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Research on Obstacle Avoidance Method of Intelligent Car Based on Optimized Fuzzy Control Algorithm

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Abstract

In order to realize the accurate obstacle avoidance function of intelligent car, we propose an intelligent car obstacle avoidance system based on optimized fuzzy control algorithm. Firstly, the kinematics model of intelligent car obstacle avoidance is established, and an efficient environment information collection system composed of multiple sensors is designed to realize the comprehensive collection of obstacle information. Then, the optimized fuzzy control system is adopted to improve the position control accuracy and obstacle avoidance ability. Through the physical debugging and joint simulation of the intelligent car fuzzy controller in the MATLAB and Simulink environment, the simulation results show that the control method can make the collision-free path planned by the intelligent car from the initial state to the obstacle avoidance smoother, and at the same time, the obstacle avoidance of the intelligent car. The actual running distance is reduced by about 16%, which can ensure the practicability of the obstacle avoidance system, provide a new guarantee for the safe operation of the car, and also provide a new idea for the development of the unmanned car.

Keywords

Intelligent Car, Avoidance Strategy, Fuzzy Control, Driverless Car

1. Introduction

An intelligent car is a kind of multi-wheel drive intelligent robot, also known as a wheeled mobile robot. It has the advantages of small volume, low center of gravity, flexible movement, and simple control [1] [2]. The intelligent car can play an important role in automated warehouses, docks, and intelligent logistics systems [3], which can improve transportation efficiency and reduce the working intensity of porters. In terms of special operations, intelligent cars can complete the task of surveying nuclear and chemical contaminated areas [4], and accurately collect pollution samples to improve the accuracy and comprehensiveness of information collection in contaminated areas. At the same time, intelligent car is widely used in military, industrial manufacturing, life services, and other fields, which makes many researchers begin to pay attention to the control field of intelligent car, such as intelligent driving system [5], path tracking algorithm [6], control strategy [7] and so on. To ensure that the intelligent car in the process of driving, automatically adjusts the direction of travel, to prevent collision with obstacles, ensure the safety of the form of intelligent car, the automatic obstacle avoidance method is one of the core areas of research and design of the intelligent car, and automatic obstacle avoidance directly reflects the intelligent car automation, intelligent level.

With the large-scale application of intelligent cars in human production and life, the problems that humans need intelligent cars to solve are becoming more and more complex. People also put forward higher requirements for the performance of intelligent cars [8]-[13], which makes the obstacle avoidance algorithm and obstacle avoidance strategy of intelligent cars develop continuously, and improves the accuracy and real-time performance of intelligent cars. Fu *et al.* [14] proposed a new method for high-quality path acquisition of autonomous cars in the underground parking lot, which satisfied the fluency and real-time requirements of path planning. Liu *et al.* [15] designed a new type of intelligent car based on the STM32F407ZGT6 microcontroller, which can intelligently identify effective obstacles and obstacles to achieve independent decision-making. Nakrani *et al.* [16] designed an intelligent automatic parking system, which can better realize automatic parallel parking under static and moving obstacles and can realize real-time parking of cars. According to the basic theory of the artificial potential field method, Chang *et al.* [17] deduced the double-layer artificial potential field method and proposed the fuzzy processing method of path and trajectory to make the intelligent car effectively avoid static obstacles. Lopez *et al.* [18] proposed an efficient and practical method of car navigation system based on speed space optimization to keep the car in the lane while avoiding the obstacles detected by close-range sensors. Sun *et al.* [19] proposed a hybrid motion planning method based on the time elastic band method and artificial potential field to construct a dynamic obstacle safety area, realize turning or emergency stop obstacle avoidance and effectively ensure the safety of car-like robots in emergencies. De Lima *et al.* [20] proposed a new hybrid control method based on visual navigation, which is applied to autonomous robot cars in urban environments to optimize lane following and fast obstacle avoidance. Lv *et al.* [21] designed a fuzzy neural network obstacle avoidance algorithm based on multi-sensor information fusion, and used MATLAB to simulate the obstacle avoidance algorithm. By comparing and analyzing the simulation path of UGV obstacle avoidance movement under the navigation control of fuzzy controller and fuzzy neural network algorithm, the superiority of the proposed fuzzy neural network algorithm is verified. Chen *et al.* [22] considered computational efficiency and ride comfort, and used a quintic polynomial curve for path generation. Then, a robust fuzzy output feedback controller is designed to track the planned path. Akka *et al.* [23] proposed a trajectory tracking control method for mobile robots when there are static obstacles on the reference trajectory, and designed a fuzzy fusion controller to combine the tracking speed and obstacle avoidance speed to accomplish these two tasks at the same time.

The above-mentioned obstacle avoidance strategies and algorithms can meet the requirements of obstacle avoidance, but in the operating environment with higher requirements for obstacle avoidance accuracy, the environmental information collection system composed of multiple sensors has blind spots when collecting information, and the collected information is incomplete, and the signals generated by multiple sensors will interfere with each other. However, the traditional fuzzy control algorithm has low accuracy, which makes the intelligent car unable to accurately realize the preset obstacle avoidance strategy. To solve these problems, this paper adopts the improved fuzzy control algorithm [24] [25] to construct the obstacle avoidance method of intelligent car multi-sensor information fusion. Combining the advantages and disadvantages of each sensor [26] [27] [28], an efficient environmental information acquisition system composed of multi-sensors is designed. According to the obstacle information, the intelligent car obstacle avoidance system is constructed by using the optimized fuzzy control algorithm, which further improves the obstacle avoidance accuracy of the intelligent car, optimizes the obstacle avoidance planning path, and realizes the independent obstacle avoidance function of single obstacle and multiple obstacles.

The rest of the paper is arranged as follows. In Section 2, kinematic model of intelligent car obstacle avoidance is established and an efficient environmental information acquisition system composed of multiple sensors is designed. Section 3 designs the obstacle avoidance strategy of the intelligent car. Section 4 establishes the fuzzy controller model of intelligent car. In Section 5, the realization of fuzzy control multi-sensor information fusion obstacle avoidance optimization algorithm is described. In Section 6, the simulation comparison analysis and the obstacle avoidance test under laboratory conditions are carried out to verify the efficiency and advantages of the proposed intelligent car obstacle avoidance method based on the optimized fuzzy control algorithm. Finally, the conclusion is given in Section 7.

