Design of Intelligent Shopping Cart for Supermarket

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Abstract. With the development of science and technology and the continuous improvement of people's living standards, the demand for intelligent service equipment is increasing. In view of the supermarket environment, this paper explores the intelligent automatic following shopping cart. The idea is based on high-performance vehicle motor equipment, through the combination of ultrasonic detection technology, infrared detection technology, mobile Bluetooth technology, and other detection technologies, by the control module (TMS320F2812 chip) processing detection signal, through SLAM algorithm analysis, to achieve intelligent evasion and automatic follow. Through simulation and experimental analysis, the idea can realize the function of intelligent following shopping cart.

1. Introduction

With the development of science and technology and the Intelligentization of life, the demand for intelligent automatic following car suitable for the family living and working environment is increasing. Aiming for the special environment of the supermarket, this paper explores the intelligent auto-following shopping cart. Based on the high-performance vehicle motor device, the shopping cart will analyze the detected pedestrians and objects by algorithm through the combination of ultrasonic detection technology, infrared detection technology, mobile Bluetooth technology, and other detection technologies. Products and other shopping carts, to achieve automatic evasion and automatically follow, so as to achieve intelligent follow shopping cart function. Intelligent following shopping cart can also display the goods in the car, realize intelligent checking weight and pricing, and according to the data mining algorithm, provide targeted advertising for consumers, saving users time. In general, smart cars have a very large business prospect [1]-[2].

2. System principle design

The main workflow of the system includes as follows: the user first looks for the authentication auto-following car according to the APP or the Wechat program, through the QR code unlocking authentication, during which the mobile phone maintains the Bluetooth, the flow, the WiFi opening; the car in the normal running, braking good foundation, looking for the user launch Bluetooth information. In the part of Positioning, the car according to the original training data and Bluetooth positioning data, determine the basic orientation of the user. Then the car emitted ultrasonic signals for
specific detection, the same local area between the car to maintain communication, the car began to run, infrared signals will detect unexpected situations and avoided or parking, such as unexpected circumstances. Judging road conditions, the car can calculate the obstacle avoidance algorithm by collecting the information, so as to ensure the stable operation of the car and realize the function of auto-following shopping [3]. Therefore, the principle of the system is mainly divided into the positioning part, the power part, and the algorithm part. The overall service flow is shown in the Figure 1.

![Figure 1. Overall flow chart](image)

2.1. Positioning technology

Based on the complex environment in supermarkets, a single positioning technology may be defective [4]. Car system uses three kinds of positioning technology to coordinate: Bluetooth signal positioning shopping cart and user's distance and general orientation, ultrasonic positioning to detect the surrounding environment information, infrared positioning to detect unexpected situations, shopping cart. The information will be integrated and processed to ensure the normal operation of the shopping cart.

2.1.1. Bluetooth signal positioning. At present, mobile payment and intelligent unlocking are very popular in China [5]. Intelligent following shopping cart system also uses intelligent unlocking methods such as APP and small program. When the mobile phone is connected to the car by the network, the system will prompt the user to call the driver of the electronic magnetic compass of the mobile phone's own hardware to get the orientation information of the current mobile phone, and then send the orientation information of the mobile phone through Bluetooth. When the Bluetooth serial port of the car receives the orientation information of the mobile phone, the car receives and processes the orientation information. The controller adjusts its steering in time by calculating and controlling
the steering gear through the regulator, and then through ultrasonic positioning, realizes more accurate path following.

2.1.2. **Ultrasonic positioning.** There are three main ultrasonic positioning methods. In the process of measurement, different media will have a greater impact on the accuracy of measurement. The supermarket environment is complex and there are many commodities. Therefore, the acoustic amplitude detection method is not suitable for it [6]. The transit time detection method, also known as the round trip time detection method, is based on the principle of sound propagation time to determine the distance, technology is relatively mature, and has been widely used in practice. Ultrasound positioning used in intelligent following shopping cart is the first Bluetooth positioning and then the detection, so the stability is more important, we choose the transit time detection method.

2.1.3. **Infrared positioning.** Infrared positioning is a perfect and efficient technology [7]. Car system uses infrared technology as an auxiliary detection technology to deal with the sudden stop of pedestrians shopping and other emergencies. Similar to ultrasonic positioning, infrared positioning still considers the relationship between distance and time, but based on the difference between the speed of light and sound, infrared positioning is faster, the car through infrared positioning will be faster to make a judgment. However, infrared positioning is easy to be affected by the environment, so it is used as an auxiliary positioning method.

