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Smooth Path Planning by Fusion of Artificial Potential Field Method and Collision Cone Approach

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Abstract. A variety of path planning methods have been developed for different purposes, such as minimum path length and minimum processing time and smoothness of the path. This paper presents a novel path planning method by fusion of artificial potential filed (APF) and collision cone approach. The proposed algorithm provides smooth path and avoids local minima problem of the existing APF. And the smoothness of the path produced from the proposed algorithm is estimated by calculating the accumulated force which occurs while a robot passes a whole path. The proposed smooth path planning also can be helpful for considering vehicle kinematics and the safety of vehicle passengers. The simulation results demonstrate the performance of the proposed method.

1 Introduction

The obstacle avoidance problem is an important component of path planning. In the past few decades, a lot of methods have been studied and modified to deal with obstacle avoidance and path planning.

One of the most commonly used methods is the artificial potential field (APF) [1]. The APF method has the advantages of simple processing, small burden, and real time realization. The basic idea of the APF method is as following. First, goal generates attractive force and obstacles makes repulsive force. Then, a robot moves through the sum of those forces. However, there are some drawbacks such as local minima and oscillation situations. To avoid the problems, a hybrid approach, which integrates a priori knowledge of circumstance with local perceptions for executing the assigned mission [2]. And APF is modified by utilizing quantum particle swarm optimization which modifies the parameters of APF for adapting variety environments [3]. Other improved APF methods for dealing with local minima problem are proposed in [4-6]. In addition, the relative distance between robot and target into repulsive force to provide the global minimum is introduced in [7]

Another familiar method for path planning is the collision cone approach. The collision cone is the potential criterion that will result in a collision between a robot and an obstacle at some moment in time. If the relative velocity between the robot and the obstacle maintains a velocity outside the collision cone, collisions are guaranteed not to occur [8]. This algorithm has been improved for multi obstacles and real-time application.

In this paper, we present a smooth path planning method by applying a collision cone approach to the APF algorithm. The proposed algorithm is able to overcome local minima and provides smooth path. With the APF method, since the repulsive force depends on the distances from a robot and the obstacles, the path bends sharply at nearby obstacles. The force which avoids the collision cone is introduced to smoothen the path, and it can also escape a local minima problem.

The smooth path gives safeness and stability for the robot or robot's passengers. In this paper, the smoothness of the produced path is estimated by the accumulated force when the robot moves through the path. Two kinds of forces can be customarily treated when a robot moves. One is accelerating force and another one is centrifugal force.

The remainder of this paper is organized as follows: The next section presents related works and background of path panning methods. The traditional APF algorithm and modified APF algorithm are described, and the collision cone approach is also introduced. Next, in Section 3, our novel path planning is presented which provides smooth path and avoids the local minima problem. To verify the proposed method, we performed some simulations and analyzed the results in Section 4. Finally, conclusions and future work are given in Section 5.

2 Related works

2.1. Artificial potential field

The traditional APF is composed of the attractive field of goal and the repulsive filed of obstacles.

$$U(q) = U_{att}(q) + U_{rep}(q) \quad (1)$$

Here, $q = (x, y)^T$ is the position vector of robot's Cartesian coordinates. And artificial force is defined by the negative gradient of APF.

$$F(q) = -\nabla U(q) = F_{att}(q) + F_{rep}(q) \quad (2)$$

where $F_{att}(q)$ is the attractive force which is generated by goal, and $F_{rep}(q)$ is the repulsive force which is generated by obstacles. And they are described as following.

$$F_{att}(q) = -k(q - q_g) \quad (3)$$

$$F_{rep}(q) = \begin{cases} 0 & , \|q - q_o\| \geq d_{rep} \\ \eta\left(\frac{1}{\|q - q_o\|} - \frac{1}{d_{rep}}\right)\left(\frac{1}{(\|q - q_o\|)^2}\right)\frac{(q - q_g)}{\|q - q_g\|} & , \|q - q_o\| < d_{rep} \end{cases} \quad (4)$$

where k and η are scaling factors, q_g is the position vector of goal, q_o is the position of an obstacle, and d_{rep} is the threshold for the repulsive force.

In a particular environment, there is a risk of collision with obstacles. To avoid the risk, the attractive force is modified as (5) by introducing the threshold for the attractive force d_{att}, in [4].

$$F_{att}(q) = \begin{cases} -k(q - q_g) & , \|q - q_g\| \leq d_{att} \\ d_{att}k\frac{(q - q_g)}{\|q - q_g\|} & , \|q - q_g\| > d_{att} \end{cases} \quad (5)$$

2.2 Collision cone approach

The collision cone approach provides collision avoidance strategy, so it can be used to predict the possibility of collision between a robot and an obstacle.