2. Model Theory Derivation

2.1. Obstacle Avoidance Car Kinematics Model

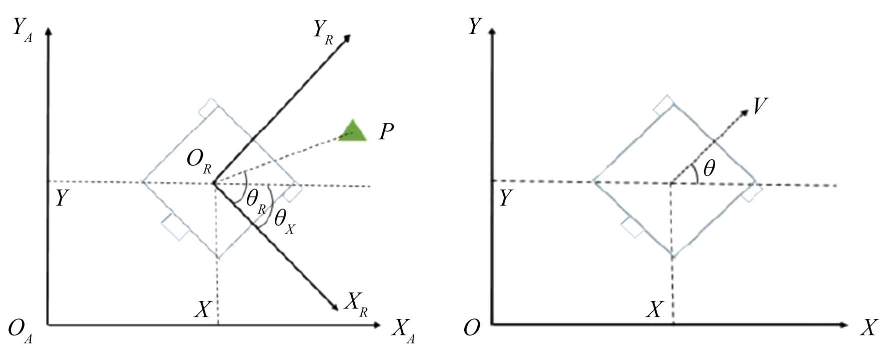
During the operation of the car control system, it is not only necessary to ensure that the car can effectively avoid obstacles at each moment, but also to effectively perceive the position of the target during the movement. Therefore, the motion pose of the car should not only be associated with the global coordinates, but also with the local coordinates. In order to describe the pose of the car more accurately, it is essential to establish a precise coordinate system. The kinematics model of the system can be calculated by using the relationship transformation in the coordinate system. By simulating its motion in the MATLAB simulation platform, the obstacle avoidance decision-making behavior of the car is obtained. The coordinate system of the intelligent car is established as shown in **Figure 1(a)**.

In the intelligent car system studied in this paper, when all the initial states are 0, the global coordinate system and the local coordinate system of the intelligent car coincide, so the kinematics of the intelligent car in the two coordinate systems is consistent. When the intelligent car begins to move, the global coordinate origin of the intelligent car remains unchanged, but the position of the local coordinate origin will change. At this time, the local coordinate origin O_R of the intelligent car is represented by the position vector ${}^{A}K_{RO}$. The relative position in the global coordinate system, the coordinate information of the robot relative to the global coordinate information is represented by the rotation matrix ${}_{R}^{A}H$, and the rotation matrix ${}_{R}^{A}H$ is an orthogonal matrix, so the global coordinate and the robot coordinate can produce a corresponding relationship. If there is an obstacle P in front of the intelligent car in the local coordinate system $X_R O_R Y_R$, the coordinate is (x_{Ri}, y_{Ri}, θ_{Ri}). The angle between the abscissa X_R of the intelligent car and the abscissa X_A in the global coordinate system is θ_x. At the moment m, the position of the intelligent car is $W = (x, y, \theta)^{\mathrm{T}}$, and the global coordinate of the obstacle P can be expressed as.

$$ {}^{A}K = {}_{R}^{A}H\,{}^{R}K + {}^{A}K_{RO} \tag{1} $$

$$ P = \begin{bmatrix} x \\ y \\ \theta \end{bmatrix} + \begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_{Ri} \\ y_{Ri} \\ \theta_{Ri} \end{bmatrix} \tag{2} $$

The kinematics model of the car in the global coordinate system XOY is shown in **Figure 1(b)**.



(a) car coordinate system diagram (b) Kinematics model of the car

Figure 1. Obstacle avoidance car kinematics model.

When moving to time *t*, the pose of the intelligent car can be expressed as.

$$P = \left(x(t), y(t), \theta(t)\right)^{\mathrm{T}} \tag{3}$$

where $x(t)$, $y(t)$ are the horizontal and vertical coordinates of the position of the intelligent car, $\theta(t)$ is the angle that the intelligent car moves to this moment. If the intelligent car meets the constraints

$$\dot{y}\cos\theta(t) - \dot{x}\sin\theta(t) = 0 \tag{4}$$

At time *t*, the left wheel speed of the car is expressed as $V_L(t)$, and the right wheel speed is expressed as $V_R(t)$. Then the linear speed $V(t)$ and angular velocity $\omega(t)$ of the intelligent car can be expressed as.

$$\begin{cases} V(t) = \dfrac{V_L(t) + V_R(t)}{2} \\ \omega(t) = \dfrac{V_R(t) - V_L(t)}{2} \end{cases} \tag{5}$$

where L is the spacing between the left and right wheels, the kinematic model of the intelligent car can be expressed as

$$\begin{Bmatrix} \dfrac{\mathrm{d}x(t)}{\mathrm{d}t} = \dfrac{V_L(t) + V_R(t)}{2}\cos\theta(t) \\ \dfrac{\mathrm{d}y(t)}{\mathrm{d}t} = \dfrac{V_L(t) + V_R(t)}{2}\sin\theta(t) \\ \dfrac{\mathrm{d}\theta(t)}{\mathrm{d}t} = \omega(t) = \dfrac{V_R(t) - V_L(t)}{L} \end{Bmatrix} \tag{6}$$

It can also be expressed as

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} \cos\theta(t) & 0 \\ \sin\theta(t) & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} V(t) \\ \omega(t) \end{bmatrix} \tag{7}$$

According to the kinematic model formula, when $V_R(t) = V_L(t)$, the angular velocity of the intelligent car at this moment is zero, and the motion state of the robot is straight. When $V_R(t) < V_L(t)$ the angular velocity of the intelligent car is less than zero, and the intelligent car turns right, when $V_R(t) > V_L(t)$, the angular velocity of the intelligent car is greater than zero, and the intelligent car turns left. Therefore, according to the kinematics model of the intelligent car, its pose can be expressed as

$$\begin{Bmatrix} x(t) = x(t0) + \int_{t0}^{t} V(t)\cos\theta(t)\,\mathrm{d}t \\ y(t) = y(t0) + \int_{t0}^{t} V(t)\sin\theta(t)\,\mathrm{d}t \\ \theta(t) = \theta(t0) + \int_{t0}^{t} \omega(t)\,\mathrm{d}t \end{Bmatrix} \tag{8}$$