2.2. **Car power system**

2.2.1. **Motor drive module.** The power system is an important part of auto-following shopping cart system. Taking into account the special environment of supermarkets, as well as braking requirements, the intelligent shopping cart system selects DC motor. The shortcoming of DC motor is that it has rectifier brush and is not suitable for high-speed and high-torque operation, but it seldom has high speed in the supermarket environment, and its start-up and speed regulation performance is good, overload ability is strong, anti-interference ability is strong, suitable for the environment required by the system.

2.2.2. **The Principle of PWM voltage regulation and speed regulation of DC motor.** PWM wave is a common control method of the control system. It is easy to produce, simple to adjust and has a wide range of application. PWM wave regulation is to adjust the pulse bandwidth by setting duty cycle, adjust and set the voltage through the DC motor, or even reverse, to achieve motor control. This system adopts the method of fixed frequency and width modulation to adjust PWM wave, as shown in the Figure 2. This method is simple in principle and mature in technology. It means that the period $T$ (or frequency) is set to a fixed value, and the duty cycle $\alpha$ is adjusted by changing the parameters of $T_1$ and $T_2$.

![Figure 2](image-url). The waveform of voltage on the armature winding of the DC motor varies with the input voltage.
The analysis shows that, in a period $T$, the average voltage $U$ of armature winding of DC current motor is:

$$U = \frac{T_1 U_1}{T_1 + T_2} = \frac{T_1}{T} U, = \alpha U,$$

(1)

$\alpha$ is Duty cycle, $\alpha = \frac{T_1}{T}, 0 \leq \alpha \leq 1$.

2.2.3. **Motor drive speed regulation module.** In the supermarket environment, the automatic shopping cart will adjust and transform according to the user's footsteps, and the DC motor will carry on the corresponding positive and negative conversion. The system adopts H-type bipolar reversible drive speed control module based on the Darlington tube to adjust and transform. As shown in Figure 3, the H-type bipolar reversible drive speed control module based on the Darlington tube is composed of two completely symmetrical parts. As shown in the Figure 3, the speed and direction of the motor can be regulated precisely by PWM wave modulation. When CON1 input high level, Q1, Q2, Q4, Q8, and Q10 tube conduction, Q3, Q5, Q6, Q7, and Q9 tube cut-off, motor forward rotation. When CON1 input low level, Q3, Q5, Q6, Q7, and Q9 tube conduction, Q1, Q2, Q4, Q8, and Q10 tube cut-off, motor reversal. The circuit design of 4 diodes and 4 inductors can also play a protective role in level conversion.

![Circuit diagram of H PWM](image)

**Figure 3.** Circuit diagram of H PWM

2.3. **Algorithm design**

After obtaining the detection information, the intelligent shopping cart will adjust the power module through algorithm analysis to realize the intelligent following. The basic idea of SLAM (Simultaneous Localization and Mapping) algorithm is to learn the environment map through the movement and measurement of the experimental point in an unknown environment, and determine the location of the experimental point itself in the map\[^8\]. Through repeated training, the test point can be automatically followed. Supermarket environment is relatively fixed, the intelligent shopping cart can learn through the machine, determine its own location, and judge the distance between users, other pedestrians and articles, path planning. Random SLAM algorithm stores the location of the car and the labels in the graph in a single state vector, and estimates the state parameters by recursive prediction and update stages. In the prediction stage, incremental trajectory estimation is used to process the information of...
car motion and estimate the uncertainty of car position. Once the characteristics of the Map store are checked again, the update phase is started to change the overall state. For better data analysis, the SLAM algorithm defines the car state, position parameters relative to the reference Cartesian coordinate system, by means of mean and covariance:

\[ \hat{X}_\delta = [\hat{x}_\delta, \hat{y}_\delta, \hat{\phi}_\delta]^T \]  

(2)

\[ P_v = \begin{bmatrix} \delta^2_{x,x} & \delta^2_{x,y} & \delta^2_{x,\phi} \\ \delta^2_{y,x} & \delta^2_{y,y} & \delta^2_{y,\phi} \\ \delta^2_{\phi,x} & \delta^2_{\phi,y} & \delta^2_{\phi,\phi} \end{bmatrix} \]  

(3)

The covariance matrix of a graph \( P_m \) contains cross-correlation information (i.e. non-diagonal terms) between features, which represents the dependence of each feature on other features in Map. Because the location of features is static, the cross-correlation between features will be enhanced with the secondary detection of features. The features in the graph can be expressed as follows:

\[ \hat{X}_m = [\hat{x}_1, \hat{y}_1, \ldots, \hat{x}_n, \hat{y}_n]^T \]  

