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Research on Smart Car Obstacle Avoidance System

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Abstract

In the context of vehicle intelligence, this paper selects smart car obstacle avoidance technology for research and analysis. In the obstacle avoidance process of smart car, the obstacle information needs to be collected and processed first. This paper uses sensors information fusion technology to fuse the information collected by ultrasonic sensors and vision sensors. Combining the advantages of both ultrasonic sensors and vision sensors, the real-time and effective of information collection is provided, and accurate data is provided for obstacle identification and location information. In the smart car obstacle avoidance control algorithm, in view of the difference in the density of obstacles encountered during the driving of the smart car, this paper combines the improved artificial potential field method with the fuzzy control algorithm to design the smart car obstacle avoidance control algorithm. The algorithm was simulated and verified by Matlab. The verification results show that the combination of two obstacle avoidance control algorithms can effectively make up for the shortcomings of the single control algorithm, thereby achieving the expected obstacle avoidance behavior requirements.

Keywords

Smart car; Sensor information fusion technology; Obstacle avoidance system; Fuzzy control algorithm; Artificial potential field method.

1. Introduction

With the rapid development of China's economy and the rapid advancement of urbanization, the number of domestic cars and road mileage has continued to increase. Although the popularity of automobiles has brought great convenience to people's travel, the accompanying problems have become increasingly prominent, such as traffic congestion, frequent traffic accidents, and environmental pollution. Although existing vehicle active safety technologies have improved the driving safety of vehicles, they have not been able to fundamentally eliminate the possibility of traffic accidents. As an important means to solve traffic problems, automobile intelligence has received great attention from home and abroad. At present, the development direction of autonomous intelligence of smart cars is relatively independent. In terms of autonomous intelligence, the Society of Automotive Engineers in the document SAE-J3016's definition of automotive automation level standards[1][2] has been widely recognized in the industry, from L0 to L5, as shown in Fig. 1. From L0 to L5, the autonomy of the vehicle is gradually enhanced until the car is fully autonomous.

In the research of smart cars, obstacle avoidance has always been the focus of research. To obtain good obstacle avoidance effect, the design of obstacle avoidance algorithm is particularly important. The design of the obstacle avoidance system for smart cars in this paper is based on the advantages of stable performance, strong directivity of the ultrasonic sensor in ranging and high sensitivity, wide dynamic range of the visual sensor. Multi-sensor information fusion technology is used to fuse the information collected by the two sensors, ultrasonic and vision, to provide accurate data for obstacle identification and location information, thereby achieving obstacle avoidance information collection

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Autonomous driving classification		Name	Definition	Steering and shifting operations	Driving environment monitoring	take over	Application scenario
NHTSA	SAE						
L0	L0	Manual driving	The car is fully driven by a human driver.	Human driver	Human driver	Human driver	No
L1	L1	Assisted driving	The vehicle performs one of the steering or shifting operations, and the remaining driving operations are performed by a human driver.	Human driver & vehicle	Human driver	Human driver	Limited scene
L2	L2	Partially autonomous driving	The vehicle completes both steering and shifting operations, and the remaining driving operations are performed by human drivers.	Vehicle	Human driver	Human driver	
L3	L3	Conditional autonomous driving	The vast majority of driving operations are performed by vehicles, and human drivers need to properly respond to system requests.	Vehicle	Vehicle	Human driver	
L4	L4	Highly autonomous driving	All driving operations are performed by the vehicle, and the human driver does not necessarily need to properly respond to the system's request.	Vehicle	Vehicle	Vehicle	
	L5	Fully autonomous driving	Vehicles reach human driving levels and can handle driving situations on any road and environment.	Vehicle	Vehicle	Vehicle	All scenes

Fig. 1 Autonomous driving classification

for smart cars. Then, the improved artificial potential field method and fuzzy control algorithm were used to design an obstacle avoidance control algorithm for smart cars. The combination of two obstacle avoidance control algorithms can effectively make up for the shortcomings of single control algorithm, and thus achieve the expected obstacle avoidance behavior requirements.

2. Obstacle avoidance information collection for smart cars

Smart car obstacle avoidance refers to the safe and effective avoidance of obstacles on the road when the car is driving towards the target point. In the process of avoiding obstacles, smart cars need to accurately collect road environmental information first. This chapter mainly introduces the sensors used in the information collection process and data collection methods.

2.1 Sensors

2.1.1 Ultrasonic sensors

Ultrasonic ranging is to measure the distance between the vehicle and the obstacle by measuring the time difference between the time when the ultrasonic wave is emitted and the time it reflects back[3]. When the ambient temperature is T, the propagation speed of the ultrasonic wave in the air is shown in formula (1)[4]:

$$v = v_0\sqrt{1 + \frac{T}{273}}\,m/s \tag{1}$$

Where $v_0 = 331m/s$.

Assuming that the time taken by ultrasonic waves from emission to reflection is t and the propagation speed of the ultrasonic wave in the current environment is v, the distance d between the vehicle and the obstacle can be calculated by formula (2), where:

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$$d = \frac{v \times t}{2} \tag{2}$$

As the ultrasonic sensor collects distance information, there is a certain blind area. If there is an obstacle in the blind area that cannot be detected, the smart car will collide with the obstacle and bring unnecessary losses. In view of this defect, it is necessary to reduce the possibility of collision by finding the installation angle of the ultrasonic sensor.

2.1.2 Visual sensors

Vision sensors have the advantages of large measurement signal range and complete information. It has always been one of the indispensable and important sensors in the research of smart cars. Vision technology is a comprehensive technology, including vision sensing technology, light source lighting technology, optical imaging technology, digital image processing technology, digital and analog video technology, computer software and hardware technology and automatic control technology[5].

Fig. 2 Visual sensor

Vision sensors usually use image resolution to describe their performance. The accuracy of the vision sensor is not only related to the resolution, but also to the detection distance of the measured object. The farther the object is, the worse its absolute position accuracy is. The vision system workflow is shown in Fig. 3.

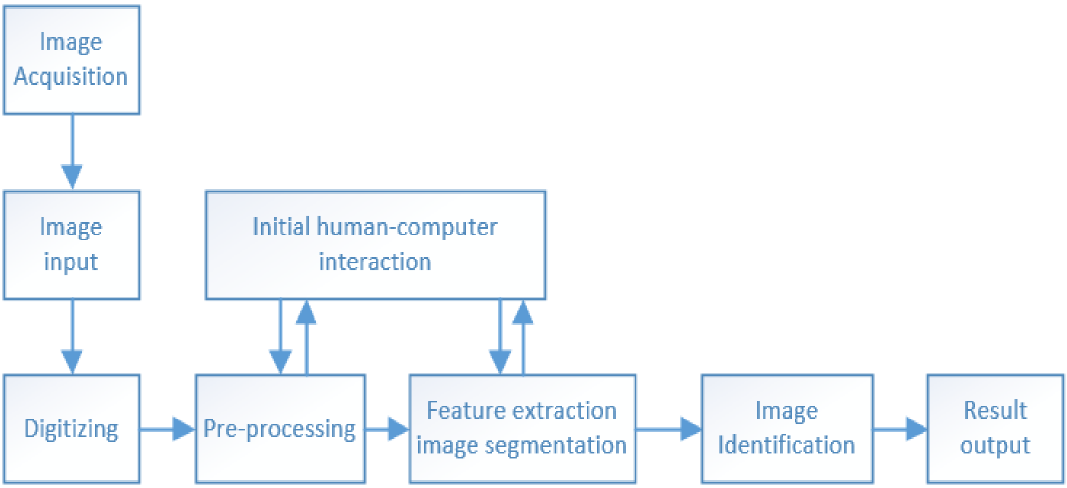

Fig. 3 Vision system workflow

2.2 Data collection methods

Data collection is a necessary part in the operation process of smart cars. The smart car first collects data information through sensors, and then feeds it back to the corresponding module of the smart car after processing and calculation. This ensures that the smart car can reach its destination smoothly in the process of operation[4]. In this paper, three pairs of ultrasonic sensors are installed on the left, middle, and right sides of the front and rear ends of the smart car to measure the distance information

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between the smart car and the front and rear vehicles. The advantage of this design is that it can better collect the information around the car, and can better realize the safety obstacle avoidance of smart cars. The vision sensor is used to collect the environmental information of the smart car on the road, so as to obtain the obstacle information useful for the smart car to avoid obstacles.

