaton route planning algorithm based on the enhanced APF method is presented in this paper. The issue of the point as target's unreachability is resolved by enhancing the repulsive field model and including specific constraints; the issue of the automaton being unable to pass two stumbling blocks that are near to one another is resolved by introducing a new field called the "guidance field." The simulation demonstrates the high viability and superior ability of the improved method to address the issue.

2. **Traditional APF method**

2.1. Traditional APF method model

APF method route planning is a virtual force method proposed by Khatib. Its basic idea is to abstract the motion environment in which the automaton is moving as a kind of APF. The point as target exerts a gravity force on the moving automaton, while the stumbling blocks encountered during the motion exert a repulsive force on the automaton. Finally, the superposition of the gravity force and the repulsive force results in the combined force, which is the driving force for the automaton's motion [10]. The following is the model of the traditional APF method [11].

Define the attraction force as the negative gradient of the attraction, shown on Eq. 1 and 2.

Gravitational potential field is

$$U_{att}(x) = k(X - X_d)^2 \tag{1}$$

Gravitational force is

$$F_{att}^{*} = -grad[U_{att}(X)] = -k(X - X_d) \tag{2}$$

In the above equation, k is the gravity gain coefficient, $X = [x\ y]^T$ defined as automaton location vector, and X_d is the point as target location vector. The orientation of U_{att} is directed from the current place of the automaton to the point as target.

Define the repulsive force as the negative gradient of the repulsive potential field, shown on Eq. 3 and 4.

Repulsive potential field is

$$U_0(x) = \begin{cases} \frac{1}{2}\mu(\frac{1}{\rho} - \frac{1}{\rho_0})^2, if\ \rho \le \rho_0 \\ 0, if\ \rho > \rho_0 \end{cases} \tag{3}$$

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Repulsive force is

$$F_0^* = -grad[U_0(x)] = \begin{cases} \mu(\frac{1}{\rho} - \frac{1}{\rho_0}) \frac{1}{\rho^2} \frac{\partial \rho}{\partial x}, if\ \rho \le \rho_0 \\ 0, if\ \rho > \rho_0 \end{cases} \quad (4)$$

In the above equation, μ is the repulsive gain coefficient, ρ_0 is a constants, express the expulsion affects the scope, ρ is the minimum distance from automaton to stumbling blocks, The orientation of U_0 is pointed from the stumbling block to the current place of the automaton.

The unmanned automaton travels towards the point as target under the combined force

$$F^* = F_{att}^* + F_0^* \quad (5)$$

2.2. Defects of the traditional APF field method

The traditional APF was found to have the following shortcomings after the actual operation

(1) When two stumbling blocks are relatively nearby, the repulsion of the stumbling block on the automaton may be greater than the attraction of the point as target on the automaton, causing the automaton to move to the local minima point, which may result in the automaton not being able to pass through the narrow passage.

(2) When the automaton, the stumbling blocks, and the point as target are on the same straight line, it may cause the automaton to move back and forth on the line formed by the three points under the control of the combined force, and fail to reach the point as target.

(3) When the automaton approaches the point as target, the repulsion of the stumbling block may be greater than the gravity of the point as target, thus causing the automaton moves in the opposite orientation and fails to reach the point as target

The drawback of the traditional APF method is that in many different cases, it may lead to zero combined gravity and repulsive forces, and the automaton is trapped in a local minima point, thus making the automaton unable to go forward and reach the point as target. The improvement of the traditional APF method is to solve the local minima points in different cases. The improvement of the traditional APF method is provided in the following paper.

3. Improved APF method

3.1. Overall structure

To address the problem that when the automaton approaches the point as target, the repulsive force is greater than the gravity force , thus causing the automaton to go to the orientation depart from the point as target, this paper improves the traditional repulsive field model by adding certain constraints so that when the automaton approaches the point as target, the gravity force keeps decreasing while the repulsive force also keeps decreasing, and when the automaton arrives at the point as target, the gravity force and the repulsive force are reduced to zero at the same time. This can solve the problem of point as target unreachability in this case.

