A real-time dynamic path planning method combining artificial potential field method and biased target RRT algorithm

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Abstract. In order to improve the efficiency and effectiveness of path planning for mobile robots in dynamic environment, based on the comprehensive analysis of multiple path planning algorithms, an improved algorithm based on fast-spreading random tree algorithm is proposed. The proposed algorithm effectively combines the artificial potential field (APF) method with the biased target RRT algorithm, and judges the local minimum point in the process of solving the APF method to complete the switching with the biased target RRT algorithm. The motion environment simulation model is established in the Python environment, and the path planning simulation case of the mobile robot in the dynamic environment is completed. The simulation results show that the combined algorithm can avoid the phenomenon that the APF method falls into the local minimum point while taking the global and real-time performance into account, reduce the planning time of the biased target RRT algorithm, and improve the quality of path generation.

1. Introduction

Mobile robot is a very important branch of robotics [1]. In order to ensure the feasibility, safety and efficiency of mobile robots, it is necessary to systematically analyze the real-time dynamic path planning of mobile robots [2]. The real-time dynamic path planning refers to the process of planning a path that can meet the robot motion constraint and does not collide after specifying the starting point and the target point on the model of the given environment. [3] Reasonable path planning can reduce the energy consumption of mobile robots, improve work efficiency, and ensure the effectiveness of the work process. At present, the most widely used path planning methods are Heuristic algorithm, APF method, fast extended random tree algorithm (RRT algorithm), etc.

The APF method [4] was proposed by Oussama Khatib. He abstracts the environment where the robot is located into a generalized potential field, which is used to express the motion environment space and force of the mobile robot. In the APF, the gravitational potential field of the target point generates gravity for the mobile robot, and the repulsion potential field of the obstacle brings the repulsive force to the mobile robot [5]. The robot moves under the combined force of gravity and repulsion, and achieves the obstacle avoidance and movement toward to the target point. The method has much of advantages, including of simple algorithm, adaption to dynamic environment, real-time obstacle avoidance capability, good security, and excellent local path planning performance. However,
due to the lack of global environmental information, the mobile robot may have a phenomenon that the gravitational force and the repulsion force are zero at a certain point on the path, that is, the local minimum point [6]. Local minimum points can cause the mobile robot to stand still or shake back and forth around the point. [7] Many scholars have proposed different methods to avoid algorithmic defects caused by local minimum points, such as RPR (Randomized Path Planner) algorithm researched by Barrquand and Latombe, MPV (minimum potential valleys) algorithm studied by Hwang, and etc. But the above algorithm does not perform very well in a dynamic environment [8].

In response to the shortcomings of the APF method, the researchers proposed many related improved algorithms, such as Virtual force field method (VFF), Harmonic Potential Function Fields method, etc. The virtual force field method is a small variant of the APF method. This method uses sensors to collect environmental information and creates a global map represented by a two-dimensional Cartesian column grid. This method analyzes the possibility of obstacles in different locations of the motion environment and calculates the repulsive force generated by each columnar grid in the map by discretization [9]. The harmonic potential function method can be used to solve the local minimum point problem generated by the APF method. By establishing a navigation function, the algorithm filters the minimum points outside the target point to ensure that the mobile robot does not fall into the local minimum points during the motion. However, the algorithm is only valid for the equivalent point. It is not guaranteed to find the global solution for the non-point object of the mobile robot. In addition, the algorithm needs to provide all the attributes of obstacles, such as shape, position, motion information, etc. when the navigation function is created. This information is difficult to provide in a dynamic real-time motion environment, so the harmonic potential function method is not suitable for dynamic real-time obstacle avoidance [10].

Rapidly-exploring Random Trees, RRT was proposed by S.M.LaValle who studies in University of Illinois and is a single-query motion path planning method based on optimal control theory and stochastic path planning [11]. According to the control theory, the algorithm quickly grows the random tree from the initial state to the new state through variable control in a short time interval. Each node of the random tree represents a state, and each directed edge represents a process from the previous state to the next state [12]. When a node reaches around the target point, the random tree stops growing and generates a motion trajectory in reverse according to the existing growth process [13]. As an efficient data structure and algorithm, RRT does not need to be pre-processed before the algorithm is executed. It can quickly search the entire state space by randomly expanding nodes, and own the ability to quickly re-plan. The advantage of this algorithm is that it has the ability to search for unknown regions and can integrate various constraints into the algorithm itself. Since randomness is an intrinsic property of the algorithm, the algorithm has probability completeness, in another word it can theoretically find a feasible path [14]. As a global algorithm, the standard RRT algorithm cannot adapt to the dynamic environment due to its poor real-time performance.

