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Courier Path Planning System Based on Automated Guided Vehicles

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Abstract. With the arrival of the digital era, the logistics industry pressure surge, the traditional logistics industry, high cost, low efficiency has been unable to meet the needs of modern logistics. There is an urgent need for intelligent logistics equipment to improve the efficiency of express operation. Automated Guided Vehicles (Automated Guided Vehicles, AGV) as one of the key equipments in the intelligent logistics system, plays an important role in reducing cost and improving efficiency. In this paper, this paper design a sorting system based on AGV path planning, adopting algorithms such as sliding filter, Kalman filter, breadth-first (BFS) search method, etc., and obtaining its own state through encoding motors, gyroscopes, ultrasonic arrays and feeding back to the upper computer ROS system, which obtains images to recognize the express delivery information through the camera, confirms its own position through machine vision and multi-sensor fusion, and makes automatic Navigation trolley AGV path planning to achieve automatic identification of courier information, automatic classification and transportation to the target location, and automatic return to the starting point. Through testing, it is proved that this design can complete the recognition of the target QR code and AGV path planning within the range of 1 meter.

Keywords. AGV, sorting, courier, path planning

1. Introduction

With the arrival of the digital era, the rapid development of e-commerce, online shopping more and more. At this stage, the high cost and low efficiency of China's traditional logistics industry can no longer meet the needs of modern logistics. Internet of Things, artificial intelligence and other new technologies are gradually applied to the transportation, sorting, distribution and other aspects of warehousing and logistics, making warehousing and logistics more intelligent, automated, digital, and improving the efficiency of the logistics industry.

As one of the key equipments in the intelligent logistics system, AGV plays an important role in reducing logistics cost and improving efficiency. [1] Automated Guided Vehicle (AGV) has the characteristics of flexible arrangement, strong robustness and high degree of intelligence.In the 1950s, Barrett Electronics developed the first traction AGV in the U.S.A., and then the electromagnetic navigation AGV was first developed in the U.K. and popularized to the market, and the application scenarios in this stage were mainly factories and garages [2], and in the 1960s automated sorting system was applied in the postal sector in the United States and Europe, and then promoted and popularized to some distribution centers and industrial production.Kiva

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robot, is a robotics project of Kiva system company acquired by Amazon hi group in 2012, Kiva robot gets the coded value through the camera to identify the QR code in navigation, and calculates the navigation angle through the relative position of the QR code and the camera, the navigation angle can control the AGV travelling. The navigation angle can control the AGV traveling direction and turning angle, inertial navigation control AGV traveling along a fixed route [3], the efficiency is increased to three times before, the accuracy of Kiva robot reached 99.99%. Since the Kiva robot foreign AGV logistics sorting system is more and more diverse.

The development of logistics in China is relatively late, and in the early days, the sorting of logistics was accomplished through manual sorting and manual handling. With the development of computer internet in China, some large-scale sorting centers in the country have also been using large-scale logistics sorting systems, and under the influence of Kiva Robotics, a new type of automated logistics sorting system was proposed by a domestic startup team, Lipiao Robotics, in 2016 [4]. Hao Guoxiao [5] proposed a control strategy for multiple AGVs in intelligent warehousing to solve the problems of congestion and path conflict encountered during AGV operation. In terms of single AGV path planning, related scholars focus on optimizing and improving intelligent algorithms such as A* algorithm [6], ant colony algorithm [7-8], and genetic algorithm [9] to obtain better initial paths, and the effect of initial path planning[10] for each AGV will greatly affect the operational efficiency of this system. With the growth of market demand, the main research direction of AGV is toward the intelligent scheduling of multiple AGVs [11].