For the pose of the car at the K moment, the pose at the $K + 1$ moment obtained by the sampling period T is

$$\begin{Bmatrix} x(k+1) = x(k) + \Delta x(k) \\ y(k+1) = y(k) + \Delta y(k) \\ \theta(k+1) = \theta(k) + \Delta\theta(k) \end{Bmatrix} \tag{9}$$

So the pose increment of the intelligent car is $(\Delta x(k), \Delta y(k), \Delta\theta(k))$, which can be expressed as

$$\Delta x(k) = \Delta T \cdot v(t)\cos\left(\theta(k) + \frac{\Delta\theta(k)}{2}\right) \tag{10}$$

$$\Delta y(k) = \Delta T \cdot v(t)\sin\left(\theta(k) + \frac{\Delta\theta(k)}{2}\right) \tag{11}$$

$$\Delta\theta(k) = \Delta T \cdot \omega(t) \tag{12}$$

The $K+1$ moment posture of the intelligent car is

$$\begin{Bmatrix} x(k+1) = x(k) + v(k) \cdot \Delta T \cos(\theta_k) \\ y(k+1) = x(k) + v(k) \cdot \Delta T \sin(\theta_k) \\ \theta(k+1) = \theta(k) + \Delta T \cdot \omega(k) \end{Bmatrix} \tag{13}$$

Therefore, the coordinates of the intelligent car at K time are $(x(k), y(k), \theta(k))$, and the coordinates of $K+1$ time are $(x(k+1), y(k+1), \theta(k+1))$.

2.2. Intelligent Car Ranging Sensor Configuration Scheme

Because intelligent cars are mostly high-speed, and ultrasonic ranging sensor has the advantages of high measurement accuracy, high speed, and will not be disturbed by light, electromagnetic waves and dust and other external factors, so the ultrasonic sensor is installed in front of the car. Due to the limited width of the car head, only the ultrasonic ranging sensor installed in the car head will have a blind area. At the same time, in order to reduce the signal interference between the sensors of the intelligent car environment information acquisition system, the infrared distance sensor is installed on both sides of the car head to realize the comprehensive acquisition of the obstacle information ahead.

The physical installation of the intelligent car head sensor is shown in **Figure 2**. The Intelligent car environmental information acquisition system consists of

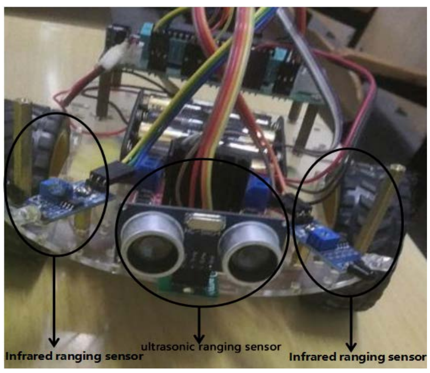


Figure 2. Physical view of the sensor installation of the transfer intelligence car.

two infrared ranging sensors (oval) and an ultrasonic sensor (circular), this environmental information acquisition system enables real-time detection of obstacles in front of the car. This configuration offers the advantages of low price and comprehensive information collection. This sensor configuration scheme for environmental information acquisition systems can be used in a wide range of cars.

3. Design and Optimization of Fuzzy Controller

3.1. Design of a Fuzzy Control System for Intelligent Car Obstacle Avoidance

As fuzzy control systems are based on fuzzy control algorithms, the design of a fuzzy control system can only be completed by analyzing the effects of the system structure and control algorithms [29] [30]. The fuzzy control system structure contains different functional modules, as shown in **Figure 3**. The role of the fuzzification interface module is to fuzzify the control inputs to determine the fuzzy values, and then the fuzzy inference machine consists of two parts: the database and the rule base. The key to the fuzzy inference machine is the affiliation function and the fuzzy language, which serves to construct the fuzzy space and formulate the corresponding control rules. Finally, there is the defuzzification interface module, which handles the conversion of the fuzzy output into an accurate control value output, enabling the intelligent car to be effectively guided through the corresponding tasks.

In this paper, the algorithm of obstacle avoidance path of intelligent car in complex driving environment is studied. Different sensors are used to detect the complex environment, and then the information is fused and classified to construct a fuzzy control system of multi-sensor information fusion, as shown in **Figure 4**. The design classifies and detects obstacles through an ultrasonic module and two infrared modules. The ultrasonic ranging sensor detects threats from obstacles in front of it, and the infrared ranging sensor detects threats from obstacles on both sides. Then the actual distance information collected by each sensor is fused and classified, and processed by error compensation to form a specific fuzzy control input, and then the fuzzy controller is used to reason and judge. Finally, the motor of the intelligent car is controlled by the defuzzification module, and finally the obstacle avoidance function of the intelligent car is realized.

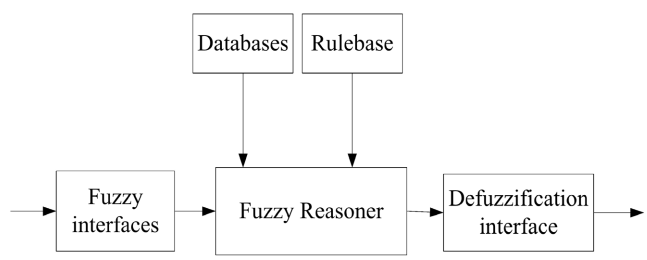


Figure 3. Fuzzy control system architecture.

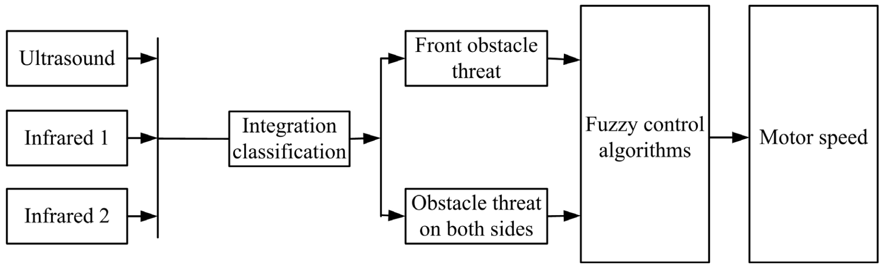


Figure 4. Fuzzy control system with multi-sensor information fusion.