In order to solve the problem that the automaton cannot cross over the narrow passage when it moves to the two stumbling blocks near each other, a new potential field is added near the local minima point, and a regulation force "guiding force" is added so that the combined force is not zero at the local minima point.

3.2. Improved APF method model

Based on the modified method mentioned above, an improved APF model is developed in this paper.

The improvement still defines the attraction force as the negative gradient of the attraction potential field, shown on Eq. 1 and 2.

$$\mathrm{U_{att}(x)} = k(X - X_d)^2 \quad (6)$$

$$F_{att}^* = -grad[U_{att}(X)] = -k(X - X_d) \quad (7)$$

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In the above equation, k is the gravity gain coefficient, $X = [x\ y]^T$ is the automaton location vector, and X_d is the point as target location vector. The orientation of U_{att} is directed from the current place of the automaton to the point as target.

Still defining the repulsive force as the negative gradient of the repulsive potential field, shown on Eq. 5 and 6.

Repulsive potential field

$$U_1(x) = \begin{cases} \frac{1}{2}\mu(\frac{1}{\rho} - \frac{1}{\rho_0})^2\rho_1^2, if\ \rho \leq \rho_0 \\ 0, if\ \rho \geq \rho_0 \end{cases} \tag{8}$$

$$U_2(x) = \begin{cases} \frac{1}{2}\mu(\frac{1}{\rho} - \frac{1}{\rho_0})\rho_1, if\ \rho \leq \rho_0 \\ 0, if\ \rho \geq \rho_0 \end{cases} \tag{9}$$

Repulsive force

$$F_0^* = -grad[U_1(x)] - grad[U_2(x)]$$
$$= \begin{cases} \mu(\frac{1}{\rho} - \frac{1}{\rho_0})\frac{1}{\rho^2}\frac{\partial\rho}{\partial x} + \frac{1}{2}\mu\frac{1}{\rho^2}\frac{\partial\rho}{\partial x}, if\ \rho \leq \rho_0 \\ 0, if\ \rho \geq \rho_0 \end{cases} \tag{10}$$

In the above equation,μ is the repulsive gain coefficient,$\rho_0$is a constants, express the expulsion affects the scope, ρ is the minimum distance from automaton to stumbling blocks, ρ_1 is distance between the current place and the point as target. The orientation of U_1 is directed from the stumbling block to the current place of the automaton, and the orientation of U_2 is directed from the current place of the automaton to the point as target. By superimposing the forces in two different orientations, the repulsive force and the gravity force decrease simultaneously as the automaton approaches the point as target.

A new potential field U_{add} is added, and the guide force is defined as the negative gradient of the guide force potential field, shown on Eq. 8.

Gravitational force potential field

$$\mathrm{U}_{\mathrm{add}} = \begin{cases} \varphi_1\rho_1^2, if\ \rho_1 > \rho_r \\ 0, if\ \rho_1 \leq \rho_r \end{cases} \tag{8}$$

guide force

$$\mathrm{F}_{\mathrm{add}}^* = \begin{cases} 2\varphi_1\rho_1\frac{\partial\rho_1}{\partial x}, if\ \rho_1 > \rho_r \\ 0, if\ \rho_1 \leq \rho_r \end{cases} \tag{9}$$

In the above equation,φ is gravity force gain coefficient, ρ_1 is distance between the current place and the point as target, ρ_r is the judgment of whether the automaton arrives at the point as target or not, the orientation of U_{add} is directed from the automaton's current place to the point as target.

The decision to add a "guide force" is made by determining whether the automaton is sink into a local minima. If the automaton is not at the local minima, the unmanned automaton moves towards the point as target with the combined force $\mathrm{F}^* = \mathrm{F}_{\mathrm{att}}^* + \mathrm{F}_0^*$, and if the automaton is judged to be at the local minima, the unmanned automaton moves towards the point as target with the combined force $F^* = F_{att}^* + F_0^* + F_{add}^*$.

This paper, determine whether the automaton is at the local minima by calculating whether the magnitude of the combined force is within a certain range λ. If the combined force is within λ, then the automaton is considered to be at the local minima and a "guide force" is added. If the combined force is outside λ, then no "guide force" is added and the automaton travels towards the point as target with the combined force $F^* = F_{att}^* + F_0^*$.