3. Obstacle avoidance information processing for smart cars

As the image collected by the sensor is fuzzy and noisy, it needs to be processed to obtain the accurate information of the vehicle on the road. On the basis of obtaining the information of driving road, the visual system of the smart car will extract the information of obstacles, and give the mathematical model of obstacles, so that the smart car can use the obstacle avoidance algorithm suitable for the current environment.

3.1 Image information extraction

As the three-frame difference method has the advantages of simple calculation, good effect, and can adapt to various dynamic environments, and has better results in image extraction than the two-frame difference method, this paper uses the three-frame difference method to extract the collected image information, so as to get the information needed in the operation of smart cars. The three-frame difference method refers to the difference operation between the first two frames and the last two frames in three consecutive frames of video images. Then adopt different statistical rules for the unchanged area and the changed area in motion, set the change detection threshold, and perform motion change detection and recognition of connected areas on the image[6]. The workflow of the three-frame difference method is shown in Fig. 4.

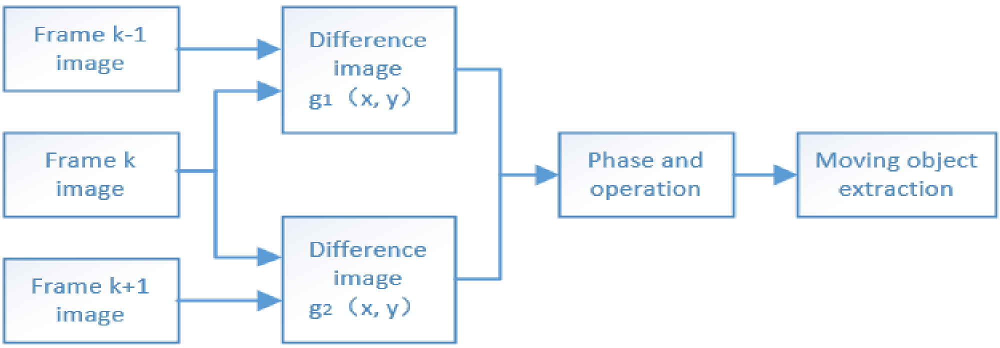

Fig. 4 Three-frame difference method workflow

Select three consecutive frames of video image as$f_{k-1}(x,y), f_k(x,y), f_{k+1}(x,y)$. After processing, the motion change images $g_1(x,y)$ and $g_2(x,y)$ of the first two frames and the last two frames of the moving object in the motion period can be obtained. Then the two images obtained are performed phase and operation together to locate the moving object. In addition, some characteristic information of the moving object itself needs to be combined to completely extract the moving object. The phase and operation formula is shown in (3):

$$P(x,y) = g_1(x,y) \otimes g_2(x,y) \tag{3}$$

Among them, $P(x,y)$describes the frame difference of three consecutive frames.

3.2 Image smoothing

Image smoothing technology is mainly used to smooth the noise in the image. This process makes the image brightness gradually change, reduce the abrupt gradient, and improve the image quality. This paper uses the median filtering method to smooth the image. Median filtering is a non-linear processing method, which sets the output of a pixel in the image after filtering to the median of the gray values of each pixel in the neighborhood of the pixel. Under certain conditions, the median filtering method can not only remove noise, but also protect image details and edges. Therefore, a better image restoration effect can be obtained[7].

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The median filtering is used to smooth the image. The image comparison before and after processing is shown in Fig. 5.

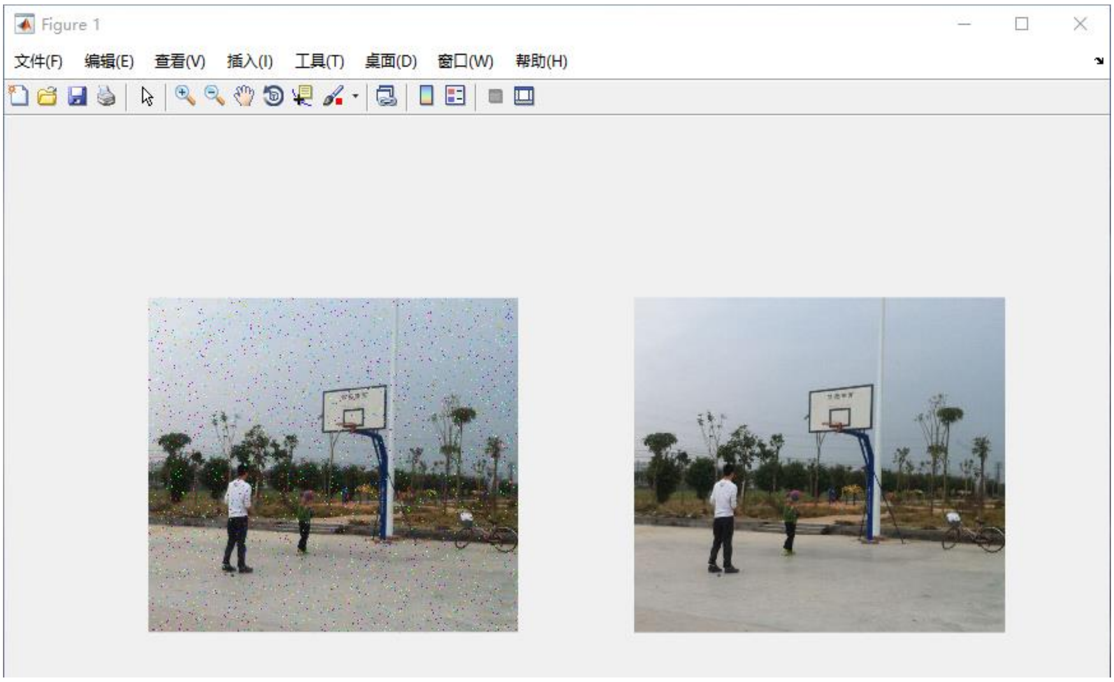

Fig. 5 Image comparison before and after median filtering

It can be clearly seen from the above comparison diagram that after smoothing images with noise using median filtering, the noise in the image can be eliminated well, and a clear image can be restored more completely.

3.3 Image segmentation

Image segmentation is one of the basic problems of image processing and machine vision. Its task is to divide the image into a set of non-overlapping regions. The division of these areas is of practical significance. They either represent different objects or different parts of object. This paper chooses the threshold segmentation technology as the technical means of image segmentation processing. Threshold segmentation technology is a region-based image segmentation technology. The principle is to divide the image pixels into several categories.

The existing image to be processed is $f(x, y)$, to select a suitable range $[TH_1, TH_2]$of gray values in the image as the threshold. The pixel in the range of gray value is 1, otherwise it is 0, and its expression can be expressed by (4).

$$g(x, y) = \begin{cases} 1 & TH_1 < f(x, y) < TH_2 \\ 0 & \text{others} \end{cases} \tag{4}$$

In image segmentation, iterative method, Otsu method, and maximum entropy method can be used to select the threshold value and process the image. The thresholds selected by these methods have little effect on image segmentation. It is necessary to select a proper size threshold. If the selected threshold is too large, the target point may be mistaken for the background. Conversely, when the threshold is selected too samll, the background may be mistaken for the target point. Therefore, the correct selection of the threshold is particularly important. Next, an obstacle analysis process is performed through an example analysis.

