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Local minimum enhanced artificial potential field method

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Abstract. Currently, the artificial potential field technique is commonly used in vehicle obstacle avoidance and route planning. However, this method may lead to local minima where the gravitational force and repulsive force are equal during the path planning process, and thus the target location cannot be reached. This paper suggests an approach to enhance the artificial potential field method in light of this. First, the calculation method of the attraction field in the traditional artificial potential field is modified for resolving the issue of unreachable targets. Second, for the local minimum, the path calculation is recovered by modifying the repulsive force range of obstacles and creating a virtual obstacle point, and applying an additional force to get rid of the gravitational force and repulsive force balance. The simulation results check the effectiveness of the designed method, which can solve the cases of unreachable targets and local minima and produce reasonable planned paths.

Keywords: path planning, local minima, artificial potential field method.

1. Introduction

The development of unmanned vehicles has received a lot of attention recently, and trail planning is an extremely important research area in driverless vehicles. There are many different algorithms for path planning, and the commonly used planning algorithms such as artificial potential field method, raster method, ant colony optimization method, A* algorithm, Voronoi diagram method, D* algorithm, roadmap algorithm, and so on [1-4]. The artificial potential field (APF) algorithm was proposed by Khatib to convert the motion trend of the robot in the predefined map into virtual force, which has the advantages of simple functional calculation, high real-time obstacle avoidance capability, and smooth planning path, and is often hailed as one of the mainstream pathfinding algorithms in robotics [5, 6]. The manmade potential field method has been applied in many aspects, such as sweeping robots, drones, and robotic arms [7, 8]. However, the traditional artificial potential field method has disadvantages such as the inability to reach the target point and easy to drop to a local minimum. These are because the repulsive force of the obstacle is too large or some point earlier reaches some point where the balance between the repelling and attracting forces occurs in the possible field such that the object has no way to reach the target point.

As a result, many researchers have put forward better approaches. Wang et al. resolved the minimum local issue of the conventional artificial potential field method by confirming the direction of the repulsive force components through the virtual target point method and the left-rotating potential field method and then shifting 90 degrees to the left as a way to skip outside the local minimum trap [9].

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Zhang et al. addressed the issue of an inaccessible target and a local minimum by using the standard artificial potential field technique by modifying the gravitational coefficient and random virtual target points [10]. Liu et al. performed the adjustment of angle and orientation on the gravitational force by dynamically varying the repulsive force coefficient as well as the angle offset when the threshold of the total force is zero. is reached, and in this way resolved the matter of unreachability and a local minimum of the target of the conventional artificial potential field technique [11].

The issues with the conventional artificial potential field method are resolved in this paper by modifying the repulsion coefficient, the gravitational coefficient, and the range of action of the obstacle, together with the introduction of a virtual obstacle to change the local minima [12].

2. Traditional artificial potential field method

2.1. Gravitational potential field

The attractiveness function in the conventional artificial potential field method is illustrated in Equation 1 [13].

$$Uatt(x) = k\ att(Xu - Xg)^2 \tag{1}$$

Shown in equation $katt$ represents the gravitational coefficient specific to the attraction force. Xu indicates the position of the robot. Xg indicates the position of the target point. $(Xu - Xg)^2$ The relative range from the robot to the target point expressed is the true distance between the two points derived from the Euclidean distance. Δ represents the unit vector sign, which is the amount of change.

For this robot is subjected to an attractive force as shown in Equation 2 [13].

$$Fatt = -\Delta Uatt(x) \tag{2}$$

2.2. Repulsive potential field

The $Krep$ shown in Eq. represents the repulsive force coefficient specific to the repulsive force. Xob indicates the location of the barrier. $(Xu - Xob)$ reflects the distance of the robot to the obstacle. Po indicates the influence range of an obstacle, which is the distance the robotic is impacted by the repulsive force of an obstacle. Δ represents the unit vector sign, which is the amount of change. For this robot, the repulsive force received is shown in Equation 3 [13].

$$Frep = -\Delta Urep(X) \tag{3}$$

2.3. Combined force potential field

Since the bot is drawn to the target point during path planning and also receives repulsive forces from obstacles, the composite force field, which is the sum of both repulsive and attractive fields is shown in Equation 4 [13].

$$Ftotal = Fatt + \sum_{i=1}^{n} Frepi \tag{4}$$

In the scene cannot exist only one obstacle, the formula i indicates the current is the first few obstacles, $nand$ indicates the total number of obstacles, so the repulsive force part needs to take into account all barriers' repellent power, so with the above-mentioned single obstacle repulsive force is different.