In the improved APF model, the gravity field is unchanged, and the repulsive field is multiplied by

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the distance between the automaton's current place and the point as target, and a certain coefficient relationship is added by the experiment. Meanwhile, the original repulsive field produces a repulsive force from the stumbling block pointing to the current place of the automaton, and this paper improves the repulsive force by adding a force from the current place of the automaton pointing to the point as target to the original repulsive force so that it can be realized that as the automaton gets closer to the point as target, the repulsive field decreases while the gravity field becomes smaller, and under the constraint of certain proportional coefficients, it can be avoided that when. The repulsive field is larger than the gravity field when the automaton is close to the point as target, which can better solve the problem of unreachability of the point as target in this case. In this paper, we add a new force called "guiding force", which is proportional to the square of the distance between the automaton's current place and the point as target. The automaton can then continue to move toward the point as target.

4. Simulation

4.1. Traditional APF method

Analogue simulation of traditional APF method

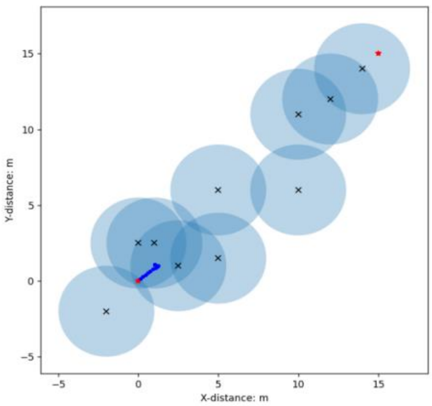

Figure 1. Simulation results of traditional artificial potential field method.

As shown in Figure 1, when the automaton passes two stumbling blocks that are close together, there is a local minima point and the automaton stops at this point and cannot continue its forward travel.

4.2. Introduction of "guided potential field"

Analogue simulation after the introduction of the "guided potential field"

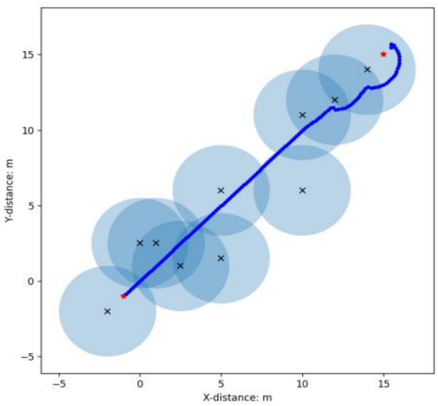

Figure 2. Join the "guided potential field".

As shown in Figure 2, after introducing the guiding potential field, the automaton successfully passed two stumbling blocks that were relatively close to the point as target, but when the automaton was almost

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close to the point as target, the problem that the repulsive force was greater than the gravity force near the point as target caused the automaton to move in the orientation away from the point as target and stop on the extension of the line connecting the stumbling block and the point as target, resulting in an unreachable end in this case. In addition, at a distance from the point as target, the gravity force of the point as target on the automaton is greater than the square of the distance between the automaton and the point as target because the gravity force of the point as target on the automaton is proportional to the square of the distance from the automaton to the point as target, thus leading to a flatter motion route.

4.3. Modification of the repulsive field model

Analogue simulation after modifying the repulsion field

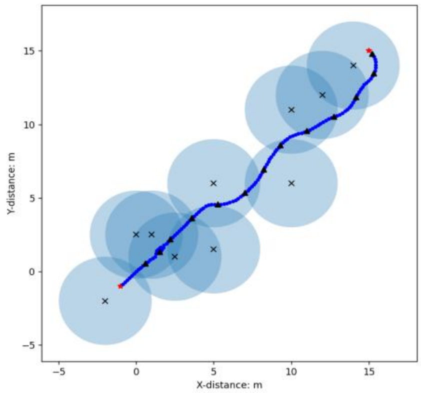

Figure 3. Improved repulsion field.