3.4 Image processing example analysis

The main function of vision sensors is to collect the environment and extract obstacle information in the process of obstacle avoidance of smart cars. In this section, aloe vera glue placed on the ground is taken as an example. The information of aloe vera glue as an obstacle is extracted from the image through many methods, including image graying, image filtering, and morphological operations. The specific workflow is shown in Fig. 6.

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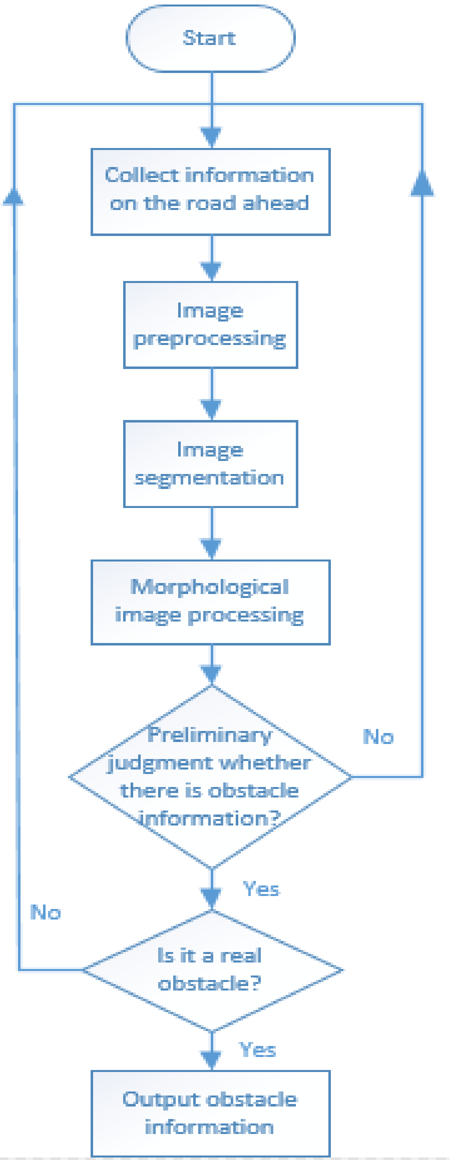

Fig. 6 Obstacle detection system workflow

The image processing results are shown in Fig. 7.

(a) The original image (b) Grayscale processed image

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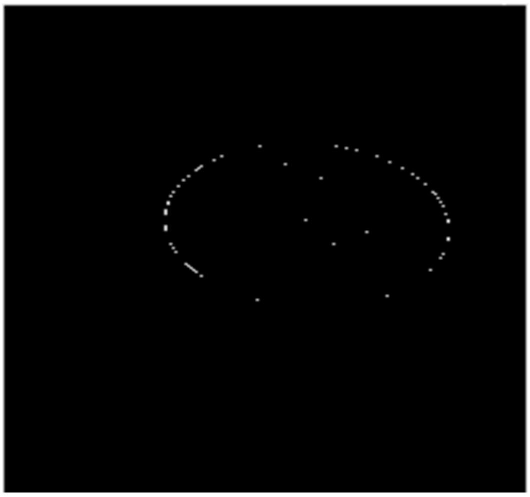
(c) Image after median filtering



(d) Image after morphological operation

(e) Obstacle information image

Fig. 7 Image processing process images

Fig. 7 shows the results of each process of image processing. First, the original image 7(a) is acquired during the movement. Since the image is acquired during the movement, the image is a bit fuzzy. In order to facilitate subsequent processing, grayscale processing is performed on the original image to obtain image 7(b). Because the image after gray-scale processing is fuzzy and noisy, the image needs to be smoothed by median filter, and the clear image 7(c) is obtained after processing. Then, morphological operation was performed on image 7 (c) to obtain figure 7 (d), which was the image after corrosion. Finally, the target obstacle was filled to get the obstacle information image.

4. Obstacle voidance strategy for smart cars

4.1 Multi-sensor information fusion

Multi-sensor information fusion is an information processing technology used to include several sensors or multiple kinds of sensors in different locations. Based on certain rules, it processes redundant or complementary data information collected by sensors in time and space to obtain a conclusion on the consistency of the measured object[8]. As a single sensor can only provide part of the information of the smart car system, the information obtained at this time is relatively one-sided and the reliability is not high, which will make the control decision accuracy of the smart car itself worse. The multi-sensor information fusion technology can effectively solve these problems and improve the complementarity, credibility and flexibility of the system to some extent.

4.1.1 Multi-sensor information fusion structure

If the multi-sensor information fusion structure is different, the way they process information is also different. According to different processing methods, the multi-sensor information fusion structure is divided into the following four structures[6]: centralized, decentralized, hybrid, and feedback.

Based on the requirements of multi-sensor information processing real-time and fusion accuracy of smart car obstacle avoidance system, this paper adopts a feedback multi-sensor information fusion structure. In the feedback-type information fusion structure, the information received by the information fusion center contains both the original information collected by the sensors and the information that has been fused, and this part of the fused information can express most of the environmental characteristics of the environment. The characteristics have a good guiding effect on the fusion of the original information collected by the sensors at this time. Therefore, it can be concluded that the feedback structure has a good promotion effect on the information fusion processing. The specific fusion structure is shown in Fig. 8.

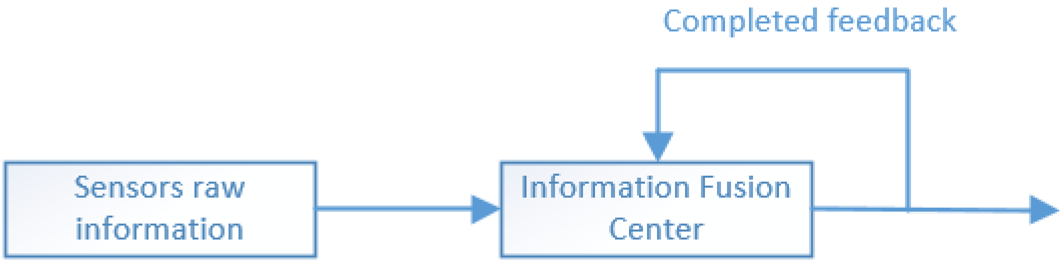


Fig. 8 Hybrid multi-sensor information fusion structure diagram

4.1.2 Multi-sensor information fusion method and implementation

Multi-sensor information fusion method

Smart car obstacle avoidance system is a typical nonlinear system. This paper uses fuzzy logic algorithm to fuse the information collected by multiple sensors. Fuzzy logic does not need to create accurate mathematical models in applications, and can directly convert expert knowledge into control signals[9]. Fuzzy logic will use corresponding models in the application of information fusion technology, which can systematically reflect some information of uncertainty in the data fusion process, and then achieve a perfect fusion of data through a series of reasoning. The specific implementation includes the following four steps: fuzzification of input and output, the design of the fuzzy reasoning, the process of the fuzzy reasoning, and the defuzzification.

Implementation of multi-sensor information fusion

Compared with classical information processing methods, multi-sensor information fusion technology has a more complicated form. Multi-sensor information fusion includes three levels of fusion: data-level fusion, feature-level fusion, and decision-level fusion. Among them, data-level fusion is the low-level fusion in the information fusion process, feature-level fusion is the intermediate-level fusion in the information fusion process, and decision-level fusion is the high-level fusion in the information fusion process.