3.2. Variable Fuzzification

From the structure of the fuzzy control system designed in this paper, it can be seen that the fuzzy control input of intelligent car obstacle avoidance in this paper is mainly the distance information and relative direction perspective information collected by each sensor. After information fusion classification, only by clarifying the position and distance membership function of obstacles can the design scheme of automatic control system be clarified. Because the output of the intelligent car obstacle avoidance algorithm in this paper is the direction of motion of the intelligent car, and the steering of the intelligent car is realized by the speed difference of the motors installed on the two wheels, the output becomes the motor speed of the intelligent car. Therefore, this topic will blur the direction, distance and motor speed variables.

3.2.1. Directional Affiliation Function

In this study, one ultrasonic sensor and two infrared sensors were installed in the front of the car during the design process, located in the middle and on both sides of the car, mainly distributed in three positions: left, directly in front, and right. At the same time, the five orientations of left, leftward, forward, rightward and rightward of the orientation information are represented by LL, FF, and RR respectively, and their corresponding affiliation functions are shown in **Table 1**.

Therefore, in the simulation, the information normalization function is the position of the obstacle viewpoint, its angle can be set to [60˚, 60˚] interval when the obstacle is less than 60˚, and greater than 60˚ respectively as 60˚ and 60˚ process analysis, in the analysis process minus indicates that the obstacle in the left position, plus indicates that the obstacle in the right position, the angle range is divided into five levels, orientation obstacles corresponding.

3.2.2. Distance Affiliation Function

As this paper research needs to use an ultrasonic sensor and two infrared sensors, to collect information effectively as well as to improve the processing efficiency, if the synchronization will lead to errors in the analysis results, the interval of each sensor acquisition time is set to 20 ms, to clarify the distance of the obstacles, define the distance from 0 to 50 mm, the distance is too large then the default no obstacles, to improve the division of the degree of distance, this paper clarifies four levels of very close, near, moderate and far, to clarify the distance, using the symbols VC, CC, FF, VF, the details are shown in **Table 2**.

Table 1. Sensor test affiliation menu.

Sensors	Left (LL)	Front (FF)	Right (RR)
Ultrasound	0	1	0
Infrared 1	1	0	0
Infrared 2	0	0	1

Table 2. Table of distance detection affiliation functions.

Distance	Very Close (VC)	Close (CC)	Far (FF)	Very Far (VF)
Less than 20 mm	1	0	0	0
30 mm	0	1	0	0
50 mm	0	0	1	0
Farther than 50 mm	0	0	0	1

When establishing the corresponding main fuzzy control function, the following principles should be followed: when the input value is large, the quantization factor of the sub-fuzzy controller should be appropriately reduced to prevent the response from exceeding the input domain of the sub-fuzzy controller, resulting in overshoot of the system. When the input value is small, the quantization factor of the sub-fuzzy controller should be appropriately increased to improve the system regulation efficiency and reduce the system regulation inertia.

4. Implementation of Multi-Sensor Information Fusion Obstacle Avoidance Optimization Algorithm for Fuzzy Control

According to the above multi-sensor information fusion, a fuzzy control system structure can be seen, this paper's controller design optimization algorithm fusion classification, ultrasonic and infrared measured the position, distance, and other information, and then the direction and distance as the input to the controller. After the fuzziness has been resolved, a matching controller design criteria are created based on obstacle avoidance and its associated knowledge base system, and the computational output is completed. The algorithm implementation flowchart for the intelligent car corresponding to the motor speed is shown in **Figure 5**.

As can be seen from **Figure 5**, ultrasonic and infrared collected different kinds of obstacle distance direction information, according to the information collected by the sensor combined with the type of obstacles, information fusion, calculate the de-threatening impact area, to get the intelligent car movement path need to avoid the obstacle area orientation and location information.

