



(RESEARCH ARTICLE)



Design of a Dual-AGV Call System Based on STM32 and ZigBee

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Abstract

To address the challenges of path conflicts and communication in cooperative operation of dual Automated Guided Vehicles (AGVs) in industrial logistics, a low-cost intelligent dual-AGV calling system based on STM32 microcontroller and ZigBee wireless communication technology is proposed. The system employs the STM32F103C8T6 as the core controller, integrating TB6612 motor driver, TCRT5000 infrared tracking, and HC-SR04 ultrasonic ranging modules to achieve autonomous navigation and dynamic obstacle avoidance for AGVs. A star communication network is established via ZigBee for transmitting instructions from the host computer and receiving AGV status information. The core innovation lies in a dynamic avoidance strategy based on random priority decision-making: when the ultrasonic sensors detect an inter-AGV distance less than 40cm, a random number generation mechanism (seeded by ultrasonic ranging data) is triggered. Decision information is exchanged via ZigBee, and the AGV with the higher number gains priority passage. Experiments demonstrate that the system stably realizes dual-AGV cooperative calling, path tracking, and intersection conflict resolution, with an average response time of approximately 185ms. ZigBee communication exhibits a delay below 50ms and a packet loss rate less than 0.5%, providing a highly reliable and low-cost solution for flexible production line logistics.

Keywords: Dual-AGV; ZigBee; STM32

1. Introduction

With the advancement of industrial automation and logistics intelligence, Automated Guided Vehicle (AGV) systems are increasingly widely applied in modern manufacturing and warehousing logistics. Traditional single-AGV systems face efficiency limitations in complex scenarios and large-scale operations, making dual-AGV and multi-AGV collaborative operation crucial for enhancing logistics efficiency and production line flexibility. However, core challenges in multi-AGV coordination include path planning conflicts, real-time reliable communication, and efficient dynamic obstacle avoidance strategies [1].

Currently, AGV control systems predominantly employ high-performance microcontrollers. The STM32 series is widely adopted due to its excellent processing capabilities, rich peripheral interfaces, and low-power characteristics. Regarding communication, Wi-Fi and Bluetooth suffer from channel congestion, high latency (>500ms), and high packet loss rates (>10%), making them unsuitable for the high real-time requirements of multi-AGV coordination[2]. ZigBee technology, known for its low power consumption, self-organizing network capability, low cost, and moderate real-time performance (latency <50ms), is utilized in industrial sensor networks[3]. Nevertheless, its effectiveness in dynamic multi-AGV coordination requires further validation. For obstacle avoidance strategies, centralized scheduling algorithms exhibit high complexity, while distributed negotiation strategies necessitate simple yet effective conflict resolution mechanisms[4].

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To address these issues, this paper designs and implements a dual-AGV coordinated dispatch system based on STM32 and ZigBee. The core objectives of the system are: (1) to realize a low-cost, high-reliability dual-AGV hardware platform; (2) to construct a stable and efficient bidirectional wireless communication network; and (3) to design a simple and reliable distributed dynamic avoidance strategy. The system employs a host computer for unified scheduling, utilizes infrared line tracking for path following, senses neighboring AGVs using ultrasonic ranging, and innovatively incorporates a distributed decision-making mechanism based on random priority to resolve intersection conflicts. Experiments validate the system's effectiveness in coordinated calling, dynamic obstacle avoidance, and communication performance, providing a feasible approach for low-cost multi-AGV coordinated scheduling in industrial scenarios.

2. Overall structure design

The dual AGV collaborative calling system is designed to achieve the following core functions:

- The host computer sends start/stop call commands to specified AGVs via the ZigBee network;
- Upon receiving the commands, AGVs autonomously track and navigate along pre-set black trajectory lines;
- Real-time monitoring of the distance between the two AGVs, triggering an avoidance strategy when the distance falls below the safety threshold (40 cm);
- Negotiating passage order based on random priority to prevent collisions;
- AGVs transmitting ranging information back to the host computer's monitoring interface via ZigBee.

3. Hardware structure design

3.1. MCU Hardware System

The STM32F103C8T6 was selected as the core controller for the AGV. At the beginning of the design, a comparative analysis was conducted among STM32F103C8T6, STM32F407, and traditional 8051 MCUs to validate its suitability. While the STM32F407 offers higher performance, its elevated cost and power consumption render it unsuitable for the design's low-cost requirements. Conversely, the traditional 8051 MCU, despite its low cost, exhibits significant limitations in multi-sensor parallel communication and complex motion control algorithms[5]. Therefore, the STM32F103C8T6 emerged as the optimal choice due to its balanced performance, cost-effectiveness, and abundant peripheral resources.