4.2 Specific fusion method of ultrasonic sensor and vision sensor

The camera used in this research is a monocular vision camera. It can not collect accurate distance information between smart car and obstacles, and can only determine the distribution of obstacles. The ultrasonic sensor belongs to ranging sensor in this paper, which can collect accurate distance between smart car and obstacles. The fuzzy control method is used in the paper to fuse the information collected by the visual sensor and the ultrasonic sensor. The visual sensor can obtain the distribution information of the obstacles and detect the basic characteristics of the obstacles. The distance detected by the ultrasonic sensor is used as the fuzzy logic Input, using smart car obstacle avoidance behaviors as output. Through the integration of ultrasonic sensors and vision sensors, smart car can safely and stably bypass obstacles as well as drive safely to the destination.

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4.3 Fuzzy control system

Fuzzy control is a high-level control strategy based on fuzzy mathematics, using language rules to describe knowledge and experience, combined with advanced computer technology, and using fuzzy reasoning to make decisions.

4.3.1 The composition of fuzzy control system

The fuzzy control system usually consists of five parts: input/output interface, fuzzy controller, actuator, controlled object as well as measurement and feedback device. Among them, see Fig. 9 for the fuzzy controller and Fig. 10 for the schematic diagram of the fuzzy control system.

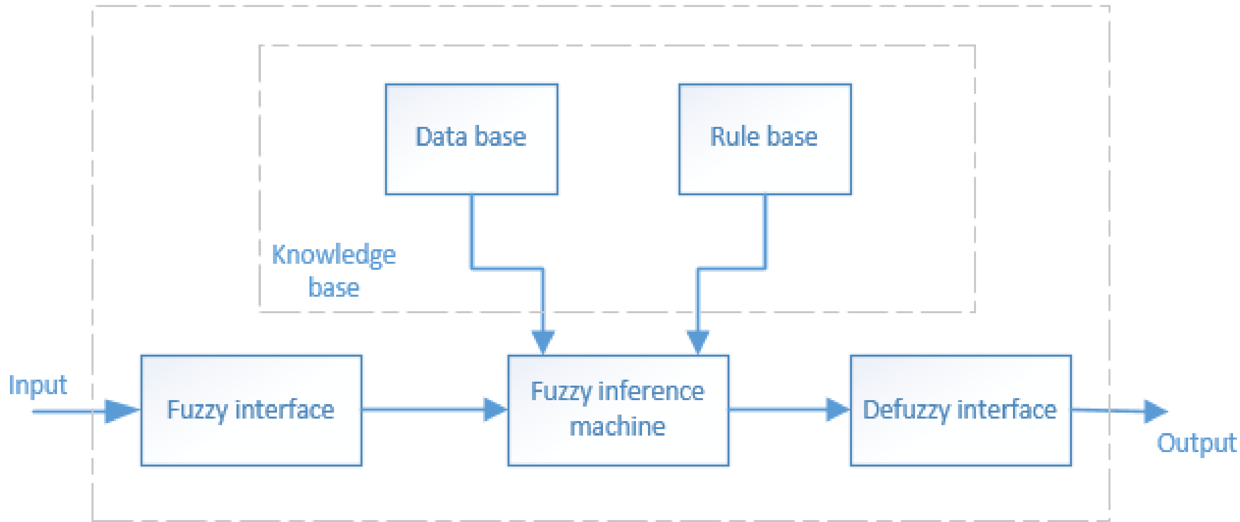

Fig. 9 The composition of fuzzy controller

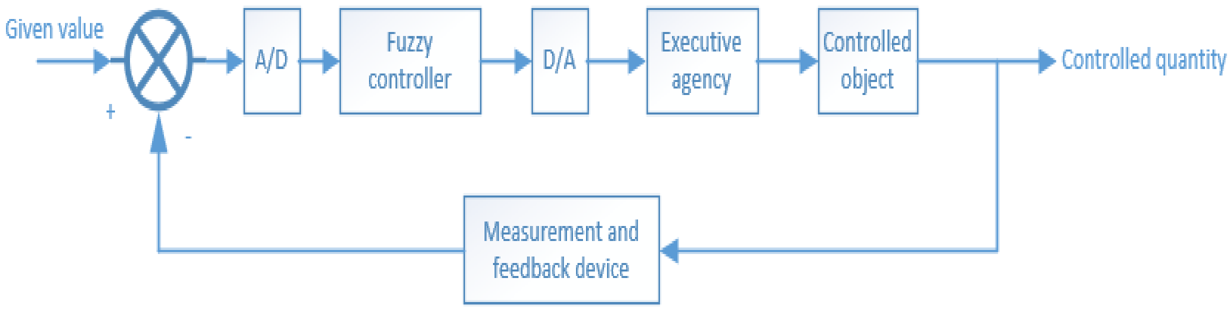

Fig. 10 Schematic diagram of fuzzy control system

4.3.2 Fuzzification steps

The main function of fuzzification is to select the input amount of the fuzzy controller and convert it into the recognizable fuzzy quantity of the system, which specifically includes the following three steps: 1. Process the input quantity to meet the fuzzy control demand; 2. Transform the scale of the input quantity; 3. Determine the fuzzy language value of each input quantity and the corresponding membership function.

4.3.3 Defuzzification

The corresponding fuzzy value is obtained through fuzzy reasoning. This value cannot be directly applied to the controlled object, and the fuzzy control amount needs to be defuzzified to obtain the corresponding accurate control quantity. After the digital-to-analog conversion, the accurate analog quantity is obtained and sent to the actuator, which controls the controlled object. In this process, the controlled quantity will be collected and controlled continuously[10]. This process is called defuzzification. There are many methods for the de-blurring process, and there are currently three methods commonly used: the median decision method, maximum membership method, and the

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weighted average method. As the median decision method is more complicated in calculation, and it lacks sufficient attention to the dominant information provided by the larger membership elements, which makes this method limited in practical application[11]. At the same time, many non-maximum membership elements in the maximum membership method are lost, and the method appears rough, which is only suitable for defuzzification of fuzzy systems with general performance requirements. Therefore, this paper chooses the weighted average method to operate the de-blurring process of the fuzzy control system. The calculation formula is shown in (5):

$$z_0 = \frac{\sum_i^n \mu c'(z_i) z_i}{\sum_i^n \mu c'(z_i)} \tag{5}$$

Compared with the traditional control system, the control system combined with fuzzy control takes less time to reach steady state, and has more stable performance as well as strong anti-interference ability. Therefore, this paper uses fuzzy control in sensor information fusion and smart car obstacle avoidance control.

4.4 Obstacle avoidance behaviors design for smart cars

In real life, we must consider the actual situation to design obstacle avoidance behavior of smart cars. When the types of obstacles are different, the avoidance behavior adopted will also be very different. Based on the classification of obstacles, this paper roughly divides the obstacle avoidance behaviors of smart cars into the following three categories: straight-to-target behavior, direct obstacle avoidance behavior, and emergency obstacle avoidance behavior. The obstacle avoidance workflow of smart cars is shown in Fig. 11.

