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STM32-Based Bluetooth-Controlled Smart Car: Tracking and Obstacle Avoidance for 'Last Twenty Meters' Delivery

Yashi Zhu*

Computer Science and Technology, Changsha University, Changsha, Hunan, 410000, China
* **Corresponding author Email:** liyuhuoshui@gmail.com

Abstract: This paper introduces the design and implementation of an intelligent tracking car based on STM32 micro-controller, aiming to provide a low-cost and efficient solution to deal with the challenge of "last twenty meters" distribution in the logistics industry. The system integrates a variety of sensors to realize autonomous movement in complex environment, with intelligent obstacle avoidance, tracking and Bluetooth control functions. By optimizing the hardware cost and simplifying the design, the project has demonstrated significant application value in the field of intelligent logistics, especially the practical application potential in short-distance automatic distribution.

Keywords: Intelligent car; Intelligent tracking; STM32F407; Intelligent logistics; The last twenty meters.

1. Introduction

With the rise of online shopping, the logistics industry has undergone revolutionary changes, and there is an urgent need for fast, efficient and affordable distribution solutions. At present, solving the "last 20 meters" transportation distance from Cainiao Station to the doorstep has become the focus of the logistics industry. Traditional delivery methods are less efficient at this distance, and the cost is higher. In order to meet this challenge, it is particularly important to develop a low-cost and efficient intelligent tracking car.

Based on STM32 single chip microcomputer, this project aims to design and implement an intelligent car that can move autonomously in a complex environment. The car integrates a variety of sensors, has intelligent obstacle avoidance, tracking and Bluetooth control functions, and can provide a cost-effective solution in short distance distribution. By reducing hardware costs and simplifying system design, we aim to achieve an intelligent car that meets the needs of practical application scenarios and provides support for the further development of intelligent logistics systems. In this paper, the design and implementation of the system will be introduced in detail, and its potential in practical applications will be discussed.

2. Literature review

Previous research has made significant progress in the field of autonomous vehicle navigation, especially in sensor integration and control algorithms.[1]

However, these studies tended to focus on high-cost solutions, limiting their popularity in practical applications. Many existing systems are difficult to popularize in cost-sensitive application scenarios due to complex hardware and software requirements.

The advantage of this research is that through the use of STM32 micro-controller and cost-effective sensor technology, a low-cost solution is provided, which is suitable for application in practical logistics scenarios. Our system is not only cost-competitive, but also demonstrates good practicability and reliability in solving the "last twenty meters" distribution problem. This design, which combines low cost and efficient performance, offers new possibilities in the field of intelligent logistics.

3. Research methods

3.1. Overall design of the system

The overall design of intelligent tracking car system based on STM32 includes four main modules: total control module, infrared tracking obstacle avoidance module, DC motor module and Bluetooth control module.

The total control module uses STM32F407 single chip microcomputer, which is responsible for coordinating the work of each module. Infrared tracking and obstacle avoidance module obtains path and obstacle information through infrared sensor to realize automatic tracking and obstacle avoidance function. The DC motor module drives the movement of the car according to the path planning, and controls its speed and direction. The Bluetooth control module allows users to remotely control the car through smart devices, enabling manual control and status monitoring.

Figure 1 shows the System block diagram. The system design pays attention to the cooperative work between modules to ensure the stable operation of the car in a complex environment, with autonomy and flexibility.[2]

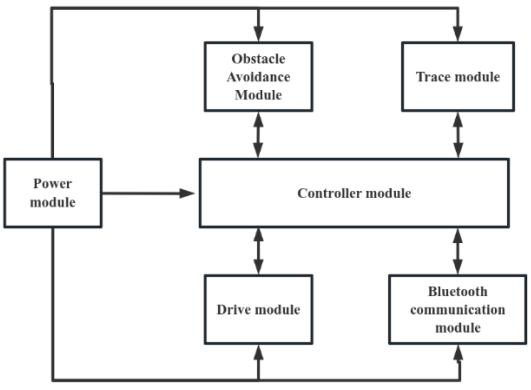


Figure 1. System block diagram.

3.2. System workflow design

After the system is started, the STM32 micro-controller conducts self-test and initializes the sensor and Bluetooth module. After entering the standby state, the user selects the automatic tracking obstacle avoidance or manual remote control mode through Bluetooth.