Using AGV for express sorting can greatly save labor costs, time costs, and improve sorting accuracy. Combining AGV with traditional automated sorting systems can effectively compensate for the shortcomings of traditional sorting systems, such as poor flexibility and robustness. Therefore, this article aims to design an efficient and practical AGV path planning and sorting system to meet the urgent demand for automation and intelligence in the modern logistics industry. To achieve this goal, this paper have comprehensively applied various technical means such as sliding filter, Kalman filter, and breadth-first search (BFS) algorithm. These algorithms can not only help AGV accurately obtain their own status information, but also ensure accurate and efficient path planning in complex environments. The system acquires real-time status data of AGV through sensors such as encoders, gyroscopes, and ultrasonic arrays, and feeds these data back to the upper-level ROS system. The upper computer then uses a camera for image recognition to obtain express information. Through machine vision and multi-sensor fusion technology, the system can accurately confirm the pose of the AGV and formulate an optimal path planning scheme accordingly. This scheme can achieve automatic recognition of express information, automatic classification and transportation to the target location, and automatic return to the starting point, thus greatly improving the efficiency and accuracy of logistics sorting.

2. System Design Program

The system is divided into two main parts, the system frame is shown in Figure 1.

The first part is the main controller based on FreeRTOS, the main controller is responsible for the acquisition of sensor data packaging and uploading is responsible for the control of the underlying actuators and the warning of abnormal states. The controller uploads the underlying sensor data to the local host computer through the serial port.

The second part is the machine intelligent recognition system, which is divided into the local host computer and the remote monitoring platform, the host computer is responsible for image acquisition and image processing of the data uploaded by the bottom controller for fusion processing, fusion of the data for localization and motion control, and finally combined with the results of the path planning to the bottom controller to issue control commands. Remote monitoring platform, the remote monitor has the function of checking the real-time running status of the system, making changes to the path, and remotely controlling the sorting trolley.

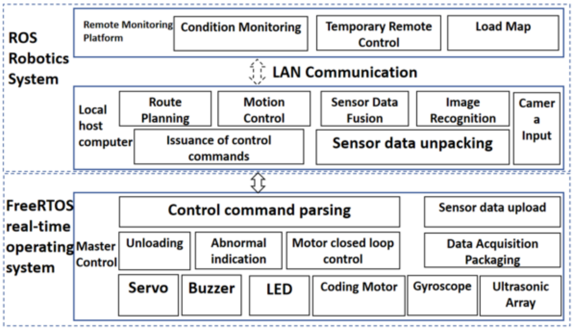

Figure 1. System framework

3. Sorting Control System

3.1. Main Control System

The system controller is based on FreeRTOS real-time operating system built, FreeRTOS is a small real-time operating system kernel, can be in accordance with the task priority time-shared execution of different tasks, and interrupt priority is not the same as the FreeRTOS task priority number the larger the higher priority. Each sub-task is independent of each other in a dead loop, in the task to add the system delay can be task scheduling, the task can be communicated through the system's message queue, the event flag bit and so on. The program framework of this system and the functions of each task are shown in Figure 2. The tasks are executed in time-sharing under the system scheduling, maximizing the use of the chip's performance, each task has its own role and collaborate with each other to complete the control of the cart system, mainly controlling the host computer communication, status indication, gyroscope data acquisition, motor drive, ultrasonic distance measurement and other tasks.

3.2. PID and Motor Closed-loop Drive

In the control system in accordance with the error with the target for proportional P, integral I, differential D for dynamic adjustment algorithm for PID algorithm [12]. The PID algorithm implementation process is very simple, the use of the sensor feedback of the error of the proportional, integral, differential three parts of the adjustment. The PID control part of the motor control task is carried out in the interrupt, and the control of the motor speed can be realized by changing the target speed of the motor structure body inside the motor control task. The motor control task is shown in Figure 3 and the PID control flow is shown in Figure 4. Inside the motor task, the main task is to get the current current and slide filter, judge the current state of the motor to carry out the corresponding operation, and turn off the motor output to protect the motor from being burned when the motor current is too large. Update the total mileage of the motor encoder, and then need to be uploaded to the host computer for data fusion in the communication task.