To make a collision cone, it is assumed that the robot and obstacle move with a constant velocities v_t and v_o, respectively. Moreover, the shapes of them are assumed as a circle. If the relative velocity vector $v_t - v_o$ is contained in a collision cone, a potential collision occurs. Finally, it is assumed that the robot is a point and the size of the robot is added to that of the obstacle. The concept of collision cone is shown in Figure 1.

3 Proposed path planning method

APF method has some disadvantages such as local minima and unstable oscillation. In this paper, we proposed the new path planning method to deal with the disadvantages and provide a smoother path by fusion of APF method and collision cone approach.

3.1. Artificial force from a collision cone

In order to avoid collision effectively, an additive artificial force is presented from a collision cone approach

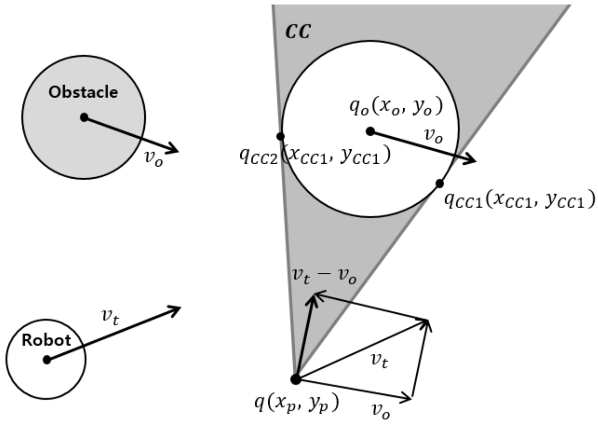

Figure 1. Concept of collision cone between a robot and an obstacle.

$$F_{CC}(q) = \begin{cases} 0 & , v_t - v_o \notin CC \\ \mu\frac{(q_o - q_{CC})}{\|q_o - q_{CC}\|} & , v_t - v_o \in CC \end{cases} \quad (6)$$

where μ is a scaling factor, q_{CC} is a closer point between q_{CC1} and q_{CC2} from the relative velocity vector $v_t - v_o$ as shown in Figure 1. For example, in that case the relative velocity vector $v_t - v_o$ is closer to q_{CC1} than q_{CC2}, q_{CC1} becomes q_{CC}.

If there is a potential risk of a collision ($v_t - v_o \in CC$), the proposed artificial force F_{CC} is added to the existing attractive and repulsive forces. Therefore, the entire artificial force is redefined as following.

$$F(q) = F_{att}(q) + F_{rep}(q) + F_{CC}(q) \quad (7)$$

4 Simulation results

In this section, we analyze the proposed path planning method with two aspects, local minima problem and smoothness. The simulation results about local minima problem are shown in Figure 2 and 3. The results about smoothness are presented in Figure 4 and 5.

The simulation conditions are arranged as following. The robot starts from (0, -11) to the goal which is set (0, 11). A static obstacle is located at (0, 1) in a simulation of local minima problem, a static obstacle is placed at (-2, 1) for a simulation of smoothness. In order to use the collision cone approach, the sum of the sizes of the robot and obstacle is set as a radius of 4. In addition, the parameters are set as follows: k =0.5, η =1, d_{att} =10, d_{rep} =10, μ =1.

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4.1 Local minima problem

Local minima problem generally occurs when the attractive and repulsive forces are equal as shown in Figure 2. And there are some solutions for local minima problem such as changing the direction of repulsive field which is caused by circle obstacles.

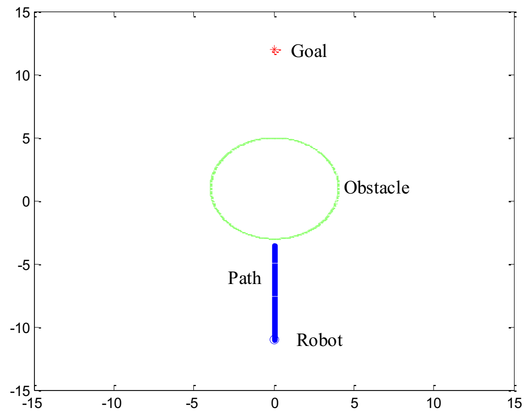

Figure 2. Local minima problem with APF.

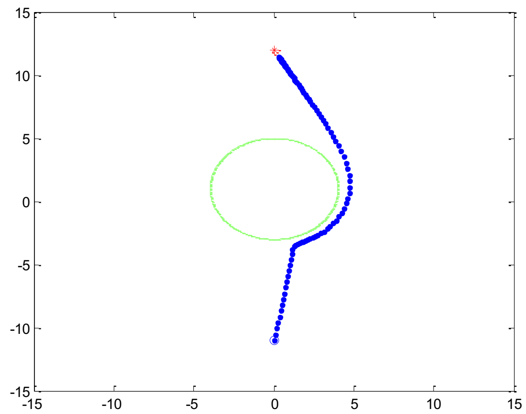

Figure 3. Local minima avoidance with the propose method.