In the automatic mode, the car continuously collects data through the infrared sensor to judge the path and detect obstacles, adjust the direction of travel in real time and avoid obstacles, and the DC motor drives the car according to the path planning.

In manual mode, the user sends instructions through Bluetooth to control the car's actions. The system feeds back the motion status in real time, and the user can adjust the control strategy according to the feedback. After the task is completed, the system stops and enters a low-power standby state, waiting for a new command or shutting down.

The process ensures stable operation of the dolly in a complex environment, with flexible operation combined with sensor data and Bluetooth control.[3] The system working flow chart is shown in Figure 2.

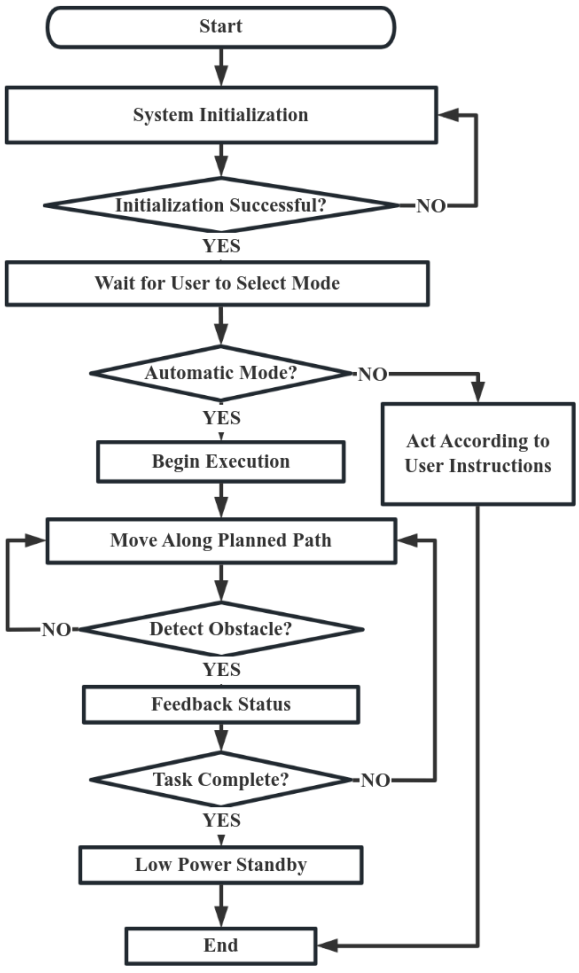


Figure 2. System working flow chart.

3.3. System module design

3.3.1. General control module design.

The total control module adopts STM32F407 MCU development board, based on ARM Cortex-M4F kernel, and the working frequency is up to 168 MHz

The module is known for its low cost and high cost performance, which is ideal for projects and educational application scenarios with limited budgets. Its design provides a rich external interface that can connect a variety of sensor and actuator modules, support diverse sensor access, and enhance the scalability and flexibility of the system. This enables the module to adapt to changing environmental requirements in practical applications, such as intelligent cars, robot navigation and so on.

The core functions include data processing, module coordination and system control to ensure that the modules work together to meet the needs of autonomous mobility in complex environments. Figure 3 displays the schematic diagram of the micro-controller.

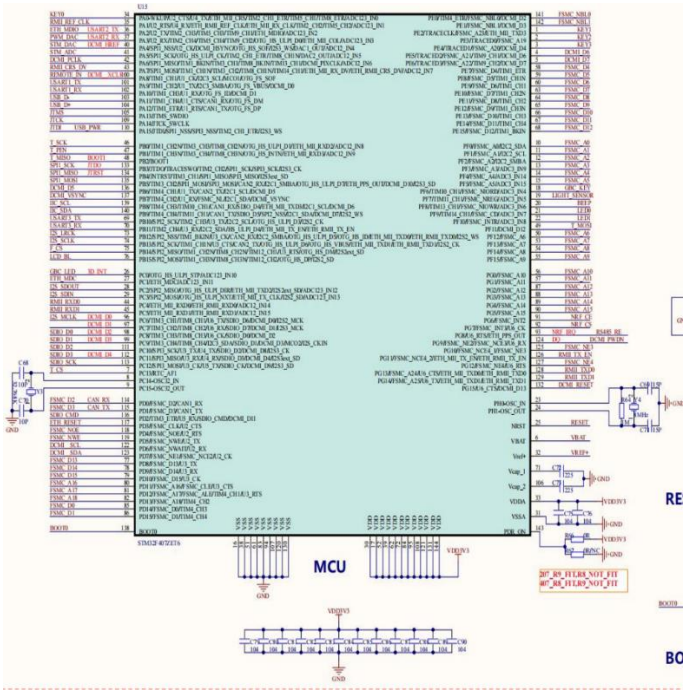


Figure 3. Schematic diagram of the micro-controller.