2.4. Problems with conventional artificial potential field technique

Two common and typical drawbacks to the traditional artificial potential field method. The first is the unreachability of the target point. The robot approaches the target point, as the attraction drops to a relatively small value, but the surrounding obstacles have a great repulsive force, resulting in no way for the robot to reach the target point, as shown in Figure 1. The second is the problem of local minimum. With this method, the robot is not able to continue its movement because it is subjected to a combined force of zero, which may be caused by a single obstacle or multiple obstacles, as shown in Figure 2. The local minimum is essentially similar to the above problem of target unreachability, and it can be said

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that the unreachable case, is a special case of the local minimum. Similar to the unreachable case is the case where there is an obstacle in the vicinity of the target, resulting in a confrontation between the obstacle's repellent force and the attractive force of the target point when approaching the target point, leading to when both forces are equal to zero. For the above cases, the cause is that the sum of the attracting and repulsive forces is zero.

All the above-mentioned problems are to be solved in the improvement of the artificial potential field technique.

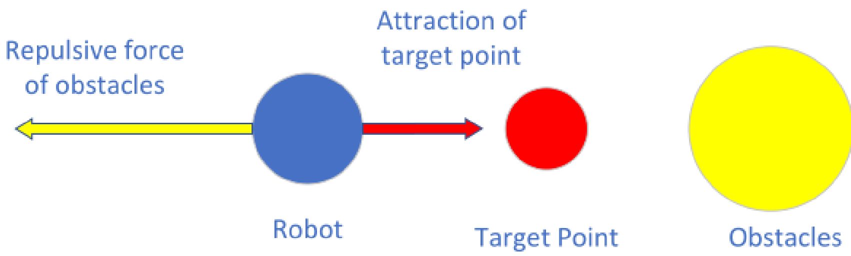

Figure 1. Force diagram of the robot for the target point unreachability problem.

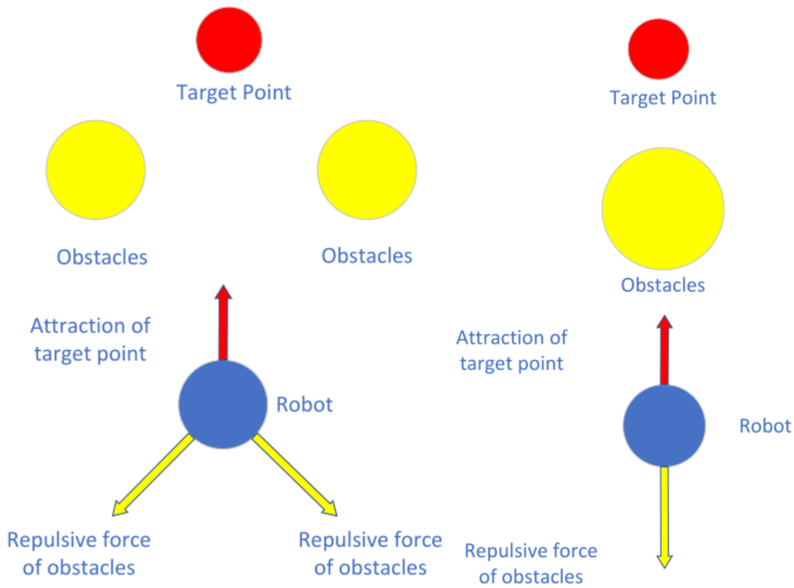

Figure 2. Local minimum problem robot force diagram.

3. Improved method

3.1. Improve the attractive potential field

According to the reasons for the unreachability of the target proposed in the previous paper, the algorithm design is improved so that when the robot encounters this situation, the coefficient of attraction is positively increased to ensure that the robot is subjected to an attractive force to move away from the circumstance where there is no combined force. After calculating the attractive and repellent forces acting on the robot, the relationship between the two forces is judged at each movement, and the conditions are determined between the impediment, the target, and the robot, and the robot is displaced if it meets the judged conditions and can move normally, and if it does not meet the judged conditions, the relationship between the three positions is the coefficient of attraction is changed, and the coefficient of attraction is increased by 0.2 for each judgment result of non-conformity, and re-enter the cycle for calculation, to allow to move and finally reach the target point. Figure 3 displays the precise simulation results.