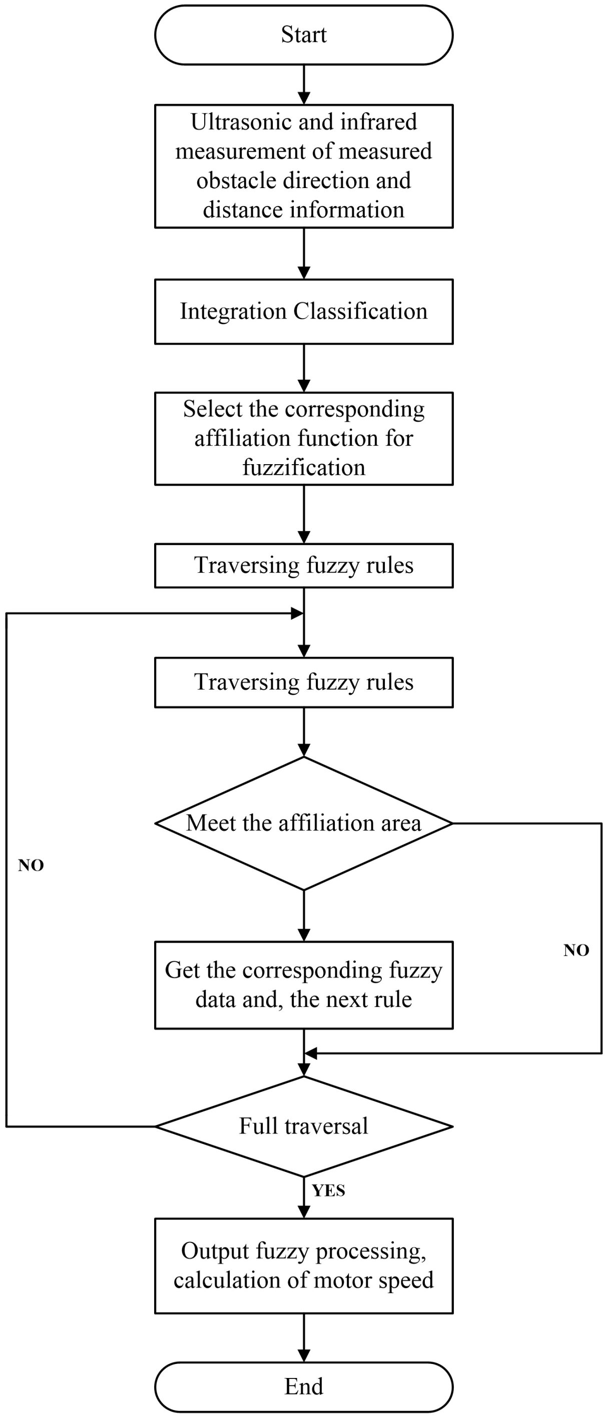


Figure 5. Obstacle avoidance algorithm implementation flow.

In the process of ultrasonic and infrared acquisition of obstacle information, this paper uses ultrasonic distance measuring sensors to detect information about the distance, type, and shape of the relevant obstacles, to prevent mutual interference between sensors and lead to errors, so the time interval of 20 ms, also to improve efficiency in the acquisition process, the maximum detection distance of 50 mm is defined, more than 50 mm is considered no obstacle. As the individual sensors need to compensate for the obstacle information combined with the actual situation after the data has been collected to reduce the error caused by the application environment deviation to ensure timeliness, the least squares method is used in this study.

To comply with and ensure the relevant requirements for the use of intelligent cars and to guarantee the safe operation of intelligent cars, the target detection of the intelligent car obstacle avoidance system needs to ensure the real-time detection of obstacles, this paper selects infrared for the target detection of environmental obstacles, and then measures and solves for the information content of the obstacles. However, for many reasons such as the weight of the GPU itself and the power supply system, it is not practical to mount it on the intelligent car, so this paper transmits the content of the information collected by the intelligent car's infrared light to the road. The problem can be solved by an obstacle monitoring system based on the remote control.

Considering the problems such as the number of multi-sensor information fusion obstacle avoidance algorithm collection and a large amount of calculation, the software system implementation of the algorithm uses the STC89C52RC main control chip, and the system software includes the ultrasonic sensor system software based on the STC89C52RC control integrated IC, the laser acquisition system, the four motor regulation system software, and the upper computer software according to the WIFI control module, the lower computer communication system and its supporting parts. The controller is designed to avoid obstacles. The STC89C52RC is the core of the Cortex-M and ST offers a better function library for this IC chip so that during product development you can immediately perform the relevant work according to the numbered slots of the ST function library and then get rid of the actual operation of the minimal memory layer.

The control algorithm structure is changed to outer loop fuzzy obstacle avoidance control + inner loop PID position control fuzzy control part of the rules are changed fuzzy logic input for sensor fusion after the detection of obstacle distance and sensor position number, the output is x position offset and y position offset. The algorithm is fuzzy obstacle avoidance control + internal PID control. In process control, the PID controller, which controls by proportional (P), integral (I), and differential (D) deviation, is one of the most widely used automatic controllers.

The fuzzy control algorithm in this paper is the Mamdani algorithm [31], an algorithm for the truth value of the F conditional proposition "$A \to U$" (fuzzy implication relation), and the formula for calculating the true value of the F implication relation

$$R(a,u) = (A \to U)\min\left(A(a), U(u)\right) = A(a) \wedge U(u) \tag{14}$$

This paper makes use of the fuzzification approach provided by MATLAB: the centroid area center of gravity method, with the formula

$$x \text{ Centroid} = \frac{\sum_i \mu(x_i) x_i}{\sum_i \mu(x_i)} \tag{15}$$

PID controls its parameter settings, as shown in Figure 6.

A schematic diagram of the specific motion coordinate time runs is shown in Figure 7. The curve in the figure shows that the X position offset meets the obstacle avoidance requirements of smart cars.

The minimum detection distance diagram is shown in Figure 8. The shortest detection distance in the figure meets the obstacle avoidance requirements of intelligent vehicles.

The intelligent car attitude angle change is shown in Figure 9. The attitude angle of the smart car in the figure meets the obstacle avoidance requirements of the smart car.

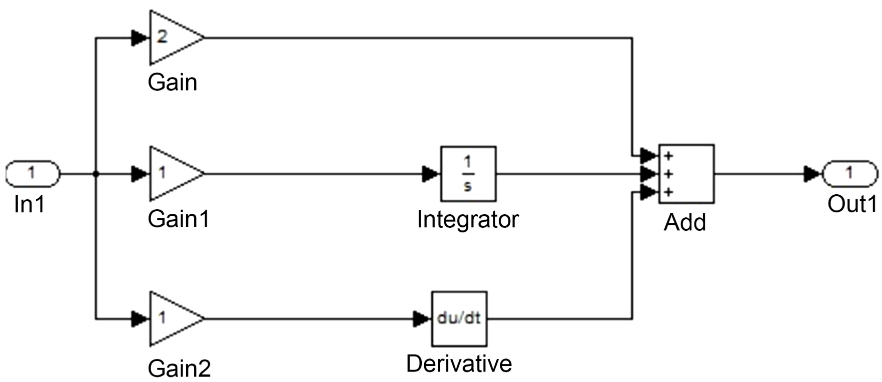


Figure 6. Diagram of the specific parameters of the PID controller.