(4)

\[ P_m = \begin{bmatrix} \delta^2_{x_1,x_1} & \delta^2_{x_1,y_1} & \ldots & \delta^2_{x_1,x_n} & \delta^2_{x_1,y_n} \\ \delta^2_{y_1,x_1} & \delta^2_{y_1,y_1} & \ldots & \delta^2_{y_1,x_n} & \delta^2_{y_1,y_n} \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ \delta^2_{x_n,x_1} & \delta^2_{x_n,y_1} & \ldots & \delta^2_{x_n,x_n} & \delta^2_{x_n,y_n} \\ \delta^2_{y_n,x_1} & \delta^2_{y_n,y_1} & \ldots & \delta^2_{y_n,x_n} & \delta^2_{y_n,y_n} \end{bmatrix} \]  

(5)

The algorithm estimates the motion of the car relative to the previous position according to the trajectory, changes the part of the state vector \( \hat{X}_v \), \( P_v \) and \( P_{vn} \) in the state covariance matrix, but does not change the relevant terms of \( \hat{x}_m \) and \( P_m \) in the graph. The algorithm estimates the position change \( \hat{X}_\delta = [\hat{x}_\delta, \hat{y}_\delta, \hat{\phi}_\delta]^T \) and covariance \( P_\delta \) of the car by its own location and trajectory change and finds out the relative position relationship between the sequences in each signal detection by batch data association algorithm, the change process is shown in the Figure 4.

![Figure 4. Position change chart of the trolley](image)

Therefore, the enhanced state of prediction can be expressed as
In the Jacoby matrix are:

\[
\begin{bmatrix}
\hat{x}_v + x_\delta \cos \phi_v - y_\delta \sin \phi_v \\
y_v + x_\delta \sin \phi_v + y_\delta \cos \phi_v \\
\phi_v + \phi_\delta
\end{bmatrix}
\]

\[P_a = \nabla f_{x_a} P_a \nabla f_{x_a}^T + \nabla f_{x_a} P_\delta \nabla f_{x_a}^T \tag{7}\]

Among them, the definition of \(\nabla f_{x_\delta}\) and \(\nabla f_{x_\delta}\) in the Jacoby matrix are:

\[
\nabla f_{x_\delta} = \frac{\partial f}{\partial x_\delta} \bigg|_{(x_\delta, x_\delta)} = \begin{bmatrix}
\nabla g_{x_\delta} \\
0^T \\
I_m
\end{bmatrix}
\]

\[
\nabla f_{x_\delta} = \frac{\partial f}{\partial x_\delta} \bigg|_{(x_\delta, x_\delta)} = \begin{bmatrix}
\nabla g_{x_\delta}
\end{bmatrix}^T
\]

The definition of \(\nabla g_{x_\delta}\) and \(\nabla g_{x_\delta}\) in the Jacoby matrix are:

\[
\nabla g_{x_\delta} = \frac{\partial g}{\partial x_\delta} \bigg|_{(x_\delta, x_\delta)} = \begin{bmatrix}
1 & 0 & -x_\delta \sin \phi_v - y_\delta \cos \phi_v \\
0 & 1 & x_\delta \cos \phi_v - y_\delta \sin \phi_v \\
0 & 0 & 1
\end{bmatrix}
\]

\[
\nabla g_{x_\delta} = \frac{\partial g}{\partial x_\delta} \bigg|_{(x_\delta, x_\delta)} = \begin{bmatrix}
\cos \phi_v & -\sin \phi_v & 0 \\
\sin \phi_v & \cos \phi_v & 0 \\
0 & 0 & 1
\end{bmatrix}
\]

Since the Jacobian matrix only affects the covariance matrix \(P_a\) and the corresponding cross-correlation \(P_{erm}\) of the car, equation (7) can be expressed as follows:

\[
P_a = \begin{bmatrix}
\nabla g_{x_\delta} P_a \nabla g_{x_\delta}^T + \nabla g_{x_\delta} P_\delta \nabla g_{x_\delta}^T & \nabla g_{x_\delta} P_{erm} \\
(\nabla g_{x_\delta} P_{erm})^T & P_m
\end{bmatrix}
\]

The SLAM algorithm considers four key issues: map representation, information perception, data association, location, and composition. Combining with the special environment of the supermarket, the car can predict the early warning behavior of pedestrians’ route and measure the speed to avoid a collision. At the same time, a server can be designed in a supermarket or region, and the route prediction between cars can be realized. While ensuring the safety of the cars, the information can also be transmitted to achieve a wide range of high-precision algorithm prediction, so as to achieve intelligent follow.