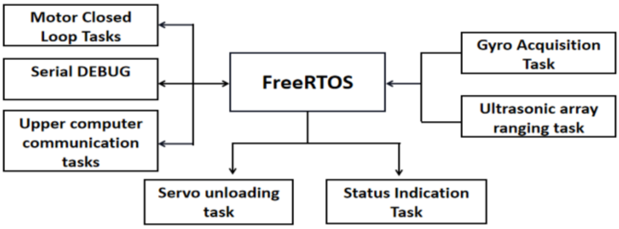

Figure 2. Microcontroller software framework

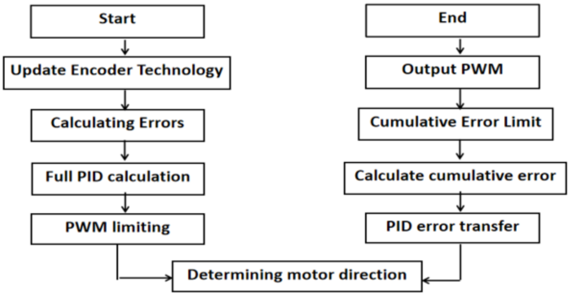

Figure 3. Block diagram of the motor control task

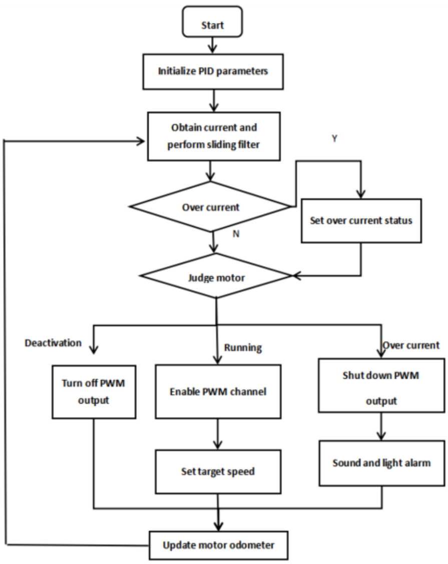

Figure 4. Block diagram of pid adjustment

In the PID interrupt processing not only need to carry out formula calculations, but also need to limit the PWM output, if the output value calculated by the PID formula is greater than the maximum output value of the motor output maximum value. In the PID calculation also need to limit the cumulative error to avoid some accidental circumstances so that the motor integral adjustment to reach a large value affecting the motor control, so need to be based on the actual situation of the integral adjustment of the motor to control the impact of a reasonable range.

3.3. Sliding Filter and Ultrasonic Array Ranging

Sliding filter algorithm can effectively remove random noise is a smooth waveform, the specific implementation of a buffer in a sequential insertion of N each sampling data, each sampling of new data on the earliest collection of that data to throw away, calculate the total value of the buffer inside, and then subtract the maximum and minimum values, and then calculate the average value as in Figure 5, you can derive the smooth waveform, but in determining the size of the buffer should be noted that, although the larger the buffer the smoother the waveform will be, but the more serious the data hysteresis will also be, so in accordance with the actual demand for the determination of the size of the buffer.

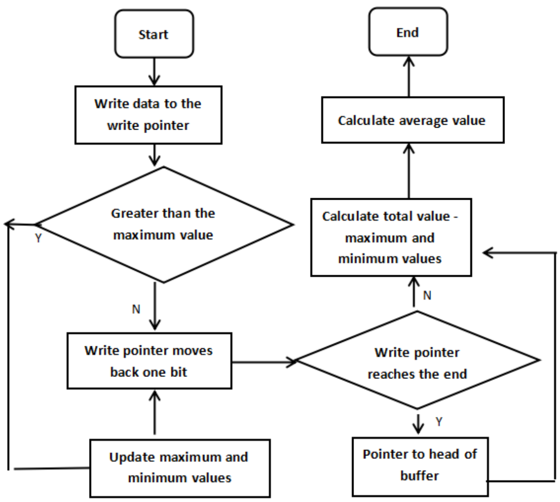

Figure 5. Sliding filter algorithm

The ultrasonic array consists of eight ultrasonic modules, eight ultrasonic modules are distributed in the front of the robot in two thirds of a circle. The eight ultrasonic modules emit sound waves at the same time when measuring the distance, and the echo of the sound waves is received after an interval time t. Assuming that the current speed of sound is V, the relationship between time t and distance D is shown in Equation (1).

$$D = \mathrm{t}(\mathrm{s}) \bullet \frac{V(m/s)}{2} = t(us) \bullet \frac{V(mm/us)}{2000} \tag{1}$$

However, because the velocity of sound in air is affected by temperature, temperature correction is required, and the relationship between temperature T and the velocity of sound in air V is shown in equation (2)

$$V = 331 \bullet \sqrt{1 + (T/273)}(\mathrm{m}/s) \quad (2)$$

The ultrasonic ranging task refreshes the distance of the ultrasonic array at a frequency of 100 Hz and updates the ambient temperature every second to adapt to the temperature changes in the environment, after calculating the ultrasonic distance a sliding filter with a buffer length of 5 is performed and after the filtering the distance value of the ultrasonic array is updated.