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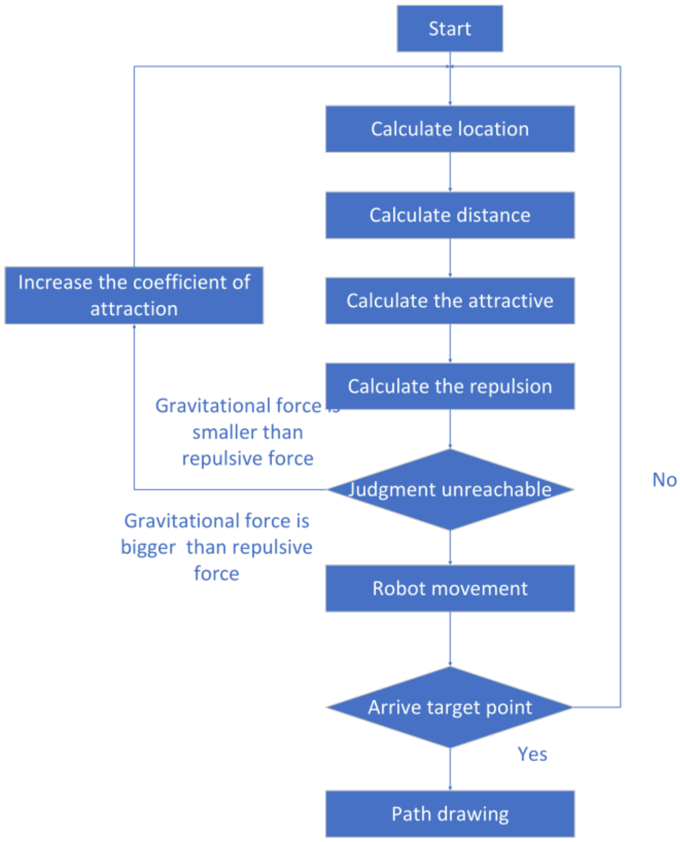

Figure 3. Flow chart of modified attraction algorithm.

3.2. Attraction coefficient modification

Based on the analysis of the causes of the issue of the local minimum described above, difficulty with the local minimum can be effectively gotten rid of by breaking the situation in which the robot causes the combined force to be zero during the motion. Based on this idea and the experience of modifying the unreachability of the target point, the situation in which the combined strength is nil can be broken by modifying the attraction coefficient. The distance and direction between the robot and the barrier and the finish location are carried out at the beginning of the algorithm as a way to calculate the repulsive and attractive forces. Based on the calculated repulsive and attractive forces, the judgment of the local minimum problem is performed. The main criterion for the judgment is based on whether the combined force is zero and the influence of the position of the obstruction and the aiming point on the robot. When judged to be caught in the local minimum, the function of attraction coefficient adjustment is executed, and the attraction coefficient is increased by 0.2 for each call until it gets to eliminate the issue with local minimums, then the robot is moved and drawn. In Figure 4, the precise algorithm flow is displayed.

3.3. Obstacle repulsion range modification

During the algorithm planning process, many factors affect the coefficient of attraction mentioned in the previous section also mentioned the obstacle repulsion's range factor affects the force applied to the robot. A new hypothetical direction is designed to address this influencing factor, and the algorithm is modified and parameters set. When the combined force is judged to be zero by the algorithm and the robot suffers from a local minimum problem, the function that modifies the obstacle repulsion force algorithm is called, and each time the function is called, the range value is reduced by 0.5 and the judgment is made again until it gets removing the regional minimum. Adjusting the range of obstacles force will form a gap in the force, resulting in the total force acting on the robot is not zero, removing the regional minimum problem. In Figure 4, the precise algorithm flow is displayed.

3.4. Virtual obstacle introduction

In addition to starting through various factors affecting the force on the obstacle, it is proposed that the robot force situation can be modified by introducing some external factors. A new method is proposed to provide a new repulsive force to the robot caught in the local minimum problem by introducing a virtual obstacle to get it out of the situation where it is subjected to a combined force of zero. The first step is to calculate both the repellent force and the attractive force, followed by the distance in Euclid and the location of the obstruction, the target point, the robot, and whether the total force acting on the robot is null. If it is the case of local minimum, the introduction of virtual obstacles is performed by adding 1 to both X-axis coordinates and Y-axis coordinates based on the coordinates of the robot's present location, and if it is not the case of local minimum, scheduling the robot's path is performed. In Figure 4, the precise algorithm flow is displayed.