As shown in Figure 3, with the modified repulsive field, as the automaton approaches the point as target, the gravity force becomes smaller while the repulsive force becomes smaller as the automaton's current place gets closer to the point as target, and when the automaton arrives at the point as target, the gravity force and the repulsive force are zero at the same time, so that the automaton can reach the intended point as target. In addition, since the magnitude of the improved repulsive force is related to the distance between the automaton's current place and the point as target, the repulsive force is larger when the current place is farther away from the point as target, thus avoiding the influence of the repulsive force when the distance between the automaton's current place and the point as target is larger, which makes the route planning more effective. However, without adding the "guide field", it can be seen that when passing two stumbling blocks close to each other, the automaton jitters due to the change of the repulsive field, even though it passes through the narrow passage, which means that there is a local minima here.

4.4. Add a "guide field" and modify the repulsion model

Analogue simulation after adding the "guide field" and modifying the repulsion model.

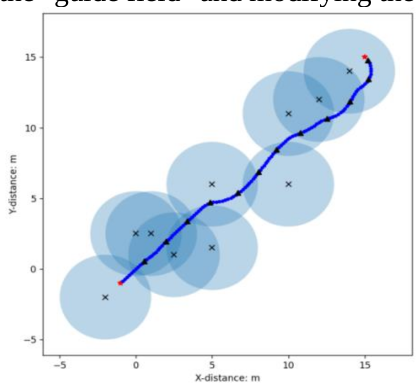

Figure 4. Add a "guide field" and modify the repulsion model.

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As shown in Figure 4, it can be seen from the above figure, after adding the "guide field" and modifying the repulsive force model at the same time, there is no jitter when passing two stumbling blocks close to each other, and the route is relatively straight, i.e., the appearance of local minima is avoided. When the unmanned automaton approaches the point as target, the gravity force and the repulsive force are reduced at the same time, and the point as target can be reached smoothly.

4.5. Validation of the improved APF model

Analogue simulation after modifying the model.

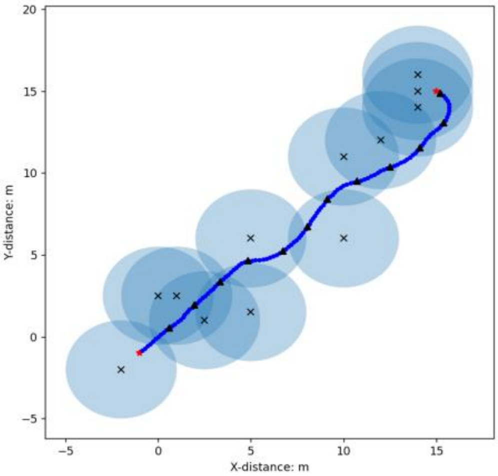

Figure 5. Reinforcing the repulsion field at the target point.

As shown in Figure 5, in order to validate the improved APF model, the repulsive force of the stumbling block on the automaton at the point as target is enhanced by adding a column of three points to strengthen the repulsive force near the point as target in the original stumbling block background. The results show that the automaton still arrives at the point as target and the Analogue simulation are still good.

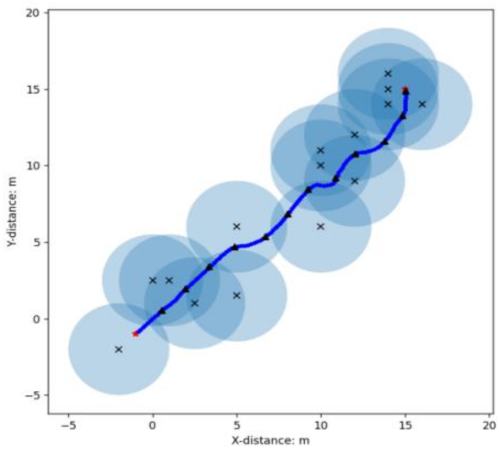

Figure 6. Adding obstacles to the path again.

As shown in Figure 6, in the previous stumbling block context, based on the strengthening of the repulsive force at the point as target, two more stumbling blocks closer together were added during the automaton's motion, and two stumbling blocks closer together were also added near the point as target to verify the rationality of the algorithm when passing through the narrow passage. The Analogue simulation show that the automaton still arrives at the point as target and passes through the two closer stumbling blocks smoothly, and the route is relatively straight without jittering.

