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Artificial potential field method for obstacle avoidance and lane keeping

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Abstract. This paper uses artificial potential field method to solve obstacle avoidance and lane keeping of autonomous driving safety assistance systems. It focuses on the lane line, direction, car obstacle, and static obstacle, which the car must pay attention to on the road. The artificial potential field method can assign different potential functions to different types of obstacles and road structures. This method also considers safety distance, limited speed, traffic rules, and safety problems. Superimposing these conditional functions will eventually result in a system that will continue to return the safety and appropriate next point until reaching the set goal point. Experiments used PyCharm to simulate a one-way, two-lane environment. The final results showed that regardless of the vehicle's initial position, the vehicle could return to the center of the regular lane and effectively avoid static and dynamic obstacles, in addition to controlling its speed to maintain a safe distance from obstacles. The result of experiments also proved that the artificial potential field method could be effectively used in the obstacle avoidance and lane keeping of automatic driving, which means that such a simple algorithm can also be installed on more lightweight navigation devices that require real-time dynamic obstacle avoidance.

Keywords: autonomous driving, obstacle avoidance, path planning, artificial

1. Introduction

Autonomous driving technology is a field that has been focused on and explored for a long time, and its practicality and value are undoubtedly very high. Therefore, this paper wants to explore and study obstacle avoidance and lane keeping assist in path planning and safe driving assistance, which is a significant and core part of autonomous driving technology. The obstacle avoidance studied in this paper includes dynamic obstacle avoidance and static obstacle avoidance. The obstacle avoidance system can slow vehicles down when they meet other vehicles on the road and change lanes when no car is in the next lane. At the same time, when there are static obstacles, such as roadblocks on the road, the vehicle can also avoid them. The lane-keeping function is to keep the car and the lane as far as possible more than half the width of the distance. This function also allows vehicles to return to normal driving after lane change and obstacle avoidance.

This paper mainly discusses two parts, obstacle avoidance, and lane keeping. Many scholars have studied obstacle avoidance for a long time. Many algorithms can solve this problem, such as the well-known neural network algorithm [1]. Although neural network algorithm is suitable for the dynamic environment, the demand is higher, and the conditions of hardware parameters adjustment are more

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difficult. The advantages of the artificial potential field approach include simple logic and conditions and can be applied to dynamic space. However, The traditional artificial field approach suffers from issues with the unattainable aim and the best local solution, which needs to be further improved, but there are most path planning in dynamic space is based on artificial potential field method to upgrade or combine other algorithms in order to approach a better effect [2][3][4][5], which are used a lot in obstacle avoidance, lane keeping assist [4][6][7]. So, this paper chooses this method as the core of the algorithm.

As for lane keeping, some scholars use visual sensor detection [8] and algorithm [9] to control them should keep to the center of the lane but do not consider the problem of the lane change. Of course, some methods of lane change and obstacle avoidance have been studied. They use GPS, inertial measurement unit sensors, and odometer capture to collect speed measurements [10]. However, most of them require more hardware and inputs than artificial potential field methods, leading to higher instability and equipment damage rates. And artificial potential field method can combine the functions of lane-keeping, speed preference, vehicle avoidance, and passing, which is simple and lightweight.

The paper adopts artificial potential field method. However, it should be noted that the safety assistance system is different from pure path planning. It should consider traffic laws and priority protection safety issues. So, the method of the artificial potential field consists of combining all the potential functions of lanes, cars, other obstacles and endpoints to create a potential field [11]. In addition, it requires using a path-tracking module and longitudinal and lateral vehicle dynamics models. This paper finally wants to achieve a simple calculation, accurate obstacle avoidance, lane keeping assistance, obey traffic rules, design a reasonable path of path planning and safety assistance system to help people drive on the road more safely, and because of the simple calculation, it may also be equipped with a smaller vehicle in the future to help more people travel safety.

2. Problem Formulation

We assume that the vehicle can plan its path by receiving the shape, speed, and position of surrounding vehicles through sensors and other processors and calculators, lane information including direction, width, signal light changes, and road traffic signs through camera sensor [9] and know the status of the vehicle. Finally, vehicles realize static obstacle avoidance, dynamic obstacle avoidance, and lane-keeping assist under traffic rules on a flat road.