3.3.2. Infrared tracking module design.

The infrared sensor module used in this project is composed of a main control board and two auxiliary boards. The schematic diagram of the main control board is shown in Figure 4, and the Schematic diagram of small board is shown in Figure 5. The former is used to adjust the sensor sensitivity, and the latter represents the left and right eyes of the car respectively. The transmitting tube configured in the auxiliary board can emit infrared rays at a certain frequency.

When the module detects a light-colored path, most of the emitted infrared rays are reflected by the path, and the receiving tube can receive most of the reflected light signals. After the processing of the comparator circuit, the signal output interface will output a low-level signal, and the LED indicator light will then light up. The schematic diagram of transmitting and receiving is shown in Figure 6.

On the contrary, when the black path is detected, most of the infrared ray is absorbed by the path, the reflected light signal received by the receiving tube is significantly reduced, after the comparator circuit processing, the signal output interface output high level signal, the LED indicator is kept off.[4]

The detection distance of the return light signal received by the sub-board can be adjusted by the potentiometer knob on the main control board, the effective detection range is 2 to 60 cm, and the working voltage range is 3.3V to 5V. In the circuit

connection that realizes the tracking function, the data read by the sensor on the right side of the main control board is input through the PE5 pin of the micro-controller, and the data read by the sensor on the left is input to the micro-controller through the PE6 pin.

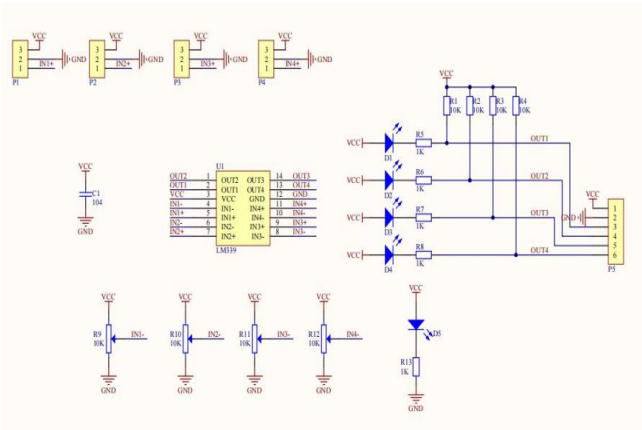


Figure 4. Schematic diagram of the main control board.

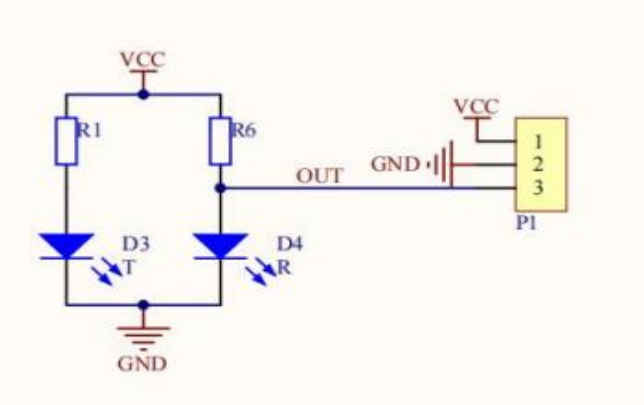


Figure 5. Schematic diagram of small board.

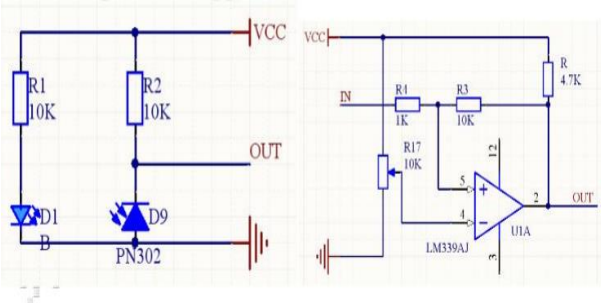


Figure 6. Schematic diagram of transmitting and receiving.