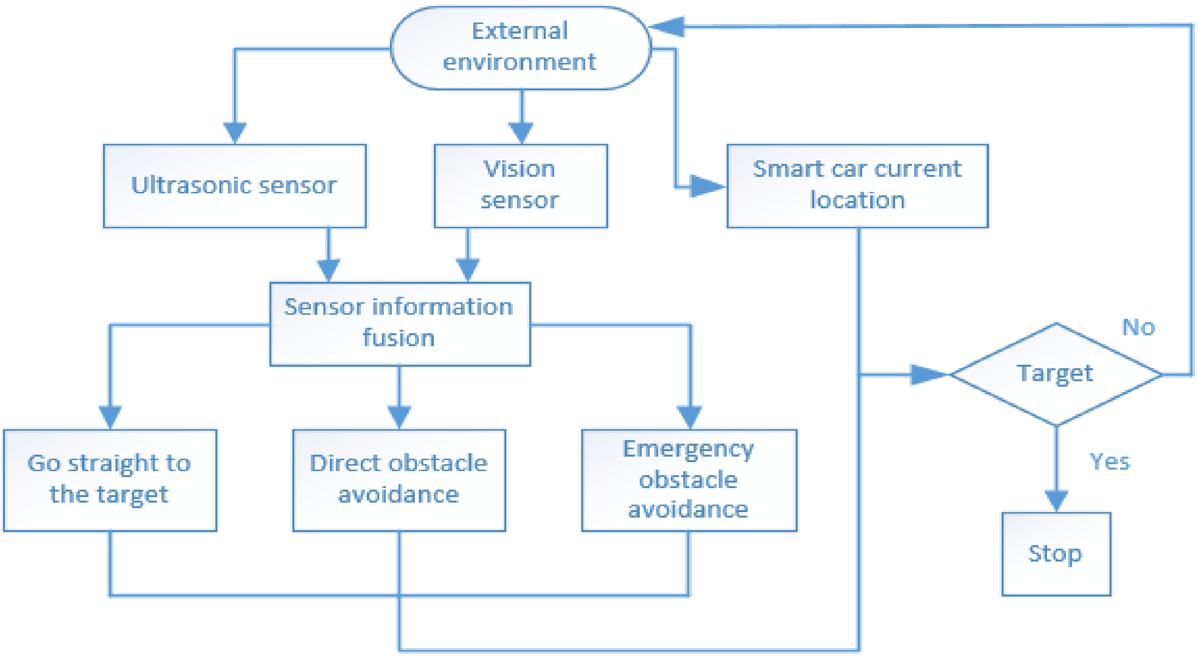

Fig. 11 Smart car obstacle avoidance workflow

4.4.1 Straight-to-target behavior

The basic task of a smart car is to start from the starting point and reach the destination safely. However, many unknown situations may occur during the driving of the car, so different measures need to be taken to deal with these situations. When the smart car is running, if the sensor detects that the road ahead of the smart car is relatively flat and there are no objects that hinder the smart car's travel, then the smart car can go straight to the target point without any action to avoid obstacles.

When there are no obstacles on the road, the driving of smart cars can be regarded as a movement on a two-dimensional plane. Then the next driving direction of the smart car can be determined by the

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angle between the current driving direction of the smart car and the direction from the smart car to the target point. A schematic diagram of the specific driving direction is shown in Fig. 12.

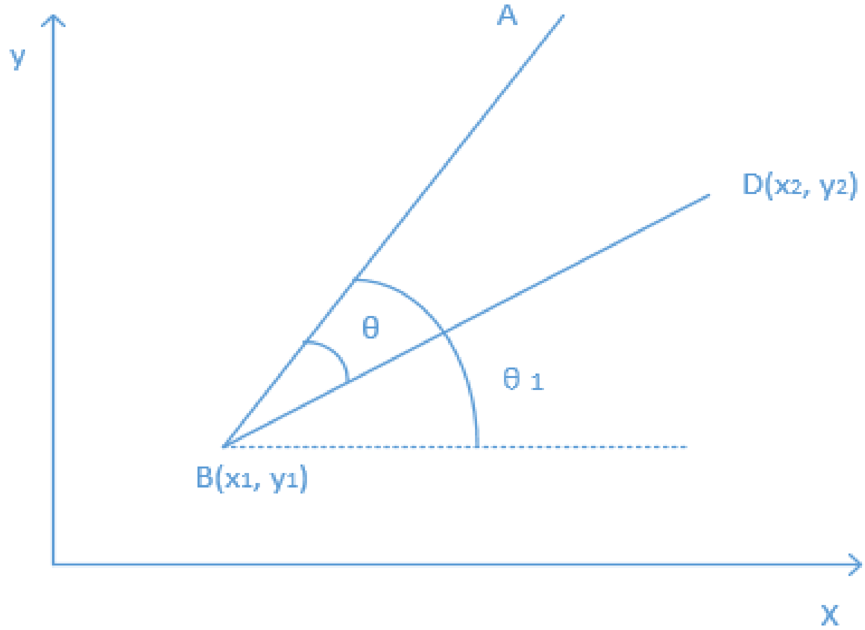

Fig. 12 Driving direction schematic diagram of straight-to-target behavior

The point $B(x_1, y_1)$ in the figure represents the current position of the smart car, the point $D(x_2, y_2)$ represents the coordinates of the target point, B→A represents the driving direction of the smart car, and angle θ_1 represents the angle between the driving direction of the smart car and the x axis, the angle θ represents the angle between the driving direction of the smart car and the direction of the smart car to the target point, that is, the angle between B→A and B→D. The data relation can be obtained as shown in formula (6).

$$\theta = \tan^{-1}\big((y_2 - y_1)/(x_2 - x_1)\big) - \theta_1 \tag{6}$$

Combining formula (6) with Figure 12 leads to the following conclusions:

When $\theta<0$, the smart car turns right, when $\theta>0$, the smart car turns left, and when $\theta=0$, the smart car goes straight. When the smart car goes straight to the target, its next moving direction depends entirely on the angle θ.

4.4.2 Direct obstacle avoidance behavior

If obstacles are detected in front, the smart car needs to make a judgment at this time and change the driving direction. As described above, in the obstacle avoidance process, smart cars obtain obstacle feature information through visual sensors, and ultrasonic sensors measure the distance information between obstacles and the smart car. After the information fusion and processing, the accurate distance value between the obstacle and the smart car is obtained, and then use the detected distance information as the input of the fuzzy controller. After the calculation of the entire fuzzy controller, an accurate output is obtained and sent to the smart car steering controller to control the smart car to avoid obstacles safely. The specific design process is as follows:

First, the smart car vision window is divided into three parts: left front, front right, and right front. Since the design is verified on the smart car platform, achievable range for ultrasonic ranging can be set to [15, 75] cm, and then the three ultrasonic sensors installed in front are divided into three groups. The distance information measured by the sensor in each group is simply fused, and the smallest data in each group is taken as the input for the reorganization. At this time, three groups of data will be obtained, which represent the distance L between the smart car and the obstacle in left front, and the distance F between the smart car and the obstacle in front right, and the distance R between the smart car and the obstacle in right front. When the distance between the smart car and the obstacles in the three directions is same, the smart car cannot determine its driving direction. At this time, the

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distances between the smart car and the obstacles in left front and right front needs to be calculated as an input. Assuming that there are obstacles in front right and the distance difference between the smart car and the obstacles in left front and right front is zero, the smart car turns left by default, which can effectively prevent the situation where the smart car cannot determine its driving direction. Finally, fuzzification is performed.

F refers to the distance information of the obstacle in front, which becomes {FD, MD, ND} after fuzzification, which means far, middle, and near respectively. E refers to the difference distance between the smart car and the obstacles in left front and right front. After fuzzification, it becomes {RF, RM, RN, Z, LN, LM, LF}, which means far right, middle right, near right, zero, near left, middle left, far left respectively. T is the output variable, which refers to the steering angle. After fuzzification, it becomes {TLF, TLM, TLN, TL, TZ, TR, TRN, TRM, TRF}, which means -75 °, -60 °, -45 °,- 30 °, 0 °, 30 °, 45 °, 60 °, 75 °. The resulting fuzzy rule base is shown in Fig. 13.

Steering angle/T		Distance difference/E						
		RF	RM	RH	Z	LF	LM	LN
Obstacle distance ahead/F	FD	TR	TR	TRN	TZ	TL	TL	TLN
	MD	TRN	TRH	TRM	TRM	TLN	TLN	TLM
	ND	TRM	TRM	TRF	TRF	TLM	TLM	TLF

Fig. 13 Input and output fuzzy rule base

It can be seen from Fig. 13 that the output is a fuzzy quantity, and the value needs to be calculated by formula (5) to obtain an accurate quantity to control the next operation of the smart car.