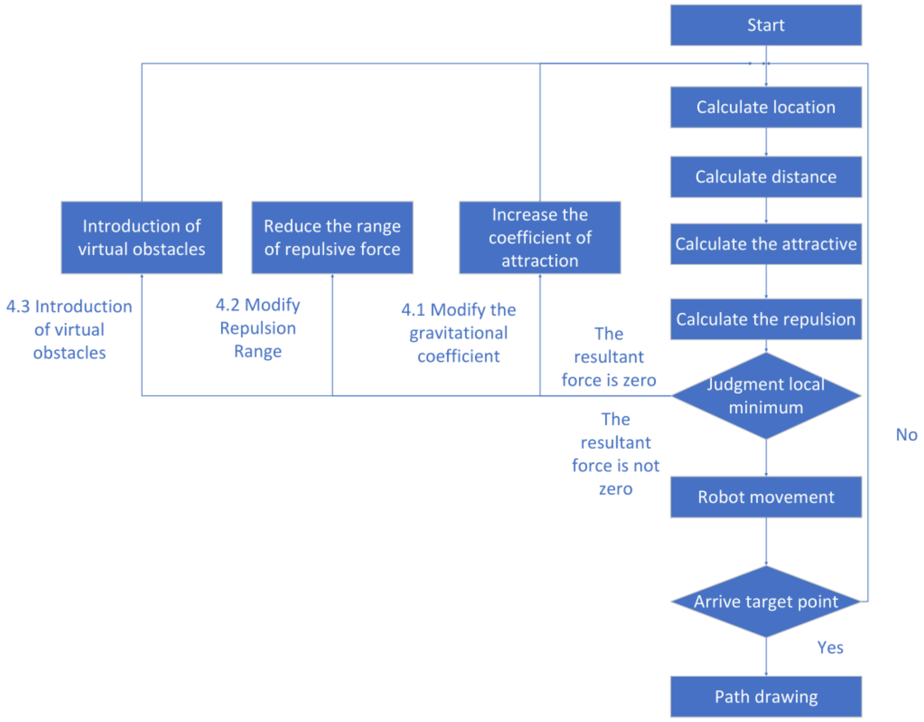

Figure 4. Points to the algorithm for finding the local minimum.

4. Experimental design for path planning

To confirm the presented theory's validity even further idea, experiments on the code implementation of the two-dimensional artificial potential field method are conducted using Python. In the design of the experiments, one and three groups of controlled trials are set up according to one method proposed for the target unreachability problem and three methods proposed in the preceding work for the local minimum problem.

4.1. Experimental design for unreachable simulation of target points

A set of controlled experiments was first conducted. The modification of the attraction coefficient was used as the only variable in both sets of experiments. One set of experiments is a simulation of the inaccessible target from the conventional field method with artificial potential, while the other set of experiments in the control experiment is a simulation of the modified attraction coefficient for the unreachable case. In the two groups of experiments, it is ensured that the parameters such as repulsion coefficient and obstacles do not change to verify the effectiveness of the attraction coefficient modification. For the obstacle setting, the positions of the two sets of obstacles are (1, 2), (2, 4), (3, 5), (6, 6), (6, 7), (8, 3), (12, 8), (11, 12), (14, 14), (16, 19), respectively. The coordinates from the target point are fixed at (15, 15) and the robot's starting point's coordinates are as follows: (0, 0).

In addition to the other parameters, the range of the obstacle repulsion is set to 3, the coefficient of repulsion is 1.3, and the coefficient of attraction is 1.1. In addition, during the experiment, a range is set within which the target point is successfully reached, and the value for this parameter is set to 2.

4.2. Experimental design for locally optimal simulation

After solving the common case of unreachable target points by improving the repulsive function. After adding some obstacles and conducting experiments again, in the upgraded artificial potential field, the issue of local optimum was discovered. The new obstacle parameters were set as (1, 2), (2, 4), (3, 5), (6, 6), (6, 7), (8, 3), (12, 8), (9, 11), (8, 10), (11, 12), (14, 14), (16, 19).