3.3.3. Design of infrared obstacle avoidance module.

Infrared obstacle avoidance module and infrared tracking module are similar in the principle of data collection, but the core of the design of the obstacle avoidance module is to detect whether the obstacle exists or reflects the light to trigger the evasive action. In contrast, the function of the infrared tracking module is based on the different absorption and reflection ability of the black path and the light path to keep the car driving along the preset black path.

In the obstacle avoidance module, when the module detects an obstacle, the emitted infrared light is reflected back by the obstacle, and the receiving tube can receive most of the reflected light signal. After the processing of the comparator circuit, the signal output interface will output a low level signal, and the LED indicator light will then light up. Conversely, when no obstacle is detected, the infrared ray is not reflected back, and the reflected light signal received by the receiving tube is significantly reduced. After processing by the comparator circuit, the signal output interface outputs a high level signal, and the LED indicator is kept off.

In the circuit connection to realize the obstacle avoidance function, the data read by the right eye sensor of the main control board is input from the PB6 pin of the single chip microcomputer, and the data read by the left eye sensor is input from the PD7 pin of the single chip microcomputer.[5]

3.3.4. DC motor module design.

The DC motor module is connected to the STM32 development board through the H-bridge circuit to control the speed and direction of the motor. The core of the design of the module lies in the precise level control of the motor drive pin to achieve a variety of motion modes.

Specifically, the left-wheel motor is managed by the control pins L1 and L2, while the right-wheel motor is handled by R1 and R2.

The direction of rotation of the motor depends on the input level state: when the L1 and R1 pins are high and L2 and R2 are low, the motor rotates clockwise, prompting the trolley to move forward; Conversely, the buggy will move backwards. If only R1 is high and L1, L2, and R2 are low, the trolley will turn left; Similarly, when only L1 is high and R1, L2, and R2 are low, the car will turn right. All pins remain low (level clear) when it is necessary to stop the motion.

The specific connection configuration of the motor pins is as follows: L1 connects to the PC9 pin of the motherboard, L2 to the PC7 pin of the motherboard, R1 to the PC6 pin of the motherboard, and R2 to the PC8 pin of the motherboard. Through the precise control of the level state of these pins, the smart car can realize its complex motion capabilities. As shown in Figure 7, this is the schematic diagram of the DC motor.

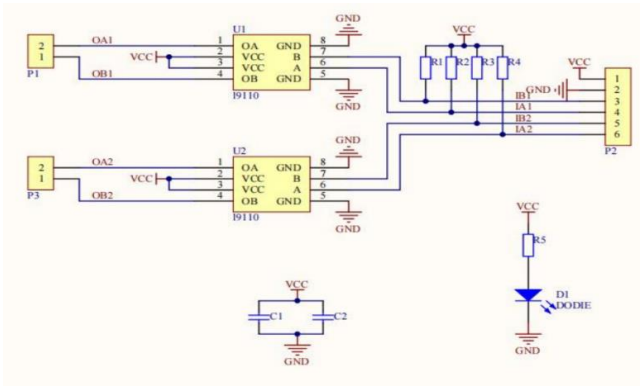


Figure 7. Schematic diagram of DC motor.

3.3.5. Design of Bluetooth control module.

The design of Bluetooth control module aims to realize the remote wireless control of intelligent car, especially suitable for the application scenario of the last 20 meters logistics distance from Cainiao station to the door.

Through Bluetooth communication technology, the module can transmit commands between the user's device and the car. The module integrates a circuit board with Bluetooth function to support short-range wireless communication. The core of its design is to receive and parse instructions through serial communication.

On the specific implementation, the sending end (TX) of the Bluetooth module is connected to the PA2 pin of the single chip microcomputer motherboard, and the receiving end (RX) is connected to the PA3 pin of the single chip microcomputer

motherboard. The module is in the automatic connection mode when working, and can transmit data according to the preset configuration. By configuring the interrupt service function, when receiving the interrupt flag bit USART_IT_RXNE, the module will parse the received instruction and execute the corresponding operation.

