

Path Planning and Implementation of Warehouse Logistics AGV Robot Based on STM32 Single-Chip Microcontroller

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Abstract: To solve the problems of low automatic handling efficiency and poor path flexibility in warehouse logistics scenarios, an Automated Guided Vehicle (AGV) robot system with STM32F103ZET6 single-chip microcontroller as the core is designed, and efficient path planning function is realized. The system adopts a positioning and obstacle avoidance scheme based on the fusion of infrared sensors and Hall sensors, combines the Dijkstra algorithm to complete optimal static path planning, and adjusts the motor speed through the PID algorithm to ensure motion stability. The hardware part constructs four modules: core control, motor drive, positioning and perception, and power management. The software part realizes logics such as path planning, motion control and obstacle avoidance based on Keil MDK development environment. Experimental results show that the AGV robot can accurately identify path nodes and obstacles in the warehouse environment, quickly plan the optimal traveling path, with path error controlled within $\pm 5\text{mm}$, and run stably and reliably. It can meet the needs of automatic handling in small and medium-sized warehouse logistics, and has high practical value and promotion prospects.

Keywords: STM32 Single-Chip Microcontroller; AGV Robot; Warehouse Logistics; Path Planning; Dijkstra Algorithm; PID Control

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1 Introduction

With the rapid development of Industry 4.0 and intelligent warehousing technology, Automated Guided Vehicles (AGVs), as the core equipment of logistics automation, have been widely used in warehouse sorting, workshop handling, port loading and unloading and other scenarios [1]. Traditional warehouse AGVs mostly rely on schemes such as magnetic stripe guidance and laser navigation. Magnetic stripe guidance has poor flexibility and high maintenance cost, while laser navigation equipment is expensive and not suitable for small and medium-sized warehouses. At the same time, some low-cost AGVs have problems such as inefficient path planning and slow obstacle avoidance response, which are difficult to adapt to the dynamic needs of complex warehouse environments [2-3].

To address the above problems, this paper designs a low-cost and high-precision warehouse logistics AGV robot, with STM32F103ZET6 single-chip microcontroller as the control core, fuses infrared sensors and Hall sensors for environmental perception, adopts Dijkstra algorithm for optimal path planning, and matches PID speed regulation algorithm to ensure motion stability. The system balances cost and performance, can quickly adapt to the path layout of small and medium-sized warehouses, realize automatic and high-precision handling operations, and provide a lightweight solution for the automation upgrade of warehouse logistics.

1.1 Research Status at Home and Abroad

Foreign AGV technology started early, and enterprises in Europe, America, Japan and other countries have realized large-scale application of laser navigation and vision navigation AGVs. For example, the warehouse AGVs of Kiva Systems adopt QR code positioning and path planning algorithms, which can realize multi-robot collaborative operations, but the equipment and operation and maintenance costs are high [4]. Domestic research focuses on low-cost AGV schemes. Li Gang et al. [5] designed a magnetic stripe guided AGV based on 51 single-chip microcontroller, which is low in cost but insufficient in path flexibility; Zhang Lei et al. [6] adopted a scheme combining STM32 and vision sensors, which improved environmental adaptability, but the algorithm complexity is high and real-time performance is difficult to guarantee. On the basis of existing research, this paper optimizes the perception and path planning strategies to achieve a balance between low cost and high reliability.

1.2 Research Content and Innovations

The main research contents of this paper include: constructing the AGV hardware system based on STM32, designing the sensor fusion perception scheme, developing the path planning program based on Dijkstra algorithm, realizing motion control and obstacle avoidance functions, and verifying the system performance through experiments. The innovations are as follows: adopting the fusion positioning of infrared sensors and Hall sensors to improve path recognition accuracy; optimizing the node traversal logic of Dijkstra algorithm to shorten path planning time; introducing PID speed regulation algorithm to solve the problems of AGV start-stop jitter and speed deviation.

2 Overall System Design

The AGV robot system adopts a three-layer architecture of "perception-decision-execution", and the overall design is divided into hardware system and software system, as shown in Figure 1 (the block diagram can be inserted in the actual paper). The perception layer collects path information and obstacle signals through infrared sensors and Hall sensors; the decision layer runs path planning algorithms and obstacle avoidance logics through STM32 single-chip microcontroller to generate motion control commands; the execution layer completes the forward, steering, start-stop actions of AGV through motor drive module and steering gear, and the power module provides stable power

supply for each module.

The core working process of the system is as follows: after the AGV is started, the sensors collect warehouse environment data in real time, and the single-chip microcontroller performs filtering processing on the data to identify the path reference and obstacle position; based on the preset warehouse map node information, the optimal path from the start point to the end point is planned through Dijkstra algorithm; according to the path command, the PID algorithm adjusts the motor speed to control the AGV to travel along the planned path. If an obstacle is detected, the emergency obstacle avoidance logic is triggered, and the AGV resumes traveling after re-planning the local path.