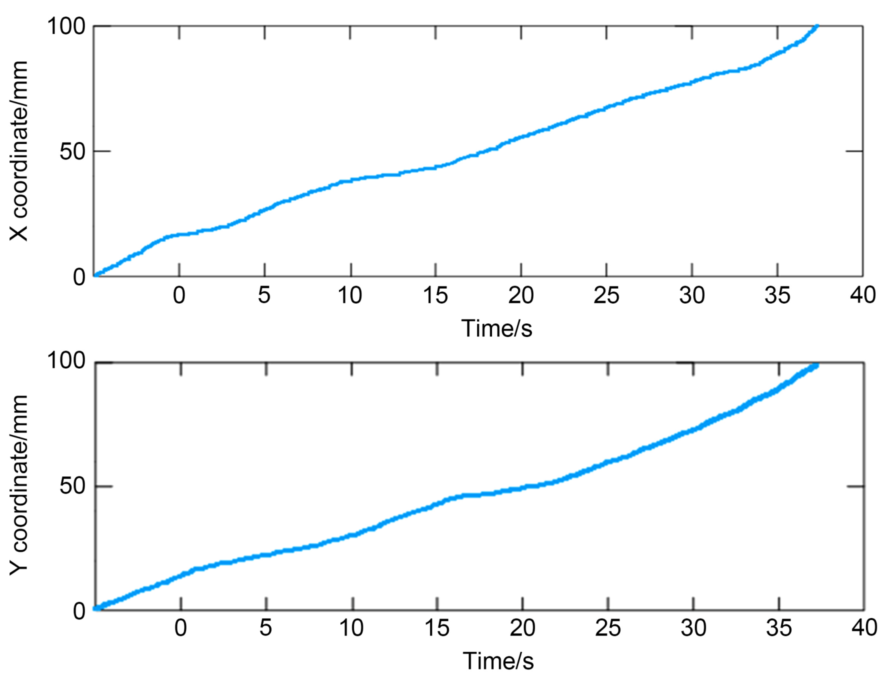


Figure 7. Schematic diagram of the specific motion coordinate timescales.

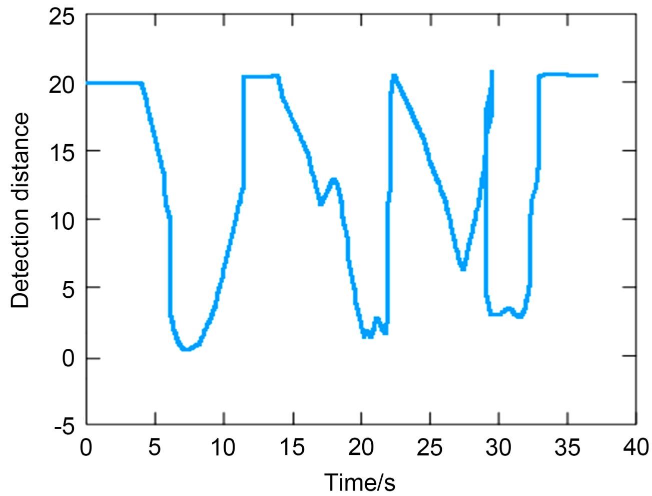


Figure 8. Optimum detection distance map.

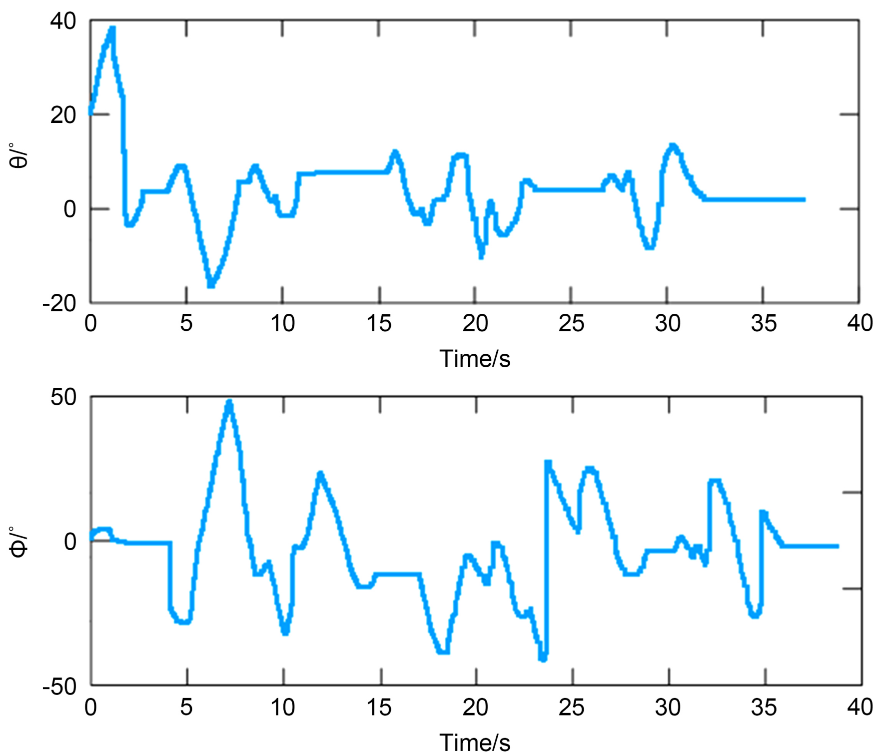


Figure 9. Intelligent car attitude angle change diagram.

Figure 10 shows the structure of the fuzzy logic in the Simulink simulation model.

The role of the sub-fuzzy controller is to use the detection information S from the sensors in the intelligent car's obstacle avoidance process as the input, and the offset dx and dy in the x and y directions of the intelligent car as the output of the intelligent car's sub-fuzzy controller, which in turn enables the intelligent car to successfully avoid obstacles. The affiliation functions of each input and output variable are shown in Figure 11 to Figure 13.

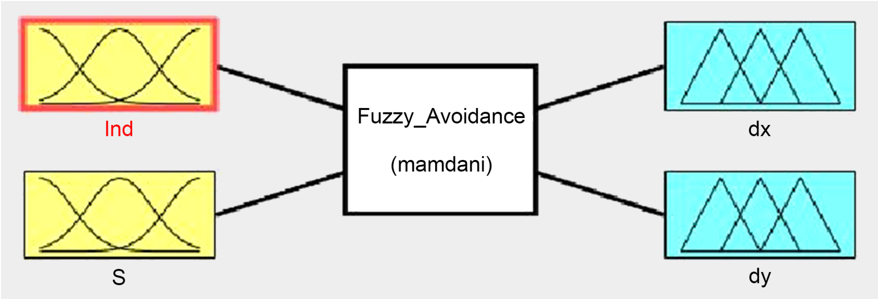


Figure 10. Fuzzy logic structure.