For example, when the character U is received, the car will be triggered to move forward; When the character B is received, the backward operation is triggered. The input voltage range of the Bluetooth module is 3.6V to 6V to ensure its stable operation. Refer to Figure 8 for the schematic diagram illustrating the Bluetooth module.

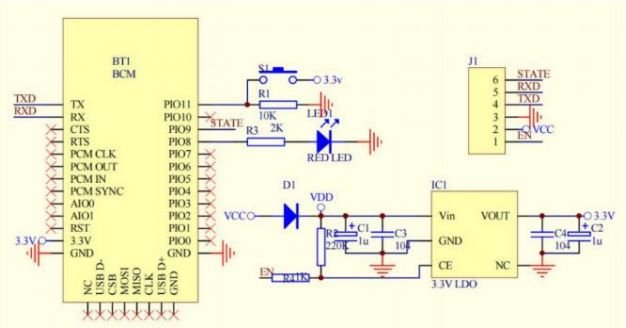


Figure 8. Schematic diagram of Bluetooth module.

3.4. System software design

3.4.1. Design of tracking algorithm.

The left eye and right eye infrared sensor on the car can monitor the light environment at the foot of the car in real time, and judge the situation at the foot of the car by emitting infrared and monitoring the reflected light signal. The returned signal will be input to the microcontroller in the form of digital signal, and the micro-controller can judge the relative position of the car on the black path according to the returned digital signal. And call the action function to make the car make the corresponding action.

Because the preset black road is narrower than the gap between the sensors in the two eyes, both sensors normally detect a light-colored area and return a low-level signal. When the left sensor detects a black path (high level) and the right sensor detects a light path (low level), the relative position of the car on the path is too far to the right, and the car needs to adjust its direction to the left. Conversely, the right sensor is high level and the left sensor is low level, indicating that the car as a whole is left relative to the path position, and the car should be adjusted to the right. If both are low, the car continues to run straight; But if both are high at the same time, it means that the car has been seriously deviated and should be stopped immediately. Figure 9 displays the flow chart for the tracking algorithm.

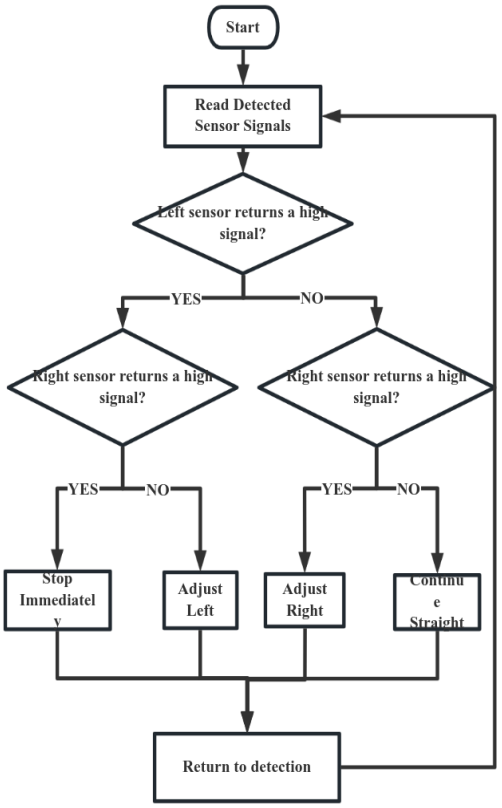


Figure 9. Flow chart of the tracking algorithm.