2. Combined application of APF method and bias-goal RRT algorithm

The APF method and the RRT algorithm have their own shortcomings and drawbacks. In order to make the two algorithms compensate each other, this paper proposes a new combined algorithm: APF method combined with biased target RRT algorithm (Bias-goal RRT algorithm). The path planning takes both global and dynamic real-time into account by exploiting the advantages of the two algorithms. The emergence of the combined algorithm is not accidental. Lack of overall situation is the inherent shortcoming of the APF method. So the mobile robot is easy to fall into local minimum points in the local planning route, which greatly affects the feasibility of path planning. Similarly, even though the Bias-goal RRT algorithm (Bg-RRT) is global, the RRT algorithm has poor real-time performance. Therefore, it is difficult to plan paths in a dynamic real-time environment.

Hence, the method that is based on the APF method combines these two algorithms according to the advantages and disadvantages of the two algorithms, adapts to the dynamic environment in a complex environment, continuously collects surrounding environmental information, and plans path avoidance obstacles in real time. When the mobile robot is trapped in local minimum points, the Bg-RRT algorithm is used for global path planning. The purpose is to guide the mobile robot to move along the path planned by the Bg-RRT algorithm, so that the robot can be separated from the local
minimum point and ensure the smooth path planning [15]. The local path planning of the APF method is combined with the global path planning of the Bg-RRT algorithm in order to make up for the global deficiencies on the basis of carrying forward the advantages of the APF method, so that the APF method can exert better effects.

The specific planning process of the combined algorithm is shown in Fig 1.

![Combined algorithm path planning flow chart](image)

**Figure 1.** Combined algorithm path planning flow chart

3. APF method

Calculations of Gravity, Repulsive Force and Robot Motion Position of Mobile Robot in APF Method:

First, generate the potential field function of the mobile robot's motion environment:

$$U_o(p) = \begin{cases} \frac{1}{2} \left( \frac{1}{\rho} - \frac{1}{\rho_0} \right)^2 & \text{if } \rho \leq \rho_0 \\ 0 & \text{if } \rho > \rho_0 \end{cases}$$

(1)

In above function: $\rho$ From a point on the obstacle to the vector on the trolley $\rho = \|P\|_2$, $\rho_0$ represents the finite distance traveled by the potential field that is generated by the obstacle. One point in the most primitive potential field method is often used. And the point is the point where the obstacle is closest to the car. The repulsion generated by the potential field:

$$F_o(p) = \begin{cases} \eta \left( \frac{1}{\rho} - \frac{1}{\rho_0} \right)^2 \rho & \text{if } \rho \leq \rho_0 \\ 0 & \text{if } \rho > \rho_0 \end{cases}$$

(2)

The attractive potential field generated by the target point is expressed in Eq. (1), the $x$ in Eq. (1) indicates the parallel vector of the car, $x_a$ is a parallel vector of the target point:
The force generated by this field acts as a controller. There must be two changes before applying this force. First, to improve the stability of this method, add a lossy force that is proportional to the speed \( x \) of the robot. Second, there is an upper limit to the maximum value of this proportional force. The potential field force is generated by the final target point:

\[
F_{id}(x) = -\frac{k_e}{k_v} e - k_i \quad \text{when} \quad \frac{k_e}{k_v} \|e\| \leq V_{max}
\]

In summary, the resultant force of the mobile robot in the field of force:

\[
F = F_{id}(x) + MF_{\omega}(p)^t, i \in [1, v]
\]

The position of the mobile robot in the force field:

\[
f = mx^n
\]

\[
x' = x^n \cdot dt
\]

\[
dx = x^i \cdot dt
\]

Judgment method of falling into local minimum point: Count the average of the nearest \( n \) positions. If the average of the current position is similar to the average of the \( n \) previous positions, it is considered to be trapped in the local minimum.

Judgment method of Deviation from local minimum point: Count the average of the positions. If the average value of the current position and the average distance of the \( n \) front positions are \( n \) linear distances, it is considered to be out of the local minimum point.

4. Improvement of RRT algorithm

The fast-expanding random tree grows from the initial point of the motion space, and acquires a random node to construct a new random tree in the motion space according to a certain stretching angle and a certain probability. When the target point becomes a child node or the area around the target point contains child nodes, the random tree stops expanding and traverses the parent node in order from the target point to obtain a path from the initial point to the target point. The basic RRT algorithm performs poorly in real-time dynamic path planning due to uniform expansion, lack of guidance information, poor real-time performance, and low path quality [16]. Therefore, when the RRT algorithm is improved, not only the computational efficiency and path generation quality of the algorithm should be considered, but also the basic idea of the heuristic algorithm can be used to improve the original algorithm. That is, the improved RRT algorithm not only searches all the motion spaces singly, but also enters heuristic information for strategic search. This strategy is to make the expansion of the random tree no longer absolute, but to increase a trend toward the target point, which can improve the timeliness of the search and improve the quality of the path.