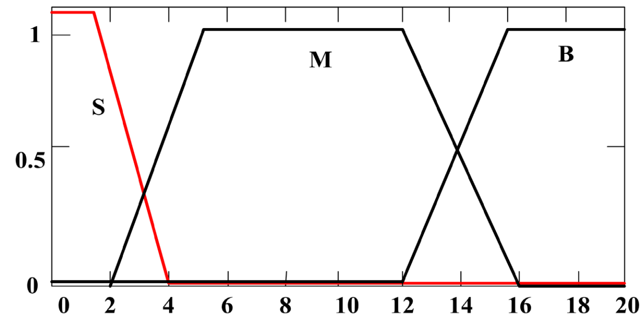


Figure 11. Detection distance S.

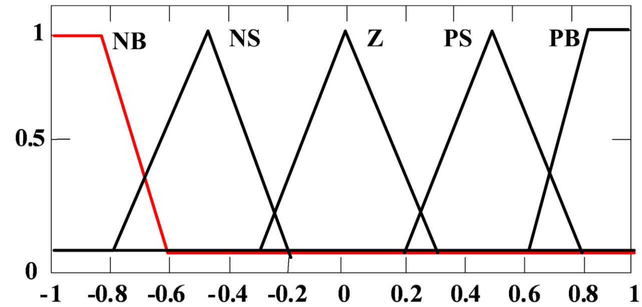


Figure 12. x-direction offset.

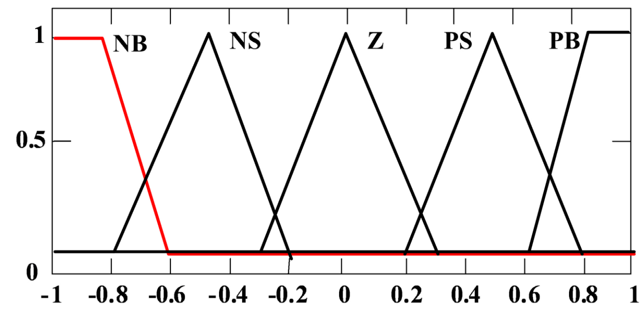
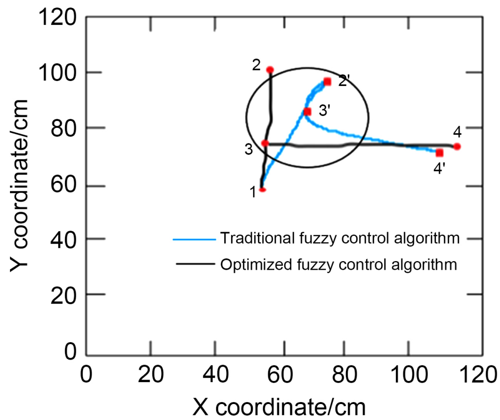


Figure 13. y-direction offset dy.

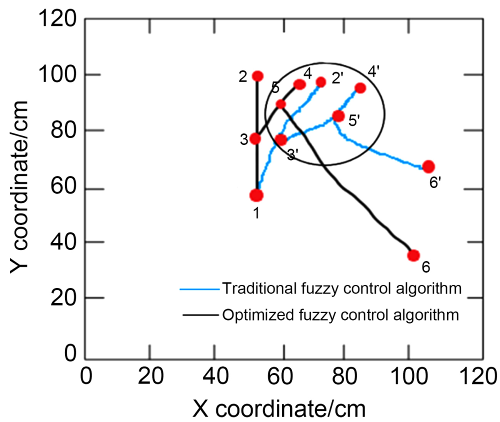
The above improvements make the current algorithm position control accuracy and obstacle avoidance ability stronger than the original algorithm. There is one. Control algorithm structure changed to outer loop fuzzy obstacle avoidance control + inner loop PID position control, fuzzy control.

5. Simulation and Experimental Analysis

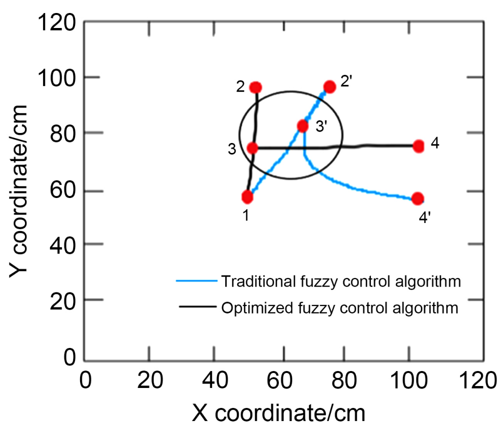
In order to verify the obstacle avoidance effect of the intelligent car using the optimized fuzzy control algorithm, the MATLAB simulation software is used to compare it with the traditional fuzzy control algorithm. Figure 14 and Figure 15 is the obstacle avoidance trajectory diagram using the traditional fuzzy control algorithm and the optimized fuzzy control algorithm.



(a)



(b)



(c)

Figure 14. Obstacle avoidance trajectory of intelligent car.