Three controlled trials were set up for the local minimum problem, and the three different methods mentioned by the avant-garde were set as the only variables for the three controlled trials while ensuring that the other parameters remained unchanged.

4.2.1. Improved experimental design of the coefficient of attraction. According to the improvement method mentioned in the previous section, a new set of control tests are conducted. A new functional function is added to the path planning code under the premise that the other variable parameters are not changed. The function of the new function is to judge the local optimum problem, that is, the combined force situation and the relationship between the three positions of the robot, and then the value of the attraction coefficient participates in 0.2 after each judgment of the local optimum.

4.2.2. Improved experimental design of repulsive force range. According to the improvement method mentioned in the previous section, a new set of control tests is conducted. A new functional function is added to the path planning code while ensuring that the other variable parameters are not changed. The function of the new function is to judge the local optimum problem, that is, the combined force situation and the relationship between the three positions of the robot, and then the value of the attraction coefficient is increased by 0.2 after each judgment of the local optimum.

4.2.3. Introduction of virtual obstacle experimental design. Regarding the method of introducing virtual obstacles and setting up a set of controlled experiments. The only variable in this set of control experiments is the introduction of the virtual obstacle, which breaks the circumstance wherein the robots' combined force is zero by generating a new repulsive force through the newly introduced obstacle, thus getting rid of the minimum local issue. While ensuring that the other variables do not change, a control experiment is formed with the previous experiments the standard artificial potential field technique to judge the situation of the combined force on the robot and the relationship between the three positions, and then after each judgment of the virtual barrier, the local minimum is introduced by adding 1 to both the X-axis coordinates and the Y-axis coordinates based on the coordinates of the current position of the robot.

5. Result and Discussion

5.1. Target unreachable simulation results and analysis

The simulation outcomes are displayed in Figures 5 and 6. Figure 5 displays the outcomes after the conventional artificial potential field path planning. Figure 6 shows the results of the planning of the artificial potential terrain approach after the gravitational coefficient. Based on the simulation outcomes in the figure, one can see that the inaccessible path issue plagues the conventional artificial potential field technique, while for the artificial potential field with improved gravitational coefficient, it is possible to reach the target point through the force relationship between the target point and the obstruction, addressing the issue of the impassable target point.

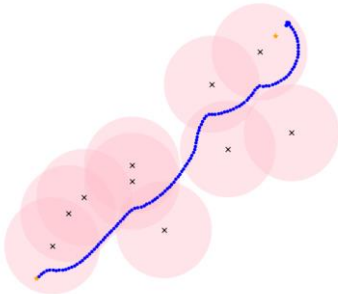

Figure 5. Results of conventional planning for artificial potential fields.

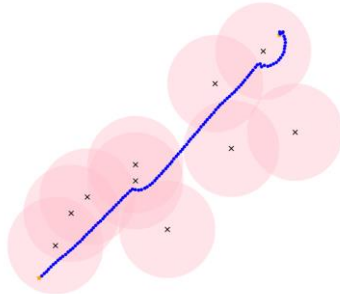

Figure 6. Results of improved planning for artificial potential fields.

5.2. Local minimum simulation results and analysis

5.2.1. Simulation results and analysis of conventional potential fields. Through the simulation experiments designed in the previous paper for practice, it is found that after the new addition of obstacles, one issue with the artificial potential field method is the local minimum, from the illustration, it is clear that the robot in the process of movement at about (4, 6) where the stagnation phenomenon occurs, in this region, there is a combined force of zero, Figure 7 displays the precise simulation results.

5.2.2. Improved gravitational coefficient simulation results and analysis. From Figure 8, one can see that the robot can travel to the desired location normally after the attraction coefficient is added positively through the function, and it can also be seen that in the act of getting to the desired location, the value of the attraction coefficient is slightly smaller because the function sets the positive floating attraction coefficient, resulting in some of the points of the images are gathered together, which is the process of attraction and repulsion resistance, Figure 8 displays the precise simulation results.

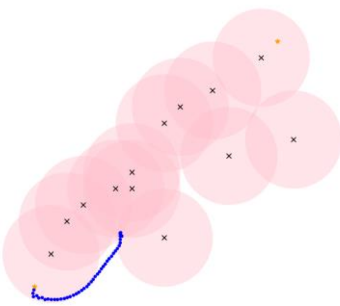

Figure 7. Local minima of conventional artificial potential fields.