3. Method

Safety assistance systems have many issues to consider. First, obstacle avoidance is necessary, related to the life and property safety of drivers and others, including surrounding vehicles and other obstacle vehicles. For discussion, they should be separated into static obstacle avoidance and dynamic obstacle avoidance. The second is obeying the traffic rules, solid lines, dotted line difference, etc. Finally, it takes into account the priority of various problems, such as solid lane changes when emergency obstacle avoidance is required. The artificial potential field approach creates a unique potential field by combining numerous barriers and traffic laws, which needs to define the potential field of each case separately and add them together last. The total potential function as

$$U_{total} = U_{lane} + U_{car} + U_{ob} + U_{d}. \quad (1)$$

U_{total} is the total potential fields. U_{lane} is the potential field of the lane. U_{car} is the obstacle vehicles on the road potential field. U_{ob} is the potential field of static obstacles. U_{d} is the potential field of driving direction, and the lowest point is the goal. The sum of potential functions is a vector that can provide the vector direction to guide the vehicle to a safe and suitable position. In addition to ensuring static obstacle avoidance, dynamic obstacle avoidance, and road maintenance, speed control also needs to be considered. When there is an obstacle in front of you, you need to slow down to keep pace with the obstacle. When there is no obstacle, you should also consider the traffic laws and regulations not to speed. So, this paper also provides a distance variable that considers all conditions to determine whether the vehicle should speed up or slow down. Finally, multiply the direction and the velocity together, and

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the next appropriate point will be got, and just loop around until the coordinate of the vehicle gets to your goal point.

3.1. Lane Potential Function

Regular roads will be marked with lanes, solid lines, and dotted lines. Under normal circumstances, the car frequently stays in the middle of the lane when it needs to change lanes to consider whether the current position is a dotted line. In addition, in an emergency, vehicles must ignore the lane to avoid danger. Based on these preconditions, the real line potential field of the lane potential function is always larger than the dashed line potential field, and their maximum potential field is not very large. Here are the functions of lane potential:

$$U_{solid} = \alpha * exp(\frac{L^2-d^2}{L}) \tag{2}$$

$$U_{dotted} = \alpha * exp(\frac{L^2-d^2}{1.5*L}), \tag{3}$$

α denotes the gain factor, which needs to be adjusted after the experiments. L denotes half the length of the lane. Usually, a lane is between 2.8 and 3.75 meters wide. d denotes the height of the car in relation to the lane line.

3.2. Car Obstacle Potential Function

In reality, following cars is not a safe behavior. It is safer to be parallel to other cars at the same distance than to be in front and behind. Therefore, this practical problem should be taken into account when defining the vehicle potential field, which is defined as a high potential field with long front and back, and narrow left and right strips. They can't affect cars that are normally in the middle of adjacent lanes, so it needs a correct radius of the resistance potential field's influence. Following is the car obstacle potential function:

$$U_{car} = \begin{cases} \beta, & \rho(x, x_{car}) < x_0 \ and \quad \rho(y, y_{car}) < y_0 \\ 0, & \rho(x, x_{car}) \geq x_0 \ or \ \rho(y, y_{car}) \geq y_0 \end{cases}, \tag{4}$$

x and y are the longitudinal and transverse directions of the lane. x_0 and y_0 are the minimum longitudinal and reverse lanes' travel routes. $\rho(x, x_{car})$ is the longitudinal distance between the vehicle and the obstacle vehicle. $\rho(y, y_{car})$ is the transverse distance between the vehicle and the obstacle vehicle.

It can be seen from the equation that if the distance in meter between the vehicle and the obstacle vehicle is greater than the minimum safe distance, then the potential field generated by the obstacle is zero and will not have any impact on the vehicle. On the contrary, a higher potential field will be generated instantly to ensure that the minimum safe distance in meter between vehicles is always maintained.

The minimum safe distance can be determined by the speed of the vehicle and the obstacle vehicle. Keep a larger distance at a faster speed, and it is not easy to be blocked when following the car slowly. Following is the equation of the minimum safe distance,

$$x_0 = \frac{v^2}{v_{car}}, \tag{5}$$

v is the speed of the vehicle. v_{car} is the speed of the obstacle vehicle. And the other minimum safe distance y_0 is a constant.

3.3. Other Obstacle Potential Function

The traditional artificial potential field method has two disadvantages that can not be ignored. One is the local optimal solution problem, where the vehicle cannot search forward for the obstacle avoidance path at a certain position. For example, the Angle between the attraction of the goal point and the repelling force of the obstacle that the car is subjected to is approximately 180°, which is almost on the

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same line. Then, the car will fall into the local optimum in front of the obstacle. It is also easier to encounter the situation that the repulsive force of several obstacles is equal in magnitude and opposite in direction to the attraction force of the goal point, then the resultant force is 0. The intelligent car itself judges that it has reached the minimum potential energy value position but does not reach the desired position of the goal point. Since the net force is zero, the car will be stuck in a position of minimal potential energy and will not be able to continue forward and turn to reach the desired goal point.