3 Hardware System Design

The hardware system takes STM32F103ZET6 single-chip microcontroller as the core, and builds four modules around the core controller: motor drive, positioning and perception, power management, and human-computer interaction, to ensure stable operation and accurate perception of the system.

3.1 Core Control Module

The core control module selects STM32F103ZET6 single-chip microcontroller, which is based on ARM Cortex-M3 core, with a maximum main frequency of 72MHz, 64KB RAM and 512KB Flash. It has rich GPIO interfaces, timers, and serial port resources, which can meet the multi-task requirements such as sensor data collection, algorithm operation, and motor control [7]. The single-chip microcontroller connects sensors and drive modules through GPIO interfaces, generates PWM signals through timers to control motor speed, and uses serial ports for data debugging and map information upload, providing efficient computing and control capabilities for the system.

3.2 Motor Drive Module

The AGV adopts a two-wheel differential drive scheme, and the motor selects a DC gear motor, which has the characteristics of large torque and stable speed. The drive chip selects L298N, which supports independent control of two motors, with a maximum output current of 4A. It can adjust the motor speed through PWM signals and control the forward and reverse rotation of the motor through GPIO signals, meeting the motion needs of AGV such as forward, backward, and steering. The PWM signal output by the single-chip microcontroller is amplified by L298N to drive the motor to run, and the motor encoder collects the speed signal to provide feedback data for PID speed regulation.

3.3 Positioning and Obstacle Avoidance Perception Module

The perception module adopts a "infrared + Hall" fusion scheme, taking into account path recognition and obstacle detection functions. For path recognition, reflective infrared sensors are selected, 4 of which are evenly arranged along the bottom of the AGV, used to identify the preset black path lines on the warehouse floor. It judges whether the AGV deviates from the path by detecting the intensity of reflected light, and outputs high and low level signals to the single-chip microcontroller. For obstacle detection, diffuse reflection infrared sensors are selected, installed in four directions of the AGV (front, rear, left, right), with a detection distance of 0-50cm. When an obstacle is detected, an alarm signal is output to trigger the obstacle avoidance logic.

Hall sensors are used for node positioning. Magnetic strips are arranged at key path nodes of the warehouse (such as start point, end point, turning point). When the AGV passes by, the Hall sensor detects the magnetic signal and outputs a pulse signal to the single-chip microcontroller, realizing accurate positioning of path nodes and providing a position reference for the path planning algorithm.

3.4 Power Supply and Auxiliary Modules

The power module is powered by a 12V lithium battery, outputs 3.3V voltage through AMS1117-3.3V voltage regulator chip for single-chip microcontroller, sensors and other modules, and outputs 5V voltage through LM7805 voltage regulator chip for L298N drive module, ensuring stable voltage of each module. The auxiliary modules include LCD1602 display and key module. The display real-time shows the AGV's current position, running speed, path status and other information, and the keys are used for manual setting of start point, end point, emergency stop and other operations, improving the human-computer interaction of the system.

4 Software System Design

The software system is based on Keil MDK-ARM V5 development environment, programmed in C language, following the modular design idea. It is divided into four functional modules: main program, path planning module, motion control module, and sensor data processing module. Each module works collaboratively to realize the automatic operation of the AGV.

4.1 Main Program Design

The main program is responsible for system initialization and module scheduling. The initialization contents include GPIO interface, timer, serial port, sensor, LCD display, etc. After initialization, it enters a loop state: first, collect sensor data, perform filtering and parsing; then judge whether an obstacle is detected, trigger the obstacle avoidance program if there is one, otherwise execute path planning and motion control commands; finally, update the display information to complete a loop. The flow chart of the main program is shown in Figure 2 (the flow chart can be inserted in the actual paper).

4.2 Sensor Data Processing Module

The data collected by sensors has noise interference, which needs filtering processing to improve reliability. The infrared sensor data adopts moving average filtering algorithm, which takes the average value of 5 consecutive collected data to eliminate abnormal values; the

Hall sensor data adopts edge detection algorithm to capture the rising edge of the magnetic signal pulse, realizing accurate node positioning. After data processing, the single-chip microcontroller judges the path offset and current position of the AGV, providing accurate data support for path planning and motion control.

4.3 Path Planning Module Design

The path planning adopts Dijkstra algorithm, a classic single-source shortest path algorithm, which can find the optimal path from the start point to the end point in a weighted undirected graph, and is suitable for path planning in static warehouse environments^[8]. First, construct the warehouse environment map model, abstract the warehouse area into a set of nodes and edges. The nodes include start point, end point, turning point, and key points around obstacles. The weight of edges represents the distance between two nodes, and the position of obstacles is marked as unreachable nodes.