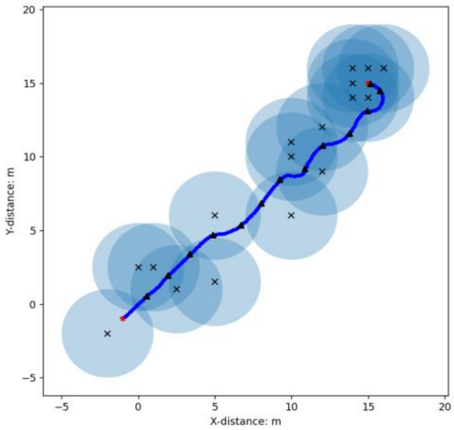

Figure 7. Adding obstacles and strengthening the resistance at the target point.

As shown in Figure 7, this paper also strengthens the repulsive force of the stumbling block at the point as target on the automaton in this way. In this experimental model, the point as target is surrounded by a circle of stumbling blocks, but the automaton still arrives at the point as target smoothly and also passes through the narrow passage on the route, and the planned route is more rounded without jittering.

From the above validation experiments, the improved algorithm provided in this paper has a better solution to the problem of point as target unreachability through closer stumbling blocks and for closer to the point as target.

4.6. Problems exist

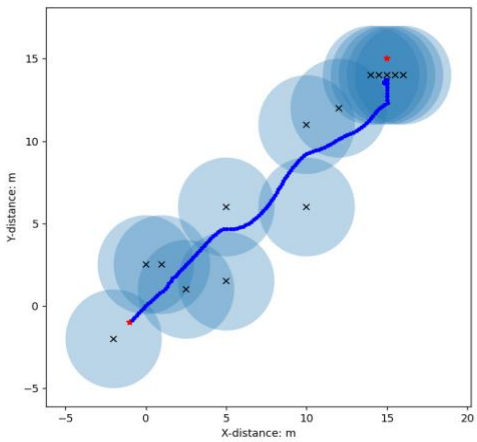

Figure 8. Unresolved problem.

As shown in Figure 8, although the improved algorithm has better results in dealing with the local minima caused by two stumbling blocks in close proximity and the problem of unreachability of the end due to the repulsive force being greater than the gravity force at the approaching point as target, the automaton cannot reach the point as target by bypassing the stumbling blocks autonomously if there is a long row of stumbling blocks in the route of the automaton to reach the point as target. Since the combined force in this case is directed by the automaton to the point as target, and the route to the point as target is blocked by a row of stumbling blocks, the automaton is also unable to bypass the stumbling blocks in the orientation of the combined force and reach the point as target. This is one of the points found in the experiments where this algorithm can be improved.

5. Conclusion

In this paper, the traditional APF method is improved and good results are achieved.

(1) By adding "guiding potential field" and judging whether the automaton is at the local minima

point to decide whether to add "guiding force" or not, it can better solve the problem that the automaton cannot pass the point due to the local minima point when it passes two stumbling blocks that are close to each other.

(2) By improving the model of the repulsive field, adding the distance from the current place to the automaton and the point as target as a factor in the repulsive field, and adding the force in the orientation from the point as target to the automaton's position, the problem of the point as target being unreachable due to the repulsive force being larger than the gravity force when the automaton is close to the point as target is better solved.

(3) The problem of unreasonable routes due to overly flat routes and the occurrence of jitter was also solved.

The practicability of the above method was proved by emulate, and better Analogue simulation were also achieved after modifying the model and adding more constraints. Through the above theoretical analysis and experimental simulation, it is shown that the improved algorithm effectively solves the problem of the end being unable to pass through narrow channels and reach the target point.

After solving the above two problems, there are still some improvement aspects of this algorithm. When there is a row of relatively long stumbling blocks around the point as target, the automaton cannot bypass the stumbling blocks to reach the point as target autonomously. It is hoped that this aspect can be improved in future research.

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