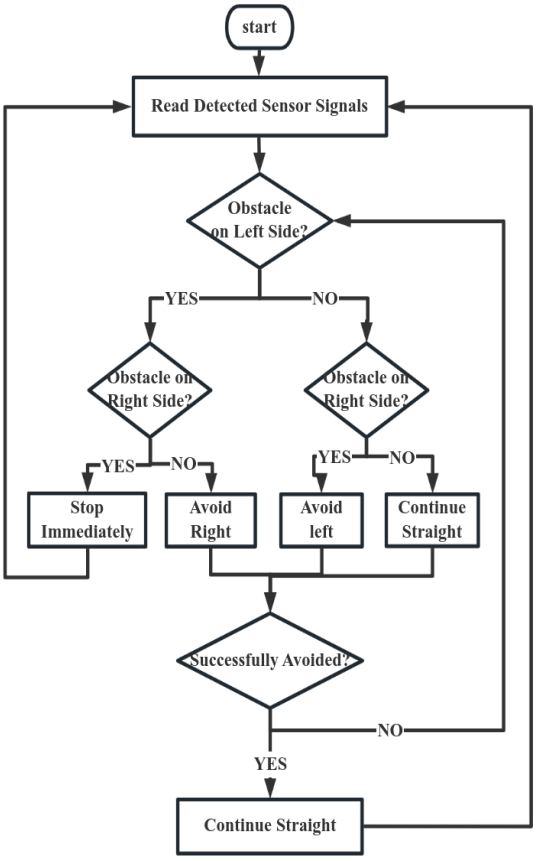


Figure 10. Flow chart of obstacle avoidance algorithm.

3.4.2. Obstacle avoidance algorithm design.

The left and right sensors on the car monitor the obstacles in front in real time, and feed the digital signal to the MCU.

When the obstacle exists, the sensor returns a low level signal; When there is no obstacle, the sensor returns a high level signal. The algorithm makes decisions based on these signals: if an obstacle is detected on the left but not on the right, it avoids to the right; If the right side detects an obstacle but the left side does not, it avoids to the left; If no obstacle is detected on both sides, continue straight ahead; If obstacles are detected on both sides, stop immediately.

In the course of avoidance, the algorithm combines the delay function, the straight line function and the basic turn function to form a stable turn strategy. Specifically, when the left sensor detects an obstacle but the right one does not, the single chip microcomputer calls the right obstacle avoidance function.

The function first stops the left rear wheel and the right rear wheel to slow down, then applies a delay function to ensure that the speed is gradually reduced. Next, all four tires stop and the delay function is applied again to stabilize the deceleration and prevent inertia from causing the load to fly. Then, the right turn function is called to make the left front wheel move, the rest of the tires stop, and the delay function is applied again to provide the turn time. Finally, if the sensor does not detect an obstacle, the straight drive is resumed. When the right sensor detects an obstacle but the left one does not, the microcontroller calls the left obstacle avoidance function. The process is similar to right obstacle avoidance, first stop the left and right rear wheels to slow down, apply the delay function, then stop all tires and delay again. Then, the left turn function is called so that the right front wheel moves, the rest of the tires stop, and the delay function is applied to complete the turn. If the sensor does not detect an obstacle, go straight back.

The timing and duration of the delay function are key to ensuring the stability of the avoidance. The Flow chart of obstacle avoidance algorithm can be found in Figure 10.

3.4.3. Bluetooth communication interrupt service algorithm design.

Bluetooth communication interrupt service function receives and processes data by configuring USART serial port.

When the USART detects incoming data from the Bluetooth module, an interrupt is triggered and the flag bit USART_IT_RXNE is set to invoke the interrupt service function. In this function, the character data in the receive buffer is read first, and the corresponding cart action is performed according to the character: Character U calls the go_up1() function to make the car go forward, B calls the go back() function to make the car go back, S calls the stop() function to make it stop, X calls the trace() function to put it into track mode, and Z calls avoid_() to turn on avoid_mode.

After data processing is complete, clear the USART_IT_RXNE interrupt flag bit, prepare to receive new data packets, and realize real-time control of the car. The flow chart of the Bluetooth communication interrupt service algorithm is illustrated in Figure 11.

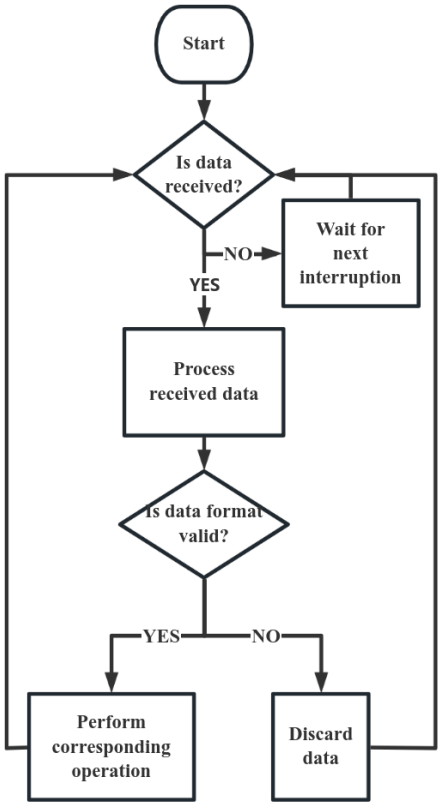


Figure 11. Bluetooth communication interrupt service algorithm flow chart.