4. Robot Intelligent Recognition System

4.1. Framework of the host computer system

The block diagram of the upper computer system is shown in Figure 6, and the upper computer, as in Table 1, is divided into six main parts, which are each publishing and subscribing to some ROS topics. Serial communication and image recognition collect sensor information for motion control, combine various sensor data in motion control to make path planning, as well as control the movement of the cart and realize obstacle avoidance. The final control is to send control commands to the microcontroller through the serial port to control the motion of the cart. The remote UI interface can view various real-time states of the cart and load the map.

Table 1. ROS Customized Feature Packs.

Process	Role
Serial communication	Master controller communication
Image recognition	1Recognizes color blocks and QR codes.
Interactive	Loads maps, temporary remote control, status monitoring.
Data fusion	Fuses multiple sensor data according to weights.
Path planning	Path planning based on its own position and courier information.
Motion control	Motion control based on fused data.
Multi-computer	collaboration.

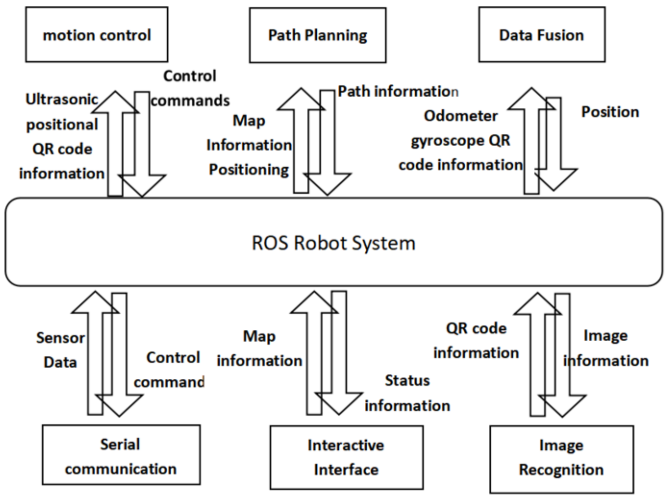

Figure 6. Upper computer software framework

4.2. Kalman filtering and data fusion

In the sensor data fusion before the sensor data to be filtered in order to use, the filtering algorithms used in the host computer are sliding filter and Kalman filter, for the real-time strong gyroscope data I used Kalman filter, other sensor data is to use the sliding filter.

Kalman filtering[13] is considered a recursive linear minimum variance estimation. An algorithm for estimating the optimal state of a system from observed data, for discrete linear systems:

$$\mathrm{x}(k) = Ax(k-1) + B(u(k) - w(k-1)) \tag{3}$$

$$\mathrm{y}v(k) = Cx(k) + v(k) \tag{4}$$

where w(k) is the process noise signal and v(k) is the measurement noise signal.

The Kalman filter algorithm is divided into two steps:

- Prediction: Assuming k moments as the current moment, estimate the state of the system at k moments according to the predicted value at k-1 moments, and derive the pre-estimated value of the system at k moments;
- Update: The current value of the system is measured by the sensor at k moments, and the pre-estimated value is corrected and updated to obtain the predicted value at k moments, and the pre-estimated value at the next moment (k+1 moments) is calculated.