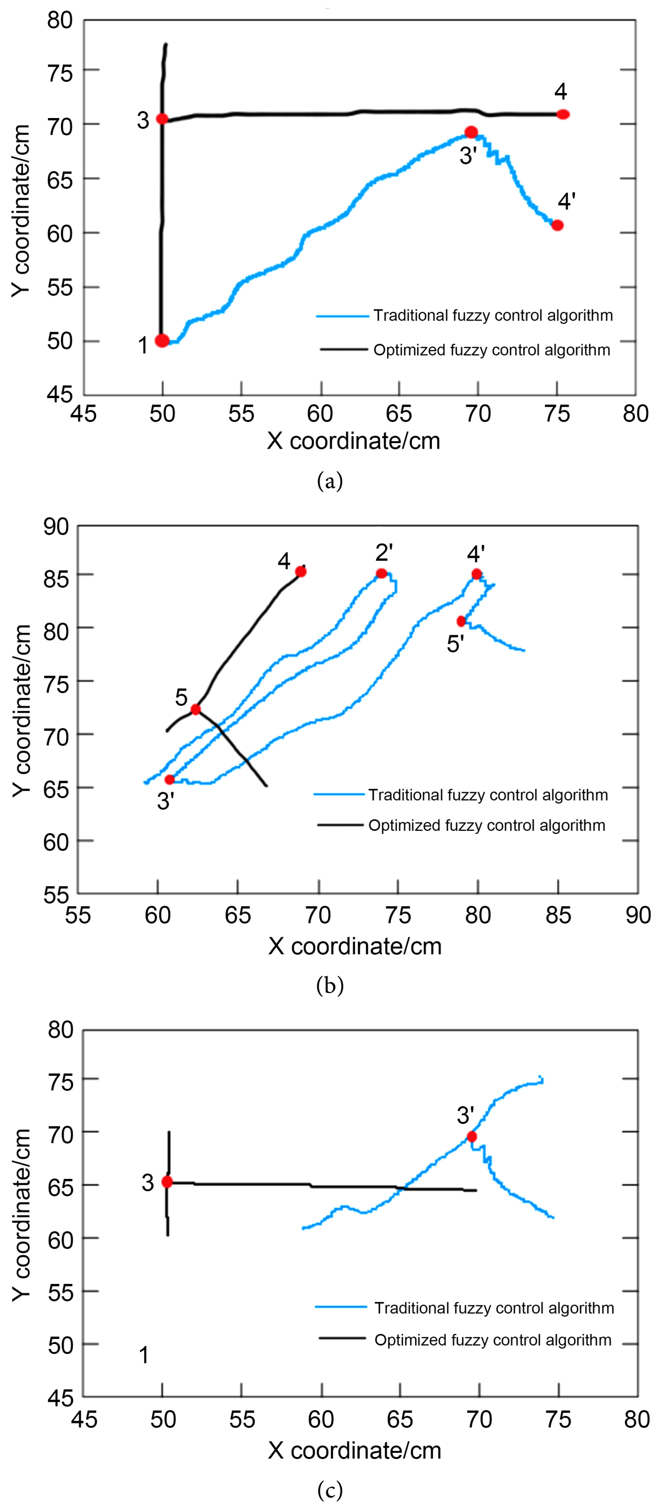


Figure 15. Local enlargement of obstacle avoidance trajectory of intelligent vehicle.

First, the environment diagram shown in **Figure 14** is created, where **Figure 14(a)-(c)** correspond to the three different types of obstacles in the obstacle avoidance strategy in Section 3.1. The blue line is the obstacle avoidance route of the intelligent vehicle based on the conventional fuzzy control algorithm, and the black line is the obstacle avoidance route of the intelligent vehicle based on the optimised fuzzy control algorithm. Setting the starting point of Figure 14(a) and Figure 14(c) as (50, 50) and the ending point as (100, 50), observing the blue line in Figure 14(a), the starting point of the intelligent car is (50, 50) but the first return point is (80, 100) at point 2' and then the movement to (70, 80) at point 3' does not coincide. Observe the black line in Figure 14(a), the intelligent car starts at (50, 50) in front of which there is an obstacle at (50, 100), the intelligent car first straight line to point 2 then straight back to point 3 and finally through a 90˚ turn to point 4 to successfully avoid the obstacle finally successfully reached the set (80,100) end point, Figure 14(b) and Figure 14(c) simulation results are similar, the blue line of the obstacle avoidance route are with the set end point. The black line is consistent with the theoretical obstacle avoidance strategy of Figure 4 as the shortest path. Throughout the process, the simulated trajectories based on both the traditional and optimised fuzzy control avoidance algorithms were able to plan a collision-free path from the starting point to the target point within the specified range. Compared with the traditional fuzzy control algorithm, the optimised fuzzy control algorithm can achieve better obstacle avoidance without contacting the obstacle, and the obstacle avoidance distance of the example run after avoiding the obstacle is reduced by approximately 16%.

A partially zoomed in image is shown in Figure 15. As can be seen in Figure 15, the intelligent car runs from point 3'' in Figure 15(a), points 2', 3', 4', 5' in Figure 15(b), and Figure 15(c) 3' points, the trajectory of the intelligent trolley appears jagged. The reason for the jaggedness is that the quantization factor of the conventional fuzzy control algorithm is fixed. When the input value is at the boundary value of the fuzzy domain for a long time, the output value will always be in a large state, easily forming overshoot and generating the sawtooth phenomenon. The optimised fuzzy control algorithm can make the obstacle avoidance trajectory of the intelligent vehicle smoother and more robust.

6. Conclusion

In this paper, the optimized fuzzy control algorithm is used to realize the obstacle avoidance function of intelligent car accurately. Firstly, the kinematics model of distributed electric drive three-wheeled intelligent car is established to accurately describe the attitude of intelligent car in obstacle avoidance. Secondly, an efficient environmental information acquisition system composed of multiple sensors is designed to avoid the problem of incomplete information collection and mutual interference of signals generated by sensors. The fuzzy control algorithm is optimized, and the learning algorithm is introduced to optimize the parameters, so that the intelligent car can perfectly perform the designed obstacle avoidance strategy, avoid obstacles more flexibly and accurately, and its planned collision-free path from the initial state to avoid obstacles is smoother and shorter. The actual running distance of obstacle avoidance of intelligent car can be reduced by about 16%. This study can improve the obstacle avoidance ability of intelligent cars. The verification test in the laboratory environment proves the effectiveness of the algorithm and control strategy. It provides a new feasible way to solve the problem of collision avoidance trajectory planning of intelligent cars, and improves the collision avoidance control ability of intelligent cars.

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Author Contributions

Zhaowen Deng proposed the idea, Shijie Guan and Chenxin Xi designed and carried out the simulation, Shijie Guan and Zisong Liu analyzed simulation results, Anran Liu has unique insights in the analysis of the results, Shijie Guan, Anran Liu and Chenxin Xi wrote the manuscript, Zhaowen Deng and Youqun Zhao guided, reviewed and checked the simulation analysis, and Zhaowen Deng funded the project.

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Code or Data Availability

The data and code are available in a public repository.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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