The proposed method can solve the local minima problem easily by introducing an additive artificial force to avoid collision cone. The simulation result about local minima avoidance with the proposed method is displayed in Figure 3.

4.2 Smoothness of the path

The smoothness of paths can be evaluated by using some physical variables. The path curvature and the derivative of path curvature are adopted for the calculating the smoothness [9]. And the angular velocity and the angle difference between the nodes of path are used for considering the smoothness [10].

In this paper, we test the smoothness of the path by calculating the forces applied to the robot. Generally, two kinds of forces can be occurred when the robot moves. One is the accelerating force f_a and another one is the centrifugal force f_c.

$$f = f_a + f_c = ma + mR\omega^2 \tag{8}$$

The robot drives through the whole path, and the accumulated force (energy) E applied to the robot can be represented as follows:

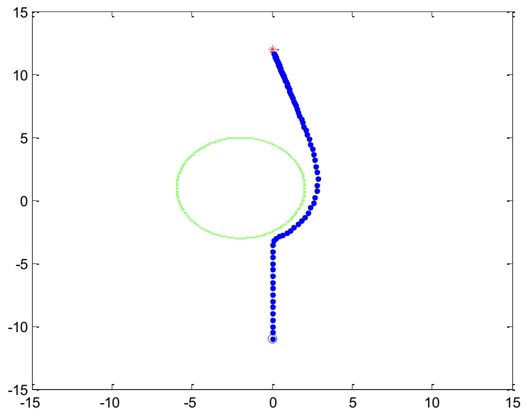

Figure 4. Path planning with APF.

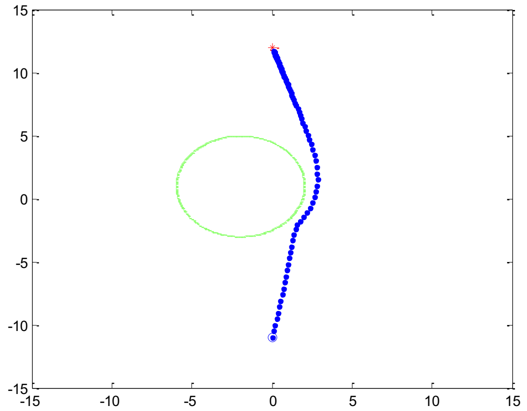

Figure 5. Path planning with the proposed method.

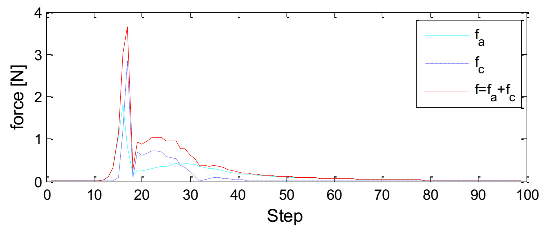

Figure 6. Generated forces from APF.

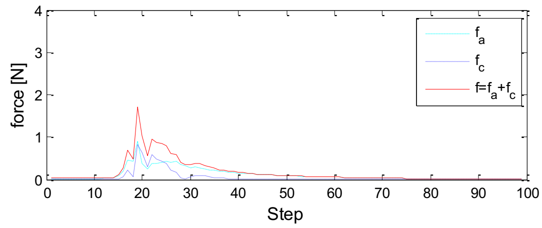

Figure 7. Generated forces from the proposed method.

$$E = \int_{t=t_0}^{t=t_f} ma + mR\omega^2 \tag{9}$$

The simulation results of path planning with APF and the proposed method are shown in Figure 4 and 5. And Figure 6 and 7 display the generated forces from APF the proposed method. The accumulated force by using APF (E =26.4324) is much bigger than that by using the proposed method (E =16.6892), when m and sampling time are assumed to be 1 and 0.1, respectively.

5 Conclusions and future works

In this paper, we present a novel path planning method by applying a collision cone approach to APF algorithm. The proposed algorithm avoids the local minima problem of the existing APF, and it is verified in simulation results. The smoothness of the path from the proposed algorithm is compared with that of the path from the previous algorithm. Although the smoothness is easily noticed by the paths' shapes, we considered the forces which occur when a robot passes a whole path. As a result of comparison, the superiority of the proposed algorithm is proved. And if the parameters for path planning are tuned well, the performance will be better. In addition, the smooth path planning is also able to assist to consider vehicle kinematics, and be helpful for the safety of vehicle passengers if the algorithm is adapted to the field such as an intelligent wheelchair.

In the future works, we attempt to improve the smoothness of the planning path by tuning the parameters, and consider multi obstacles complicated environment, and real-time application.

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