The time update equation for the Kalman filter is expressed as:

$$\hat{x}_{\bar{k}} = A\hat{x}_{k-1} + Bu_{k-1} \tag{5}$$

$$P_{\bar{\mathrm{k}}} = AP_{\mathrm{k-1}}A^{\mathrm{T}} + Q \tag{6}$$

The state update performance equation for the Kalman filter is expressed as:

$$K_{\mathrm{k}} = \frac{P_{\bar{k}}H^{\mathrm{T}}}{HP_{\bar{k}}H^{\mathrm{T}} + R} \tag{7}$$

$$\hat{x}_k = \hat{x}_{\bar{k}} + K_k(z_k - H\hat{x}_{\bar{k}}) \tag{8}$$

$$P_k = (I - K_k H)P_{\bar{k}} \tag{9}$$

Among them: $\hat{x}_k$ and $\hat{x}_{k-1}$ denote the predicted values of the system at k-1 and k moments, respectively; denote the predicted value of the system at time k-1 and time k, respectively; $\hat{x}_{\bar{k}}$ denotes the pre-estimated value at moment k; $P_{\mathrm{k-1}}$ and P_k denote the covariance of the predicted values at moments k-1 and k, respectively; $P_{\bar{\mathrm{k}}}$ denotes the pre-valuation covariance at moment k;;H is the transition matrix from state variables to measurements; z_k is the input to the filter; K_k is the Kalman filter coefficients; A is the state transfer matrix; Q is the process excitation noise covariance; R is the measurement noise covariance; and B is the matrix that transforms the inputs into states.

It is now widely used in the fields of communication, navigation, and control. Kalman filtering is able to estimate the state of a dynamic system when the measurement variance is known. By adjusting the fusion ratio of estimated and actual values, the filtering effect and data lag can be well balanced.

For trolley positioning, this paper can combine the data of motor odometer, gyroscope and QR code to synthesize the positioning. When the trolley is in a position where it can scan the QR code, the angle information on the QR code has the largest weight, when the camera is just above the QR code, the angle of the QR code is used as the basis for correcting the angle calculated by the gyroscope and resetting the odometer, and the angle calculated by the gyroscope and the odometer is half of the trolley's angle when turning, and if the rate of change of the angle calculated by the odometer and the gyroscope is too large, then the weight of the other sensor will be increased. If the rate of change of the angle calculated by one of the two sensors is too large, the weight of the other sensor will be increased. The cart's displacement information is based on the odometer, but the odometer information is reset when it reaches the QR code label.

4.3. Path Planning

There are a variety of path planning algorithms inside the package integrated path planning[14] in ROS, but because the map information of this system is a low-density map, the package integrated by ROS used is too much overhead for the system, so this system path planning uses breadth-first (BFS) search method for path planning on the data structure map [15]. Breadth-first search process is shown in Figure 7, first the initial point into the first queue, then search the first queue of the node's neighboring points, and add the unvisited neighboring points to the second queue, and then search the second queue of the node's neighboring points, and add the unvisited neighboring points to the third queue to loop the process until the target node is found, find the node of the first neighboring point of the previous layer into the path stack The first neighbor of the previous layer is added to the path stack, and the process is repeated until the starting point is added to the stack. In this way the shortest path is found.

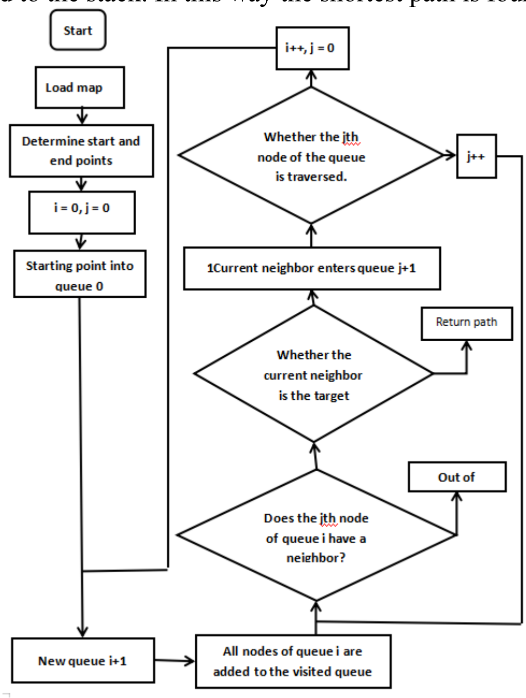

Figure 7. Breadth-first search

4.4. Motion Control

4.4.1 Motion control Framework.

Motion control is based on the state machine model written in Figure 8, as shown in Table 2 state machine has five states.