4.4.3 Emergency obstacle avoidance behavior

When a dynamic obstacle suddenly appears, emergency obstacle avoidance behavior is required. The chance of this happening is far less than the direct obstacle avoidance behavior, but once it happens, if the smart car does not make a timely response, it will face inestimable losses.

Therefore, in the research on obstacle avoidance of smart cars, the design of emergency obstacle avoidance behavior is essential. This paper uses a three-frame difference method to detect dynamic obstacles. When the sensor detects a dynamic obstacle appears suddenly in front of the smart car, and it is very close to the smart car, the smart car will take an emergency obstacle avoidance measure, immediately make a braking response, and stop moving forward until the obstacle is away from the safe distance of smart car. At this point, the smart car will restart its journey towards the target point.

4.5 Introduction and improvement of artificial potential field method

Artificial potential field method is one of the algorithms commonly used in obstacle avoidance of smart cars. It is easy to understand and can meet the real-time requirements of obstacle avoidance of smart cars. It has been widely used in the research of smart car technology.

4.5.1 Introduction to artificial potential field method

The traditional artificial potential field method needs to construct an artificial virtual potential field in the environmental space[12]. Among them, there is a virtual attraction between the smart car and the target point, and a virtual repulsion between the smart car and the obstacle[13]. This algorithm abstracts attraction and repulsion into two functions, attraction function and repulsion function. The attraction function is derived from the force of the target point to the smart car, and the direction is that the smart car is pointing to the destination; the repulsion function is derived from the force of the obstacle to the smart car, the direction is that the obstacle is pointing to the smart car. The final direction of the smart car is the direction pointed by the combined force of attraction and repulsion, as shown in Fig. 14.

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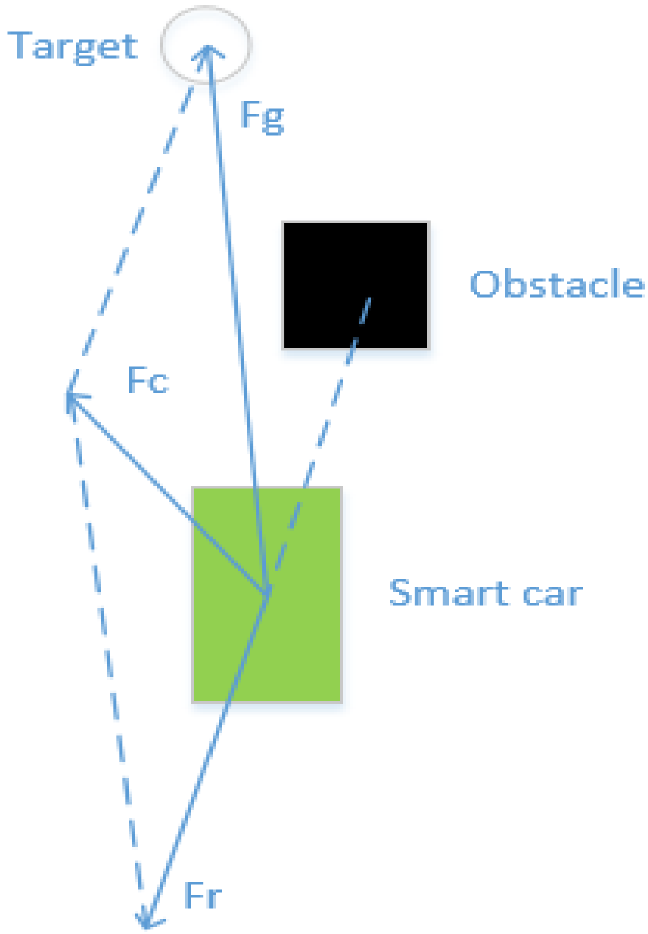

Fig. 14 Synthetic diagram of traditional artificial potential field method

1) Attraction function

The attraction function is set on the basis of the Euclidean distance between the smart car and the target point. The size of the attraction F_g depends on the distance D between the smart car and the target point. When D is larger, the F_g is larger; conversely, when D is smaller, the F_g is correspondingly smaller. Until D is zero, the size of the F_g also becomes zero, and the entire operation process ends. The computational formula of the attraction function is as follows:

$$F_g = K|X - X_A| \tag{7}$$

Among them, K is the proportionality coefficient of the attraction function, and X and X_A are the vector coordinates of the smart car and the target point respectively.

2) Repulsion function

In the repulsion field, obstacles have a repulsive effect on the smart car, and the size of the repulsionF_r depends on the distance d between the smart car and the obstacle. When d is larger, F_r is smaller; conversely, when d is smaller, F_r is larger. The computational formula of the repulsion function is as follows:

$$F_r = \begin{cases} K\left(\frac{1}{\rho(q,q_0)} - \frac{1}{\rho_0}\right)\frac{1}{\rho^2(q,q_0)}\nabla\rho(q,q_0) & 0 \le \rho(q,q_0) \le \rho_0 \\ 0 & \rho(q,q_0) > \rho_0 \end{cases} \tag{8}$$

Where K is the proportionality coefficient of the repulsion function, q and q_0 represent the position of the smart car and the obstacle in the environmental information respectively. $\rho(q,q_0)$ represents the vector of the shortest Euclidean distance between the smart car and the obstacle, and ρ_0 represents the influence distance of the obstacle on the smart car, which is a constant. When the obstacles are arranged regularly, the traditional artificial potential field method can normally

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complete obstacle avoidance operations, to make the smart car bypass the obstacles and reach the destination safely. The simulation result at this time is shown in Fig. 15.