3.5. Design and analysis of application experiment

3.5.1. Experimental scheme.

This experiment set up a simulation scene to reproduce the process of cargo transportation from the Rookie post station downstairs to the family door, and built a model with a scaling ratio of 1:50. The design of the experiment includes the key variables such as the type of goods, the number of obstacles and the preset path. The width of the selected goods is controlled within 15 cm, and according to the weight of the goods, it is divided into four classes: no package (0 kg), small package (<0.5 kg), medium package (0.5-1 kg), and heavy package (1-1.5 kg). The types of obstacles are divided into barrier-free (0), low (1), medium (2-3) and high (3-4) according to the number of obstacles. The schematic diagram of the scene is shown in Figure 12.

The preliminary work of the experiment included ensuring the normal operation of the power supply system and calibrating the sensitivity of the sensor according to the light intensity condition in the field. After debugging, the car is placed at the starting position of Rookie post station, and the selected goods are placed on the acrylic plate on the roof of the car, and the automatic tracking obstacle avoidance mode is activated for preliminary testing. The experiment consisted of 16 rounds of situational tests, each of which carried out 20 experiments, to fully evaluate the carriage's transport performance under various conditions. The preset path was manually pasted with black tape from the post station to the elevator.

After the car reached the test node of the elevator, the experiment introduced manual control by the user through a Bluetooth device. The operator located on the upper floor connected the car system and steered the car out of the

elevator and along a preset path to the door. This stage focuses on testing the response speed and accuracy of the Bluetooth control to manual operation, ensuring that the device can complete the final transportation task on schedule under the manual instruction. [2]

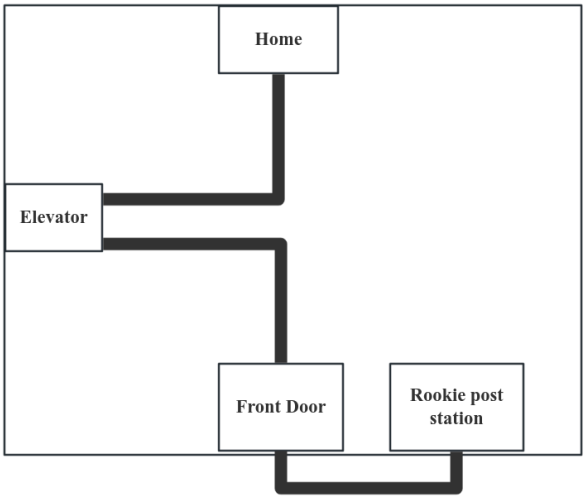


Figure 12. Schematic diagram of the scene.

3.5.2. Experimental data.

Experimental statistics of the number of car collisions with obstacles and the number of transport failures are obtained in Table 1:

Table 1. Experimental data table.

Number of obstacles	Type of package	Number of trials	Number of collisions	Number of transport failures	Number of Bluetooth connection failures
Accessibility	No packages	20	0	0	0
	Small packages	20	0	0	0
	Medium package	20	0	1	1
	Heavy wrap	20	1	1	0
Low Obstacle	No wrap	20	0	0	0
	Small packages	20	0	0	0
	Medium package	20	0	1	1
	Heavy wrap	20	1	1	0
Medium Obstacle	No wrap	20	0	0	0
	Small packages	20	0	2	2
	Medium-sized package	20	1	0	0
	Heavy wrap	20	1	2	0
High Obstacle	No wrap	20	0	0	0
	Small packages	20	2	1	0
	Medium package	20	2	1	1
	Heavy wrap	20	3	3	0

3.5.3. Experimental analysis.

Taking the number of obstacles as the main influencing factor, the collision rate and transportation success rate can be analyzed in Table 2:

Table 2. Statistical table of success rate under different number of obstacles.

Number of Obstacles	Collision rate	Delivery success rate
Accessibility	(0/80)*100%=0.00%	(78/80)*100%=97.50%
Low Barrier	(1/80)*100%=1.25%	(78/80)*100%=97.50%
Medium Handicap	(2/80)*100%=2.50%	(76/80)*100%=95.00%
High Obstacle	(7/80)*100%=8.75%	(75/80)*100%=93.75%

Table 3 can be obtained by analyzing collision rate and delivery success rate with package type as the main influencing factor:

Table 3. Statistical table of success rate under different package types.