3. The specific design and implementation of the system

3.1. An overview of system modules

The whole structure of the car adopts four-wheel differential steering. The rear wheel is driven by two independent motors and the front wheel is two universal wheels. The overall structure of the car body
is relatively simple, mainly composed of the control system, frame, armrest, ultrasonic device, the infrared detection device, battery, DC motor, universal wheel and drive wheel. For the supermarket environment, the car travels slowly. What’s more, for better safety, the car will be designed around pads, and take full waterproof into account. According to the function, the system can be divided into the control module, power module, positioning module, and driving module.

3.2. Control module
The system control module uses the TMS320F2812 chip to realize the functions of signal reception, positioning information processing, and system control. TMS320F2812 chip is a 32-bit fixed-point micro-control unit (MCU), with I2C, SPI, CAN, PWM and other bus interfaces, developed by TI (Texas Instruments) Company, USA, suitable for a C2000 platform. TMS320F2812 chip processing performance has 150 MIPS, in line with high and low temperature, vibration testing, suitable for supermarket environment, running clock reached 50 MHz, short instruction cycle, the average cycle is 6.67 ns, with a digital-to-analog conversion serial port. And can expand external memory according to the application situation to achieve different needs of users.

3.3. Power module
In order to realize the normal operation and work of the system, the lithium-ion rechargeable battery is used as the total power supply. The voltage requirements of each module in the system are different. In order to provide the different voltage for each module in the system, the system needs to design the corresponding voltage regulator circuit. The specific power distribution of the system is shown in the Figure 5.

![Figure 5. Power distribution diagram](image)

In this system, switching voltage regulator chooses TPS5430 chip which is used to realize the conversion of voltage to the power supply. TPS5430 chip is a DC / DC switching power supply conversion chip, with under-voltage locking, over-current protection and other functions, can ensure voltage regulation accuracy in transient conditions, to ensure the normal operation of the system. In the aspect of design, the TPS5430 chip can realize high output current PWM conversion, PWM wave transmission can be realized in this system, and the drive circuit wants to match.

3.4. Positioning module
The positioning module consists of a Bluetooth positioning module, an ultrasonic positioning module, and infrared positioning module.

3.4.1. Bluetooth positioning module. Host controller interface is located in the middle layer of the Bluetooth protocol stack, which is the key link to realize Bluetooth communication. Its main function is to provide Bluetooth host controller with interface services for other hardware, such as link controller, a state register, and so on, so as to realize the interaction between control module and hardware. Among them, the link controller can provide Bluetooth baseband function services, provide Bluetooth positioning communication, to meet the requirements of the system. Referring to the protocol specification of HCI (Host Controller Interface) layer of Bluetooth host controller interface,
the system designs a Bluetooth signal processing module controlled by the control module to realize the data transmission between the user and the car and realize the function of position positioning. The car can guide the user precisely, and through the ultrasonic module and infrared module, the next step operation.

3.4.2. The ultrasonic module. The ultrasonic detection module adopts the transit time detection method, which calculates the propagation time of ultrasonic wave in the air through the relationship between speed and time, so as to measure the distance between objects [9]. The ultrasonic transmitter transmits the ultrasonic wave in a predetermined direction, i.e. the user's previous position, and returns when it touches an obstacle. The receiver can calculate the time interval between the two signals when it receives the signal. Then the car through infrared detection, Bluetooth detection to determine whether the user and make the corresponding trajectory adjustment.

The formula of the transit time detection method is as follows: the ultrasonic propagation velocity in the air is fixed as \( V \), and the ultrasonic detection device can record the time. By comparing the time difference between the transmitted and received waves, the distance \( S \) between the transmitting point and the obstacle is calculated.

\[
S = \frac{v \cdot \Delta t}{2}
\]  

(13)

Because ultrasonic wave is a kind of sound wave, the sound wave will be subject to temperature, humidity, pressure changes, in which temperature on the speed of sound is particularly obvious, when the temperature rises by 1 degree Celsius, the same medium sound propagation speed will increase by 0.607 m/s. Supermarket belongs to the indoor environment, the temperature will not change significantly, but considering the difference of environmental temperature in different seasons, in order to ensure accuracy, temperature compensation factor is added. When the ambient temperature is \( T \), the formula of ultrasonic propagation speed \( V \) is:

\[
V = 331.45 + 0.607T
\]  

(14)

The system adopts TCT40-10F1 ultrasonic transducer transmitter and TCT40-10S1 receiver to transmit and receive ultrasonic signals. Their operating frequencies are all near 40KHz and they are compatible with the chip of 38KHz. Therefore, the PWM wave adopted by the main body of the system is 40KHz, which improves the stability of the system and simplifies the system.