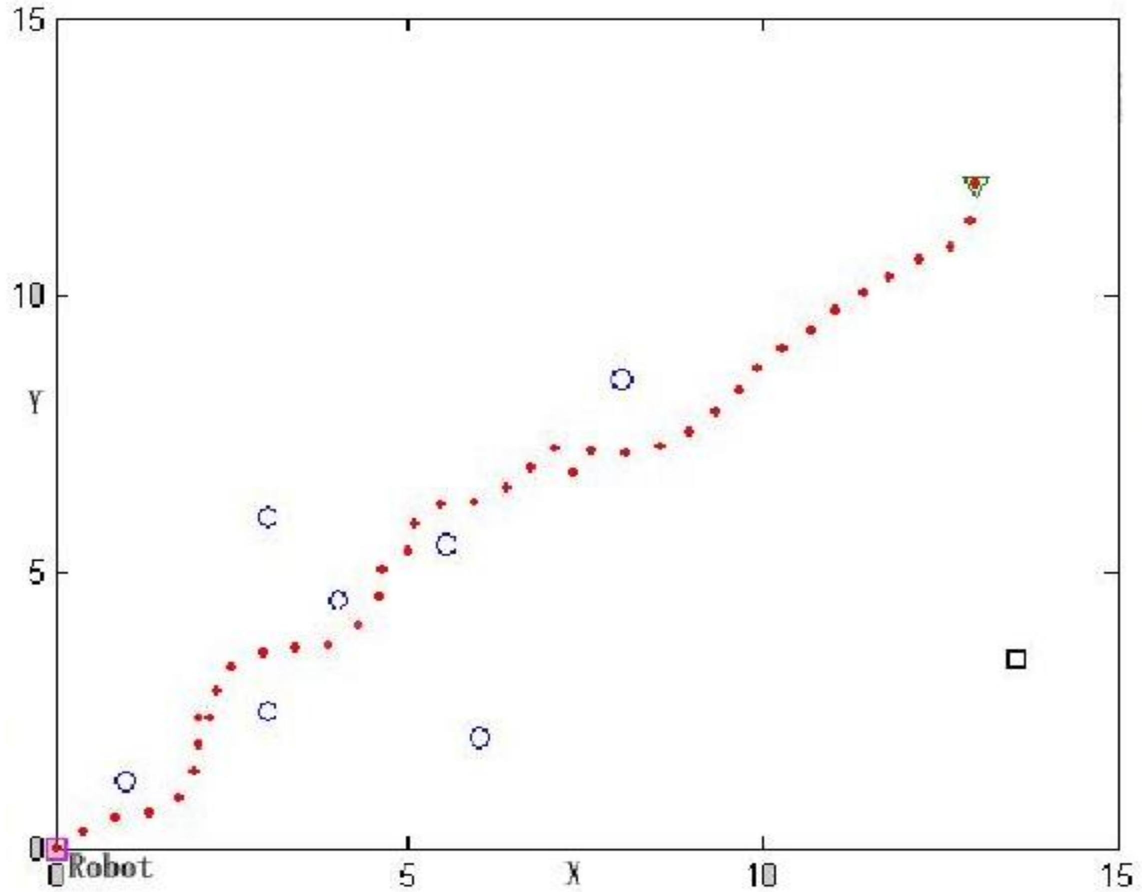

Fig. 15 Simulation result of traditional artificial potential field method

The traditional artificial potential field method often results in a situation where the resultant force is zero in the obstacle avoidance process of the smart car. When these situations occur, the smart car will stop running or swing left and right, and cannot run normally. This is often referred to as the state of zero potential energy. Then the traditional artificial potential field method is improved to solve this problem

4.5.2 Improved artificial potential field method and simulation analysis

When the obstacles are dense, it is easy to appear zero potential energy state. Through simulation verification analysis, it was found that there are two ways to improve the zero potential energy state: when the number of obstacles is small and the arrangement is dense, you can exclude the fastest distance obstacles through calculation, and a new resultant force appears. So that the smart car can move along the new resultant force direction to escape the zero potential energy domain; when the number of obstacles is large and the arrangement is dense, it is easy for an smart car to escape from a zero potential energy domain and then fall into another zero potential energy domain, at this time, a combination of algorithms is needed to allow the car to continue to run. In this case, this paper adopts a method combining improved artificial potential field method and fuzzy control algorithm.

When the number of obstacles is small and the arrangement is dense, if there is a state of zero potential energy, if the traditional artificial potential field method is still used to avoid obstacles, the smart car will not run normally. The simulation result is shown in Fig. 16. At this time, if an improved artificial potential field method is used to avoid obstacles, that is, to remove an obstacle at the farthest distance, a new resultant force appears, so that the smart car can move along the new resultant force direction. At this time, the smart car can avoid obstacles safely and proceed towards the target point. The simulation result is shown in Fig. 17.

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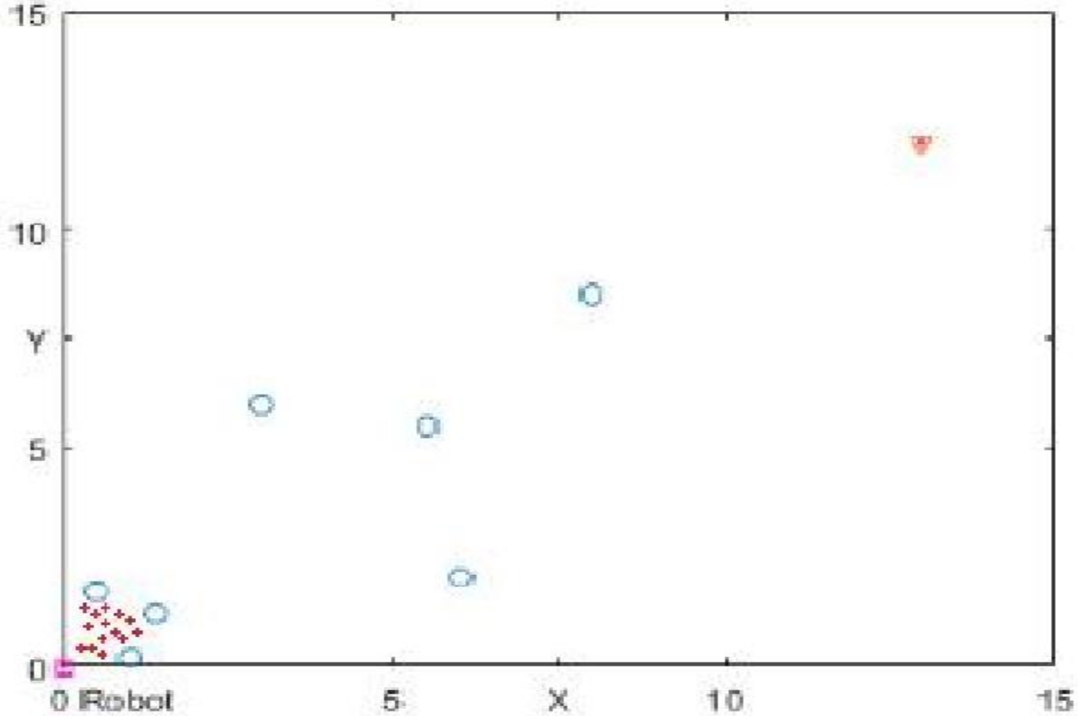

Fig. 16 Simulation result of traditional artificial potential field method

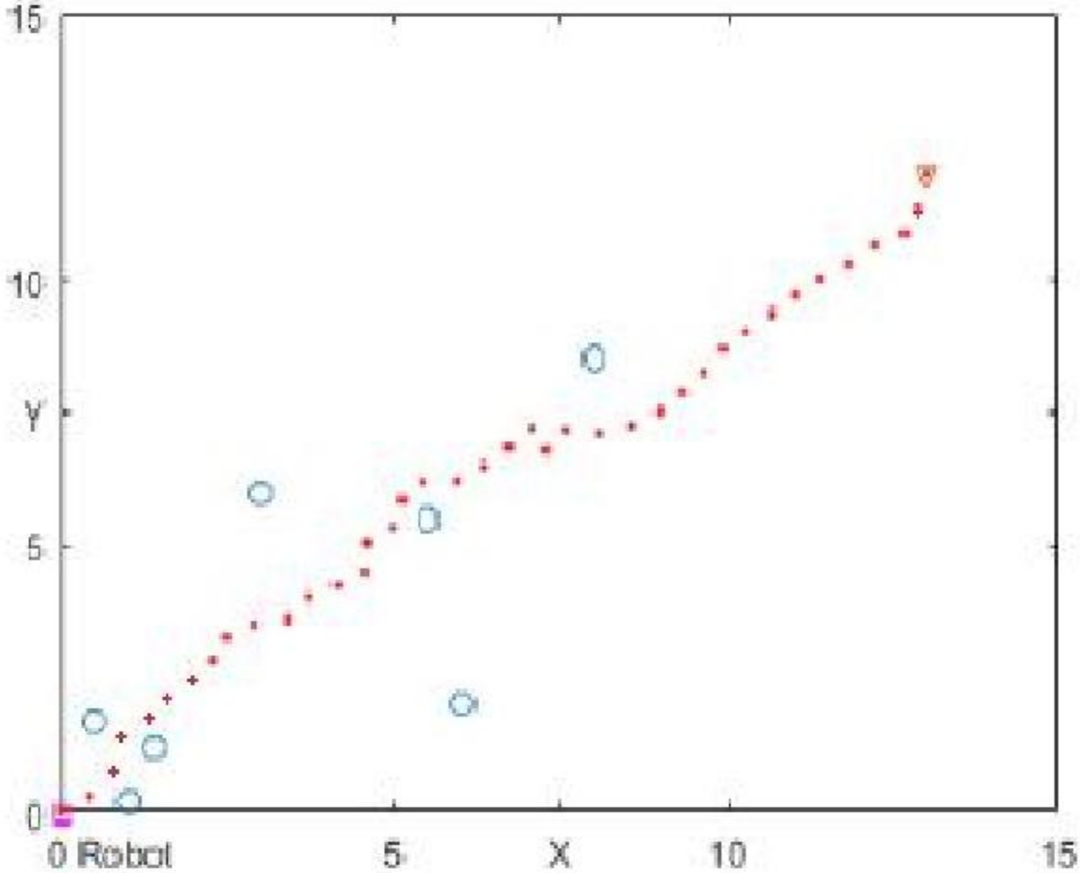

Fig. 17 Simulation result of improved artificial potential field method

When the number of obstacles is large and the arrangement is dense, when the improved artificial potential field method is used for simulation, it will happen that the smart car directly passes through the obstacles, resulting in failure to avoid obstacles. Specific simulation result is shown in Fig. 18.