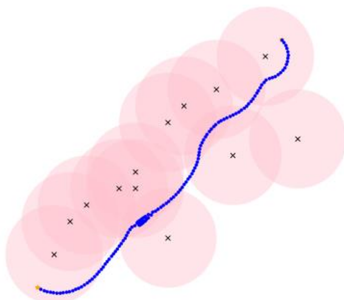

Figure 8. Force field coefficient correction to improve the local minimum problem

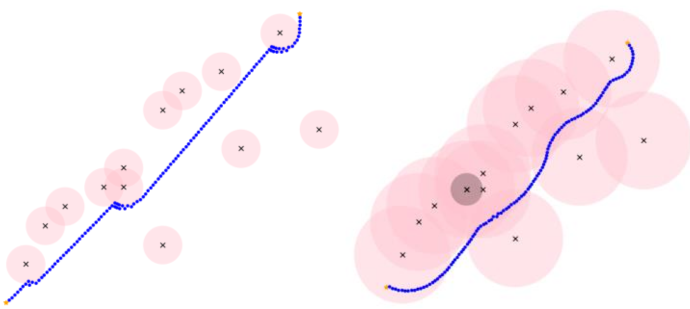

Figure 9. Repulsive force range improvement optimal problem effect.

5.2.3. Improved rejection range simulation results and analysis. From Figure 9, one can see that the range of repulsive force acting on the black part of the obstacle has been significantly reduced, and the robot can reach the desired location normally after reducing the force the obstacle is a spectrum of repelling force. At the same time, it is clear that during the path planning process, most of the scattered points are distributed around the range of barriers, and on the edge of barriers, there will be some image points are gathered together, which is the process of attraction and repulsion resistance, Figure 9 displays the precise simulation results.

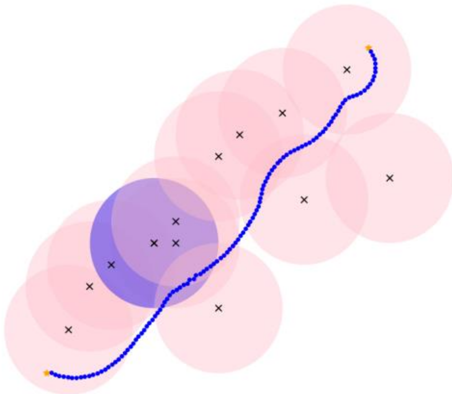

Figure 10. Virtual obstacles to improving the optimal problem effect.

5.2.4. Virtual obstacle introduction simulation results and analysis. The blue obstacle can be seen in Figure 10 as the virtual obstacle introduced. In the control experiment, it can be seen that after the virtual obstacle is introduced, the robot can get out of the situation where the attraction and repulsion forces are essentially the same, allowing it to continue with path planning. In contrast, for the experiments of the first and second methods, it can be seen that although both can make the robot eliminate this situation of local minimum, the robot is smoother during the path-planning stage compared to the two experiments of attraction coefficient change and repulsive force range of action, Figure 10 depicts specific simulation results.

The reason for this phenomenon is that the coefficient of attraction and the repulsive range of action is only a change in the critical value of the coefficient, while the virtual obstacle introduction is a direct introduction of the obstacle, in terms of judgment conditions, the former can be more biased towards the critical value and the latter is the judgment of the obstacle location.

For the above groups of control experiments, it can be seen that the proposed scenarios can effectively the issue of inaccessible target points be resolved as well as local minimum. However, it is evident from the outcomes that the final experimental findings of different methods are different. The best result from this experiment is that the introduction of virtual obstacles is the smoothest for path planning of the robot, and the other methods may have some minor differences in code implementation leading to some fluctuations when the robot is planning its route.

6. Conclusion

The problem of an unattainable aim with local minima is addressed in this study through the proposal of an improved artificial potential field approach. The robot unreachability problem is solved by using a modification of the attraction coefficient by presenting the same factors as the intended point direction and obstacle. The problem of local minima is solved by modifying the coefficient of influence of the repulsive force and changing the range of action of the obstacle. The viability and efficiency of the mentioned method are demonstrated by employing the setting of variable parameters and the controlled simulation experiments with different variables.

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