Types of Packages	Collision rate	Delivery success rate
No Packages	(0/80)*100%=0.00%	(80/80)*100%=100.00%
Small package	(2/80)*100%=2.50%	(77/80)*100%=96.25%
Medium package	(3/80)*100%=3.75%	(77/80)*100%=96.25%
Heavy parcel	(6/80)*100%=7.50%	(73/80)*100%=91.25%

Summarize the total delivery success rate, total delivery failure rate and total collision rate according to Table 1, and

analyze the transportation failure rate caused by Bluetooth connection failure as the main influencing factor, Table 4 can be obtained:

Table 4. Statistical table of success rate under the influence of Bluetooth connection.

Total delivery success rate	(307/320)*100%≈95.94%
Total delivery failure rate	(13/320)*100%≈4.06%
Total collision rate	(11/320)*100%≈3.44%
Bluetooth connection success rate	(75/80)*100%=93.75%
Shipping failure rate due to Bluetooth connection failure	(5/13)*100%=38.00%

Through the analysis of experimental data, the system shows high reliability, the total success rate of transportation is about 95.94%, and the total collision rate is only 3.44% (Table 4).

However, Table 2 shows that as the number of obstacles increases, the collision rate increases from 0.00% in the barrier-free state to 8.75% in the high-obstacle environment, while the delivery success rate decreases from 97.50% to 93.75%. This is mainly due to the difficulty of accurately maintaining the path of the car in complex environments, especially when turning. Table 3 points out that in the case of heavy packages, the collision rate is as high as 7.50%, and the delivery success rate drops to 91.25%, which shows that the trolley is prone to turning deviation when the load increases, affecting the overall efficiency.

In addition, the analysis in Table 4 shows that the Bluetooth connection success rate is 93.75%, although 38.00% of the delivery failures are caused by connection problems, the current success rate is relatively high, and a small number of failures have a significant impact on the overall performance.

To sum up, the system has a large room for improvement under the conditions of high obstacles and heavy loads, and it is the key to improve the load handling capacity of the car and enhance the stability of the Bluetooth connection. This will effectively improve the efficiency and reliability of the system to ensure smooth operation in a diverse operating environment.

4. Conclusion

This project has successfully designed and implemented an intelligent tracking obstacle avoidance vehicle based on STM32, demonstrating its feasibility and high efficiency of autonomous navigation in complex environments. The integration of a variety of sensors and optimization control algorithms allows the car to perform well in the "last twenty meters" logistics distribution, achieving a high delivery success rate and reliability.

Experimental results show that the performance of the system is particularly outstanding under barrier-free and light load conditions. However, there is still room for improvement under high obstacles and heavy loads. In particular, the system's performance can be further optimized by enhancing the load handling capacity and path correction capability of the trolley, as well as improving the stability of the Bluetooth connection.

Currently, the success rate of the Bluetooth connection has reached a high level, although a small number of connection failures do impact the overall success rate of transport. Despite this, the system has shown good application potential.

Future work will focus on further optimizing the hardware and software design to improve the adaptability and efficiency of the system in diverse operating environments. This will provide more innovative and practical solutions for the field of intelligent logistics.

References

[1] Wang, H.Y., Li, F.W., Zhang, Q.C., Yan, J.X. (2023) Design of an intelligent tracking and obstacle avoidance trolley. Equipment Manufacturing Technology., 06: 265-268.

[2] Wang, X.Y., Li, D.Y., Jin, C., Huang, X., Zhong, S.S. (2024) Design of warehouse intelligent handling trolley system based on STM32 microcontroller. Automation & Instrumentation., 06: 52-55.

[3] Zhao, H.D., Tan, Y.F., Qin, Y.B., Li, Y.F. (2023). Design of Obstacle Avoidance for Intelligent Car Tracking Based on STM32F407ZET6. Electronic Production., 13: 19-21+29.

[4] Du, Y.P. (2013). Discussion on the application of infrared sensors. China Science and Technology Information., 18: 131.

[5] Qiu, Y. (2023). Design of intelligent car based on STM32. Industrial Control Computer., 04: 158-159.