3.4.3. Infrared positioning module. The infrared positioning module is composed of two parts: the infrared transmitting tube and infrared receiving head. The infrared transmitter is placed on the car to transmit the infrared signal continuously. If the infrared signal is blocked, the signal will be transmitted to the CX20106A chip and processed by the control module. CX20106A chip can receive ultrasonic and infrared signals, low power demand, low power consumption, high gain, and because the device does not contain any inductance devices, strong anti-interference ability, not affected by electromagnetic fields. The circuit is simple, simple and easy to use, and has better compatibility and reliability. In the system architecture, the system control chip can generate 40 KHz square waves, and then connected with the inverted rectangular wave amplifier to realize the signal processing of the CX20106A chip. At the same time, the signal of the ultrasonic positioning module and the infrared positioning module are similar, which simplifies the complexity of the system design.

3.5. Drive module

50ZY12-25 permanent magnet DC motor is selected for the driving module, and SA60 is used as a driving circuit control chip. SA60 chip is a reliable PWM power output chip. It is a power output chip developed by an American company for realizing full bridge power output of medium and small DC motors. SA60 chip can realize full bridge power drive of DC motor by a simple external circuit. Its rated power is 15W, rated voltage is 12V, the maximum supply voltage is 80V, the rated speed is 3000rpm, efficiency is up to 90%, continuous load input current is 10A. The SA60 chip can simulate the direction and amplitude of the car in the case of 2D according to the PWM signal sent by the
control module, so it can control the car accurately and adapt to the complex environment of the supermarket. By the way of controlling the wheels with a single-chip microcomputer, the inertia impulse can be reduced as much as possible and the braking ability of the car can be increased when the sudden situation is detected.

4. Conclusion
The validation experiment of the system design is carried out, and the working condition of the combination of the driving module and the positioning module is analyzed. First of all, through SLAM algorithm learning, training the car with machine learning in the supermarket environment, to familiar with the supermarket environment. The maneuverability of the trolley is verified, with the emphasis on the accuracy of its motion. Considering the environment in the supermarket, the distance is relatively close. Accuracies verify by experimental results. The experimental results of the car are shown in Table 1.

|   | Setting mileage | Record mileage | Actual mileage | Travel time | Actual speed |
|---|----------------|----------------|----------------|-------------|--------------|
| 1 | 9.00M          | 9.03M          | 9.00M          | 10.12S      | 0.90M/S      |
| 2 | 7.00M          | 7.03M          | 7.01M          | 7.78S       | 0.90M/S      |
| 3 | 5.00M          | 5.03M          | 5.00M          | 5.56M       | 0.91M/S      |

Then, it starts to simulate the whole process of user use. We use xampp, PHP and MySQL environment to develop the running service system of the smart car using PHP language. And we use the VUE environment to configure the corresponding WeChat client. The user opens the service with the mobile phone, simulates the entire experimental process, and completes the simulation experiment. Through the specific experimental analysis, the car can explore the changes in the surrounding environment in real time through the combination of three detection methods, and adjust the operation of the car accordingly. According to the SLAM algorithm analysis, to meet the requirements of the system, verify the design ideas of the system.

This paper designs an intelligent follow-up shopping cart system based on the supermarket environment and the current mainstream technology. Three positioning technologies are used to cooperate with each other. Through the analysis of the SLAM algorithm, obstacles are distinguished. SA60 chip and Hall sensor are used to realize the precise control of the cart, and to deal with different situations. Therefore, the intelligent following shopping cart system is reliable, efficient, functional, and has a great commercial development prospect. The main feature of this paper is that the system design adopts the method of compound detection, which combines the technology of machine learning in the process of obstacle avoidance. In order to improve the accuracy of detection, this paper speculates that there will be more application scenarios for future composite detection technology. Artificial intelligence and data mining are the hot technologies in the current computer field. Integrating data mining and analysis into supermarket smart shopping carts will provide users with more humanized services while better reflecting the value of products. With machine learning technology, the car's obstacle avoidance algorithm will be more accurate. Compared with the design proposed in this paper, the idea provided in this paper is more valuable.

The following studies will be carried out in the future.
- The combination of the three positioning techniques will greatly improve the positioning accuracy, but the positioning time will be prolonged, and even reduce the accuracy of the algorithm. At the same time, there are also conflicts between positioning information, this paper will continue to study this aspect in the future.
- Safety is a very important factor. At present, there is still room to improve the accuracy of the intelligent follow-up shopping cart system designed by this system. The algorithm design will also take human safety as the first priority, and the mobility of the cart can be further optimized.
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