The second unreachable goal problem. Because when the car reaches the goal point, the distance between the obstacle and that location is too close, according to the potential field function, it can be known that the obstacle's repulsive force remains constant while the goal point's attraction decreases to zero. At this time, although the car reaches the goal point, it cannot stop under the action of the repulsive force field, which leads to the unreachable problem of the goal.

By adding the adjustment factor to the obstacle repulsive field model of the traditional artificial potential field method, the repulsive force and the attraction force can be reduced to zero at the same time only when the vehicle reaches the goal point so that the problem of local optimum and goal unreachable can be solved. The obstacle potential function is following:

$$U_{ob} = \begin{cases} \gamma * exp(\frac{\rho(p,p_{ob})}{d_0}) * \rho(x, x_{goal}), \ x < d_0 \\ 0, \ x \geq d_0 \end{cases}, \tag{6}$$

γ denotes the gain factor, which needs to be adjusted after the experiments. $\rho(p, p_{ob})$ represents the Euclidean distance from the vehicle to the obstacle. d_0 is the influence distance of obstacles. x_{goal} represents the X coordinate of the goal point.

3.4. Direction Potential Function

This is the attractive potential field in the traditional artificial potential field method, pointing from the height to the lowest goal point. To descend in the direction of the road in road driving. Instead of having a single point minimum in the traditional approach, it takes the desired X-coordinate value as the goal point, just like the endpoint in a running race, allowing the vehicle to reach the goal point regardless of which lane it is in. The attractive potential field function is

$$U_d = \frac{1}{2}\delta * \rho^2(x, x_{goal}), \tag{7}$$

δ denotes the gain factor, which needs to be adjusted after the experiments. $\rho(x, x_{goal})$ is the longitudinal distance between the vehicle and the goal X coordinate.

3.5. Velocity Control

Driving on a traffic road, the vehicle needs to know the speed limit rules of the lane to adjust the speed of the vehicle. The camera and related processors obtain lane information. When the speed exceeds the speed limit or the distance between the vehicle and any other obstacle is less than half of $the\ d_0$ system, the speed will slow down. When the distance between the vehicle and all of the obstacles is greater than d_0 system will make accelerates evenly. The defining equation of d_0 is

$$d_0 = v * L, \tag{8}$$

v denotes the speed of the vehicle. L is the length of the vehicle.

3.6. Summary

Every part of the potential function will be added with format (1). It provides a vector direction that leads the vehicle to the next point. And the part of velocity control comes up with a method that can set safety and suitable speed. The system multiplies the direction times the speed and finally gets the next point coordinates. This allows for an autonomous driving system with obstacle avoidance, lane keeping, and speed safety.

4. Result

The experiment was conducted in Python with the use of PyCharm. Data comparisons were performed and plotted on MATLAB. This part also through the experiment to determine the suitable gain factor. After combining all the formulas, which were multiplied by the bearing vectors of the vehicle and the obstacle in the Method section, the following functions are implemented.

Fig. 1. Simulated traffic road environment.

Fig. 2. Before a lane change.

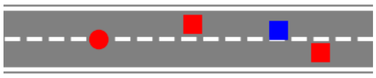

Fig. 3. After a lane change.

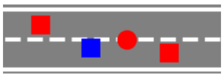

Fig. 5. Before obstacle avoidance.

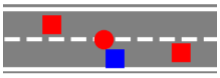

Fig. 6. After obstacle avoidance.

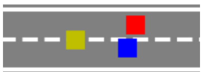

Fig. 4. Lane-keeping.

4.1. Simulated Environment

The real traffic road environment is simulated in the experiment as a flat two-lane road with dotted lines between the two lanes and solid lines at the lane edges, as shown in figure 1. The vehicles in the lane are simulated as rectangles where the blue is the experimental car and the red is the dynamic obstacle car. And the static obstacle is simulated as a circle. The green triangle represents the goal point. These graphic signs are slightly larger, sometimes overlapping a small part or obscured from the lane line.