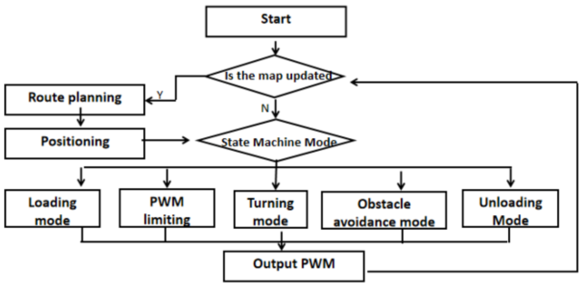

Figure 8. 5 states of motion control in state machine mode

Table 2. State machine model table.

Load mode	the status after scanning the QR code of the goods.
Straight mode	Follow the color block and update the status after scanning the QR code or encountering an obstacle.
Turning Mode	Update the status when the turning angle reaches the target angle.
Obstacle avoidance mode	Update the status after the ultrasonic distance is greater than the threshold value.
Unloading mode	Update status after unloading action is complete.

4.4.2. Basic Motion Mode.

Walking mode as shown in Figure 9, in walking mode will continue to get the Camer_Msg message from the camera topic of ROS and Ultrasion[8] array message from the ultrasonic topic, the color coordinates in Camer_Msg are used to be fused with the odometer data to make sure that the cart is walking straight to the next coordinate marking, and in the ultrasonic topic it will continue to detect whether the cart will hit the obstacle or not, and then it will be switched to the obstacle avoidance mode once it hits the obstacle, and it will switch the state based on the command when it detects the QR code command.

After entering the obstacle avoidance state, the cart will rotate 180 degrees to return to the previous coordinate point and replan the route to bypass the obstacles. The specific realization is that after the cart rotates 180 degrees, it will take the previous coordinate point as the starting point to re-plan the path, and switch the motion control mode to straight walking mode to go back to the previous coordinate point.

5. System Testing

5.1. Test environment and purpose

The system test environment is shown in Figure 10 where the laptop serves as the remote UI interface, and the trolley body contains two parts, the industrial control computer and the microcontroller. The purpose of this test is to test whether the functions are normal and to test the overall reliability of the system.

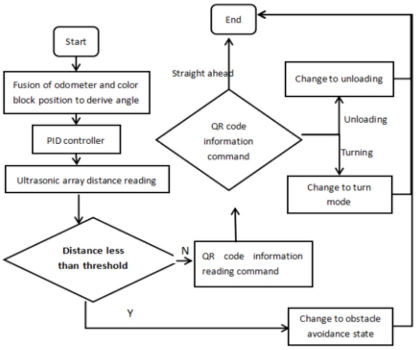

Figure 9. Flowchart of straight ahead mode

Figure 10. General Test Environment

5.2. *Main controller function test*

5.2.1. *Motor closed-loop test.*

As shown in Figure 11 and Figure 12, through the serial assistant, it can observe the change curve of the target speed and actual speed of the trolley, the red line is the set speed, and the blue line is the actual speed curve. In the process of accelerating from 0 to full speed 100, the actual speed can follow the target speed well, and reach the target speed quickly and smoothly, and in the process of decelerating the maximum speed to 0, the actual speed can be quickly and accurately reduced to 0. The test result proves that the trolley can accelerate and decelerate smoothly, and realizes the speed closed loop.

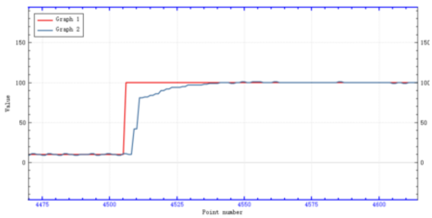

Figure 11. Acceleration response curve

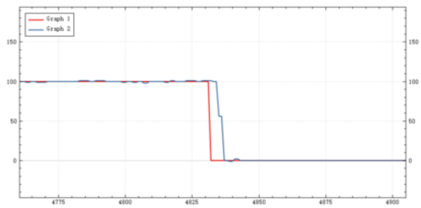

Figure 12. Deceleration response curve

5.2.2. *Servo rotation test.*

Test the rotation of the servo according to the preset angle, set different angles for the servo to see whether the servo can be output according to the set angle, the results are shown in Table 3 servo can be output at an angle according to the given instructions.