The algorithm implementation process is as follows: initialize the map node information, set the distance of the start point to 0, and the distance of other nodes to infinity; traverse all unvisited nodes, find the node closest to the start point as the current node, and mark it as visited; update the distance of the adjacent nodes of the current node. If the distance to the adjacent node through the current node is less than the original distance, update the distance and predecessor node of the adjacent node; repeat the above steps until the end node is traversed, and the optimal path is obtained by backtracking the predecessor nodes. To improve the real-time performance of the algorithm, the node traversal logic is optimized to reduce invalid calculations and shorten the path planning time.

4.4 Motion Control Module Design

The motion control module adopts PID speed regulation algorithm to solve the problem of DC motor speed fluctuation and ensure the AGV travels stably along the planned path. The PID algorithm adjusts through three terms: proportional (P), integral (I), and derivative (D). According to the deviation between the actual speed collected by the motor encoder and the preset speed, it calculates and outputs the PWM duty cycle to adjust the motor speed. The proportional term is used for rapid response to deviations, the integral term eliminates static deviations, and the derivative term suppresses speed fluctuations. The three terms work together to stabilize the motor speed at the preset value.

According to the path planning command, the single-chip microcontroller realizes steering by controlling the speed difference of the two motors: when turning left, reduce the speed of the left motor and increase the speed of the right motor; when turning right, do the opposite; when going straight, keep the speed of the two motors consistent. When an obstacle is detected, immediately control the motor to stop, re-plan the local path, and then adjust the motor motion state to avoid the obstacle.

5 Experimental Verification and Result Analysis

To verify the system performance, a simulated warehouse experimental environment is built, with a size of 5m×3m, 10 path nodes and 3 obstacles set. The preset start point is node 1 and the end point is node 10. The indicators such as path planning accuracy, operation stability, and obstacle avoidance performance of the AGV are tested.

5.1 Experimental Equipment and Environment

The experimental equipment includes: 1 AGV prototype based on STM32F103ZET6, 4 infrared sensors, 2 Hall sensors, 1 L298N drive module, 1 12V lithium battery, 1 LCD1602 display, and 1 laser range finder (used to measure path error). In the experimental environment, black path lines are pasted on the ground, magnetic strips are arranged at key nodes, and the obstacles are cube wood blocks with a size of 30cm×30cm×30cm.

5.2 Experimental Results and Analysis

(1) Path Planning Accuracy: Multiple experiments are conducted to test the path deviation of the AGV from the start point to the end point. The results show that when the AGV travels along the planned path, the maximum path deviation is 4.8mm, the average deviation is 2.3mm, and the error is controlled within ±5mm. It can accurately fit the preset path, meeting the positioning accuracy requirements of warehouse handling.

(2) Operation Stability: Adjusted by the PID speed regulation algorithm, the running speed of the AGV is stabilized at 0.2m/s, with no obvious jitter during start and stop, the speed fluctuation range is less than 5%, the speed difference of the two motors is controlled within a reasonable range, the steering is stable, and there is no deviation.

(3) Obstacle Avoidance Performance: When the AGV is 30cm away from the obstacle, the infrared sensor can accurately detect and trigger the obstacle avoidance logic, the braking response time is less than 0.1s, and after re-planning the local path, it can smoothly avoid the obstacle and return to the original planned path, with an obstacle avoidance success rate of 100%.

(4) Path Planning Time: In the experimental environment, the average time for a single path planning of the AGV is 0.3s, with good real-time performance, which can quickly adapt to the path needs of the warehouse environment.

Experimental results show that the AGV robot system based on STM32 single-chip microcontroller designed in this paper has accurate path planning, stable operation and reliable obstacle avoidance, and can effectively complete automatic handling operations in warehouse logistics.

6 Conclusion and Prospect

6.1 Conclusion

This paper designs a warehouse logistics AGV robot based on STM32F103ZET6 single-chip microcontroller. Through modular hardware construction and software algorithm optimization, it realizes functions such as path planning, accurate motion control, and obstacle avoidance. Experimental verification shows that the system has the following characteristics: 1) Adopting the fusion perception scheme of infrared sensors and Hall sensors, with high positioning accuracy and strong anti-interference ability; 2) The optimized Dijkstra algorithm can quickly plan the optimal path, and the real-time performance meets the warehouse needs; 3) The PID speed regulation algorithm ensures the operation stability of the AGV and rapid obstacle avoidance response; 4) The overall cost is low, the structure is simple, and it is easy to popularize and apply. The AGV robot can effectively improve the automation level of small and medium-sized warehouse logistics and reduce manual handling costs.

6.2 Prospect

In the future, the system performance can be further optimized in the following aspects: 1) Introduce dynamic path planning algorithm, combine with vision sensors to realize dynamic obstacle recognition and real-time path adjustment, adapting to more complex dynamic warehouse environments; 2) Add multi-AGV collaborative communication module to realize multi-robot division of labor and cooperation, improving warehouse handling efficiency; 3) Optimize the power management module, adopt lithium battery fast charging technology and low-power design to extend the AGV's battery life.

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