Based on the above ideas, this paper proposes an improved algorithm for basic RRT, namely the biased goal attribute algorithm. The reason why Bg-RRT algorithm is proposed is to reduce the blindness which is derived by the randomness of RRT algorithm, enhance node expansion efficiency and improve path quality. Under the influence of heuristic idea, the improved algorithm has the tendency to search for bias target points. When the basic RRT algorithm is extended, a non-obstacle point is randomly selected as a child node in the motion environment, that is, the parent node to be extended next. The distribution of the extended tree path depends on the generation manner of these nodes. Such a random node is local target point or target point[17].

Since the basic RRT algorithm uses the global random sampling when it selects the target point, the search efficiency of the target area environment is low and the consumption time is long. In order to improve the search speed and path quality, this paper adds heuristic information in the generation process of target points. The method in which the random tree in the basic RRT algorithm uses the
uniform distribution probability when acquiring the target point is changed to the method of using the target point as the next target point with a certain small probability. Therefore, the random tree can extend the node toward the target direction with a certain probability, make the generation process of the target point tend to be more toward the target point, reduce the number of invalid times when the node is expanded to some extent, and improve the search efficiency.

The Bg-RRT algorithm is based on the basic RRT algorithm. In the Bg-RRT algorithm, the q is the target point in the process, and the way q_target is selected during the execution of the algorithm affects the shape of the Bg-RRT. The Bg-RRT algorithm generates a target point by adding a heuristic information (the parameter Bias-goal) to make the expansion of the random tree approach the target point area more efficiently. The Bias-goal parameter is selected to use the parameter value as the threshold, and then obtain the random probability according to the uniform distribution. If the Bias-goal parameter value is bigger than the random probability generated by the algorithm, the target point is selected as q_target. If the value of the Bias-goal parameter is less than the random probability generated by the algorithm, a random point is selected as q_target. The target point generation method obtained by the above algorithm is compared with the basic RRT algorithm, so the planning path tends to be biased toward the target point, and this trend does not affect the probability integrity of the random tree expansion. Therefore, this improved Bg-RRT algorithm inherits all the advantages of the basic RRT algorithm. At the same time, the random extension of the improved algorithm converges quickly, and the quality of the path is greatly improved. The flow chart of the Bg-RRT algorithm is shown in Fig. 2.

![Flow chart of the Bg-RRT algorithm](image)

Figure 2. Flow chart of the Bg-RRT algorithm

5. Case study
This paper successfully combines the APF method with the Bg-RRT algorithm and applies it to the mobile robot path planning in a dynamic environment. The combination algorithm is verified by simulation experiments. This paper uses Python to write the algorithm, the algorithm and the experimental results are shown in the figure. The white area is the free communication space, and the black area represents the static obstacle. ①、②、③、④ are four dynamic obstacles, the red point is
the target point, and the brown point is the initial point. The refresh rate of artificial field method is 0.5 seconds / time. The refresh rate of the Bg-RRT algorithm is 10 seconds/time. Fig.3-Fig.6 show that it applies combined algorithm that move the robot from the initial position of the initial state to search path, and automatically adjusts the path and bypasses the process of moving obstacles when dynamic obstacles during motion are encountered. It can be seen that the moving robot is subjected to the APF method, and the robot does not follow the path provided by the Bg-RRT algorithm. This shows that in the combined algorithm, the robot uses the APF method as the local planning algorithm, which is subject to the repulsive force of the obstacle and the attraction of the obstacle. When the APF method falls into a local minimum, the robot uses the Bg-RRT as a global path planning algorithm to get rid of the local minimum and then reached the target point smoothly. Fig. 7-Fig. 8 show the process of the mobile robot gradually tracking the planned path and finally reaching the target point in the simulation environment.
6. Conclusions

In this paper, a real-time dynamic path planning method combining APF method and biased target RRT algorithm is proposed. The mobile robot motion environment model and APF method force model are established, and the method for judging that a mobile robot is trapped or deviated from a local minimum point is given. Finally, this paper present the simulation of motion path planning for mobile robots. In the improvement of the traditional RRT algorithm, heuristic information, namely Bias-goal selectivity parameter, is introduced, which makes the improved algorithm have stronger target and tendency in path random search, and the search convergence speed is obviously improved. The algorithm flow of Bg-RRT and the selection and judgment methods of Bias-goal parameters and target points are elaborated.

The algorithm flow of Bg-RRT and the selection and judgment methods of Bias-goal parameters and target points are elaborated. The simulation results show that the combination of the APF method and the fast-expanding random tree algorithm solves the problem that the mobile robot is easy to fall into the local minimum point when the APF method is applied, and combines with the fast expansion of random tree algorithm for global planning which is based on the advantages of local search of APF.
method can avoid the local minimum point problem that may occur. To a certain extent, it combines the characteristics of the APF method with the global and real-time characteristics of the RRT algorithm to ensure the reliability of the mobile robot during the movement process and improve the work efficiency.

![Figure 7. Use the Bg-RRT algorithm to plan the route and break away from local minima](image1)

![Figure 8. Continue using APF to reach the end point](image2)

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