4.2. Dynamic Obstacle Avoidance and Lane Change

There are four dynamic vehicles and one static obstacle. Dynamic vehicles drive at a set constant speed. The experimental car has its own initial velocity to keep forward when there is no obstacle and will not actively cross the dotted line to change lanes. When the distance between the vehicle and the obstacle in front of the vehicle decreases to twice the speed of the obstacle vehicle, it starts to slow down and slowly produces a lane change speed. If the distance between the vehicle and the obstacle vehicle continues to decrease, the resistance will increase, and lane change will be made if possible. Figure 2 shows a case where the experimental car is too close to the obstacle car, and Figure 3 shows the lane change scheme given by the algorithm. The realization of this function is to judge lane change by adding up the potential resistance of all the surrounding obstacle cars and comparing the sub-resistance perpendicular to the lane with the resistance of the lane line.

4.3. Lane-keeping Assist

Lane keeping is achieved by setting the potential resistance of steep rise in the range from the lane line to half the width of the lane line, and the resistance is greater the closer to the lane line. The resistance on the dotted line will be slightly less than on the solid line to facilitate lane changes. At figure 4, the yellow rectangle is the initial setting position of the experimental vehicle. The blue rectangle is a current position that was affected by dotted line resistance. It is obvious that the vehicle can't stay on the lane line, and the vehicle will always want to stay in the free part of the lanes.

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4.4. Static Obstacle Avoidance

When the distance between the experimental car and the static obstacle is less than the given influence distance, the resistance from the center of the obstacle to the two sides of the obstacle perpendicular to the lane will be generated so that the experimental car will stay away from the obstacle. By comparing figure 5 and figure 6, it is obvious that the car is far away from the obstacle when it passes. Some of the signs are overlapped or obscured because the signs are slightly larger.

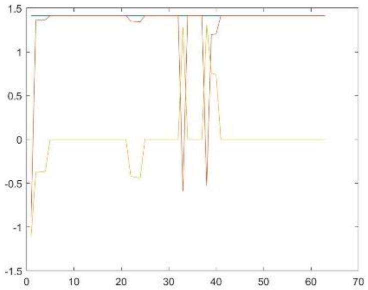

Fig. 7. Following and lane change speed and partial speed.

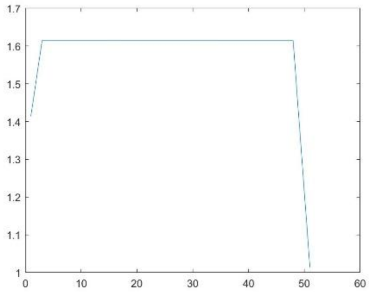

Fig. 8. Uniform velocity change and limited speed.

4.5. Velocity

The vehicle will maintain a constant speed when following. At figure 7, the blue line is the total velocity, the red line is the partial velocity along the lane direction, and the yellow line is the partial velocity in the vertical lane direction. It shows that the speed is very stable, and only when changing lanes or encountering obstacles will the vertical direction of the partial speed move in the vertical direction.

When the distance in lane direction between the experimental vehicle and all nearby obstructions is greater than multiplying the vehicle's length by its speed, the experimental vehicle will accelerate gradually. When the distance is less than half of multiplying the vehicle's length by its speed, the experimental vehicle will slow down slowly. When the distance in lane direction between the experimental vehicle and all nearby obstructions is greater than multiplying the vehicle's length by its speed, the vehicle will accelerate gradually. When the acceleration reaches a certain degree, such as the speed limit of the lane, the vehicle will move forward at the current speed at a constant speed. When the distance is less than half of multiplying the vehicle's length by its speed, the vehicle will slow down slowly, which looks like figure 8.

5. Conclusion

This paper focuses on vehicle obstacle avoidance and lane-keeping safety assistance system. The car can receive the separation between it and any nearby obstacles. Then the next position point is calculated step by step through the safety assistance system until the goal position is reached and the automatic driving is finally realized. The method part introduces four potential functions, including lanes, car obstacles, static obstacles, and direction obstacles. The sum of all potential functions can get the vector direction, and the velocity control part provides the speed. Multiplying the vector direction and speed can get the next point coordinates which is most suitable at current conditions. There are four functions, including lane change, obstacle avoidance, lane keeping, and velocity control which are displayed by the figure in the part of the result, which prove that the strategy method in this paper can be put into practice.

Of course, some problems in the experiment need to be improved. For example, when reaching a certain distance with the vehicle in front, the lane change force will be small, which is smaller than the lane keeping force generated by the road, and the phenomenon of slight fluctuation will occur. In future experiments, a stable controller should be added to avoid such fluctuations to achieve a safer and more comfortable driving experience.

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Overall, this paper finally realized basically a safety assistance system with obstacle avoidance and lane keeping through artificial potential field method.

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