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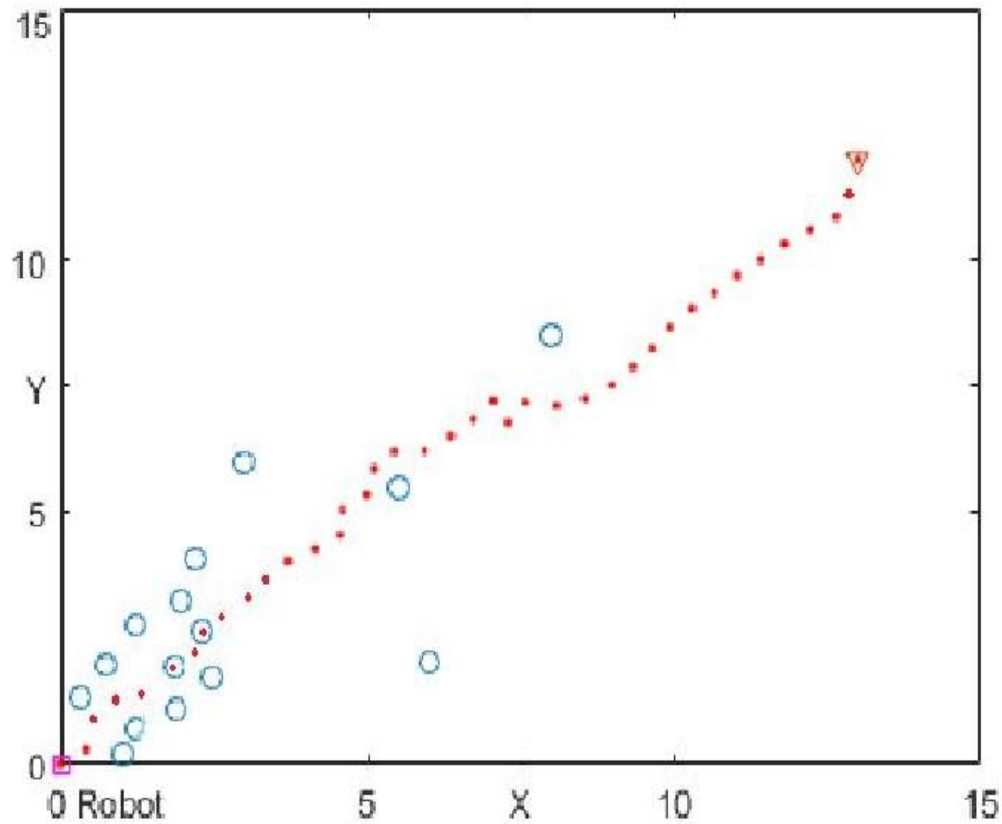

Fig. 18 Simulation result of improved artificial potential field method when obstacles are dense

Based on the above simulation results, this paper use the combination of algorithms to perform the following simulation, that is, when the number of obstacles is large and the arrangement is dense, the smart car will switch from the improved artificial potential field method to the fuzzy control algorithm to avoid obstacles. It can be seen from the simulation result that the smart car can avoid obstacles well and reach the target point safely. The specific simulation result is shown in Fig. 19.

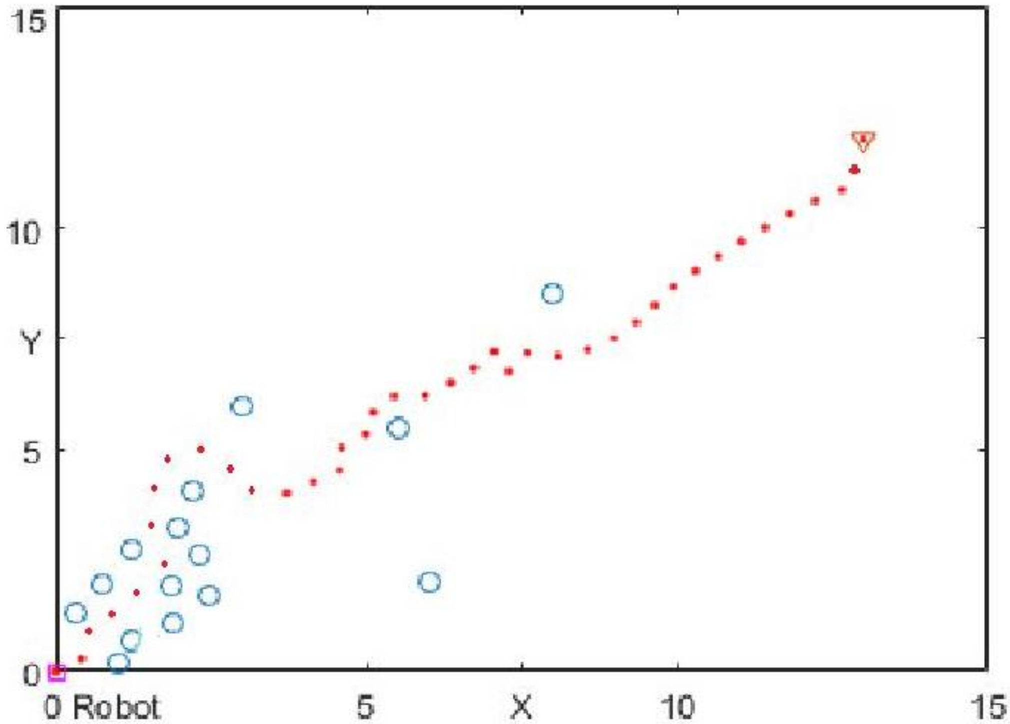

Fig. 19 Simulation result of the combination of improved artificial potential field method and fuzzy control algorithm

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5. Conclusion

This paper introduces the ultrasonic sensor, vision sensor, and data acquisition method firstly, then describes the entire process of image processing, introduces the methods and principles selected for image processing. Finally, example is given to demonstrate the entire process of image processing, which provides technical support for subsequent research on obstacle avoidance of smart cars. Then it introduces the multi-sensor information fusion technology and the related content of fuzzy control in detail, and uses the fuzzy control method to fuse the information collected by the ultrasonic sensors and the vision sensors. Based on the obstacle avoidance of smart cars, three obstacle avoidance behaviors of smart cars are designed, which are straight-to-target behavior, direct obstacle avoidance behavior and emergency obstacle avoidance behavior. When the number of obstacles is large and the arrangement is dense, the improved artificial potential field method cannot achieve normal obstacle avoidance of smart cars. Based on this, this paper proposes a method combining the improved artificial potential field method and fuzzy control algorithm. That is, when the number of obstacles is large and the arrangement is dense, the smart car will switch from the improved artificial potential field method to the fuzzy control algorithm to avoid obstacles. According to Matlab simulation, the validity of the smart car obstacle avoidance system proposed in this paper is verified. The simulation result shows that the combination of improved artificial potential field method and fuzzy control algorithm can make the smart car avoid obstacles smoothly and reach the destination safely when the number of obstacles is large and the arrangement is dense.

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