Table 3. State machine model table.

Input Angle	Output angle	Test results
0	0	Pass
90	90	Pass
120	120	Pass
180	180	Pass

Table 4. Uploaded sensor data

Data	Eelement
Gyroscope 3-axis acceleration	[594,-400,16852]
Gyroscope 3-axis angular velocity	[-32,-43,11]
Left wheel odometer	0
Right wheel odometer	12386675
Left wheel speed	0
Right Wheel Speed	0
Camera Angle	0
Calibration	0

Table 5. Verification of Command Issuance Function

Command	Phenomenon	Test Structure
Forward.	The cart moves forward.	pass
Backward.	The cart moves backward.	pass
Turn left.	The cart turns left	pass
Turn right.	The cart turns right	pass
Camera down	The cart got a camera down	pass
Camera up	The cart got a camera up.	pass
Command	Phenomenon	pass

5.2.3. Communication Stability Test.

MCU->PC test the lower unit packaged to send data as shown in Table 4 data on the upper unit to decode the display data, the upper unit unpacked successfully.

PC->MCU test upper machine packaged to send data microcontroller to execute the corresponding instructions, the test results are shown in Table 5, the instructions can be executed normally.

In the absence of human interference, the trolley lasted one hour communication test, the results of an hour later can still communicate normally, proving that the system communication is stable and reliable.

5.3. Image Recognition Test

5.3.1. QR code decoding accuracy test.

In order to test the accuracy of the QR code, the experiment was prepared with five QR codes of a class as shown in Figure 13, and the decoding was carried out in a relatively well-lit environment with a relatively clean background for 10 tests on each of the five images, and the results are shown in Table 6, which shows that the accuracy of decoding in the well-lit environment is 100%.

5.3.2. Color block recognition range test.

Test environment as shown in Figure 14 camera test test color block position recognition. The screen shows the color block after color filtering, the test process tried different distances of the color block recognition, the results are shown in Table 7 results show that the camera can identify the color block position coordinates within one meter. It meets the expectation of this system.

Figure 13. Green QR Code

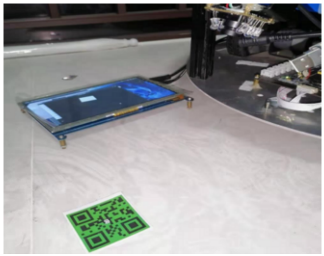

Figure 14. Color Block Recognition

Table 6. QR code decoding test

QR Code Information	Decoding Accuracy	Test Results
0,1	100%	pass
0,2	100%	pass
0,3	100%	pass
0,4	100%	pass
1,1	100%	pass

Table 7. Color Block Recognition Test

Distance between QR code and cart	Can the color block be recognized	passing rate
0cm	recognizable	100%
20cm	recognizable	100%
40cm	recognizable	100%
60cm	recognizable	100%
80cm	recognizable	100%
100cm	sporadic recognition	60%
120cm	unrecognizable	0%

6. Summary

In this paper, the main control system based on AGV is designed for express sorting, based on which the ROS robot operating system is added. Through the encoding of its and current acquisition to achieve the speed of the motor closed-loop control and overcurrent protection, gyroscope data using Kalman filtering and other sensor data using a sliding filter algorithm for data fusion, ultrasonic, encoder, camera and gyroscope light sensors combined with the breadth-first (BFS) search method to achieve the cart's automated planning and sorting of courier transportation. Through testing, the trolley's motor rotation, servo rotation angle, communication and image recognition can complete the expected results, the recognition of the QR code color block needs to be within 1 meter can achieve 100% recognition rate.

This system still has defects and imperfections, such as ultrasonic obstacle avoidance action can not bypass itself to reach the next target point directly, the system needs to load the map manually and so on. In the future, it will add multi-robot scheduling algorithm on the basis of ROS system to realize multi-robot cooperative work to improve the efficiency of the system.

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