3.2. Power Module Circuit Design

As the power supply hub for the AGV, the design quality of the power module directly influences the AGV's operational efficiency and reliability. In this design, a 7.4V Li-ion battery serves as the primary power source, with voltage conversion circuits configured to meet the requirements of different modules. The battery voltage is stepped down to provide a 3.3V supply for the control system and sensors[6]. Specifically, the 7.4V source connects directly to the VM port of the motor driver to ensure high-current output capability, while the control system generates a regulated 3.3V supply for the STM32F103C8T6 controller and peripheral sensors via a voltage regulator.

3.3. Motor and Drive Circuit Design

Given the DC power supply configuration, DC gear motors were selected to enhance system stability. The AGV employs DC 3V-6V gear motors with a torque of 0.8kg/cm and a reduction ratio of 1:48. These motors offer stable operation under varying speeds and signals, along with significant load-bearing capacity and distinct load characteristics. Speed regulation is achieved through armature voltage control, with precise PWM control implemented via the STM32F103C8T6's hardware PWM module[7]. The STM32 outputs two independent programmable PWM signals to the PWMA/PWMB inputs of the TB6612FNG motor driver. The TB6612FNG, a high-integration driver capable of bidirectionally controlling two DC motors independently, was chosen for its high efficiency, sufficient output capacity, and favorable performance-to-power ratio, making it ideal for compact, integrated motor control systems.

3.4. Line Tracking Hardware Design

The line tracking system utilizes three TCRT5000 infrared photoelectric sensors. These reflective optical sensors, consisting of an infrared emitter and a phototransistor encapsulated in a 3.5mm lead package with visible light filtering, operate by emitting infrared light and measuring the intensity of reflected signals to detect surface color changes. With a typical output current of 1mA and a peak working distance of 2.5mm, the TCRT5000 sensors are well-suited for industrial sensing applications. During operation, the sensors are positioned close to the ground, and their sensitivity can be adjusted via a potentiometer on the module to ensure consistent detection performance. When traversing a white

surface with a black tape path, the sensors trigger state changes upon encountering the black line, enabling the controller to adjust the AGV's trajectory accordingly.

3.5. Ultrasonic Ranging System

The HC-SR04 ultrasonic sensor module was selected for distance measurement. With a precision of 3mm and a measurement range of 2-400cm, it meets the design requirements while remaining cost-effective and easy to implement. Operation involves sending a trigger pulse of at least 10 μ s to the TRIG pin, which initiates an ultrasonic burst[8]. The ECHO pin then outputs a high-level signal proportional to the time taken for the ultrasound to reflect off an object and return. By timing this pulse width, the controller calculates the distance using the speed of sound. Continuous cycling of this process enables real-time distance monitoring essential for collision avoidance.

3.6. Host Computer System

Among popular host computer development tools such as Qt and Visual Studio, Qt was chosen for this design due to its cross-platform capabilities. As a comprehensive framework, Qt extends C++ functionality through its Meta-Object Compiler (MOC), enabling seamless development across Windows, Linux, iOS, and other operating systems. This allows software developed on one platform to be ported to others with minimal code modifications. For example, an industrial monitoring application developed on Windows can be easily adapted for Linux systems, reducing development time and maintenance costs while enhancing software portability across diverse hardware and operating environments.

3.7. Communication Module

The CC2530 system-on-chip (SoC) from Texas Instruments was selected for its ZigBee protocol compatibility. A high-performance, low-power 8051-core industrial-grade chip, the CC2530 operates reliably across a temperature range of -10°C to 125°C and features a robust RF core optimized for 2.4GHz ISM/SRD bands[9]. Its low-power characteristics make it ideal for end nodes in star topology networks, while its RF capabilities ensure reliable communication in mesh configurations. This design implements a star network topology with a coordinator and terminal nodes, chosen for its simplicity, ease of configuration, and suitability for small-scale, high-stability applications like dual-AGV systems.

4. Software architecture design

4.1. Motor Drive Control

Two PWM channels (TIM3_CH1 on PA6 and TIM3_CH2 on PA7) generate pulse-width modulation signals. Motor speed is regulated via TIM_SetCompare1(TIM3, pwmVal) and TIM_SetCompare2(TIM3, pwmVal). Direction control (forward/reverse) is achieved by configuring TB6612's AIN1/AIN2 and BIN1/BIN2 pins, enabling bidirectional movement and steering maneuvers.

4.2. Infrared Line Tracking

Three TCRT5000 sensors are connected to STM32 GPIO pins configured as pull-up inputs. The control logic interprets sensor states (e.g., 000=all white/stop, 010=center="center/drive straight", 110="left deviation/turn right", 011="right deviation/turn left") and invokes corresponding movement functions (CAR_Forward (), CAR_Left (), CAR_Right (), CAR_Stop ()).

4.3. Ultrasonic Ranging

The HC-SR04 module's Trig pin (PB9) is configured as a push-pull output to send trigger pulses, while the Echo pin (PB10) uses floating input mode with TIM2's input capture feature to measure pulse width. Distance calculations are formatted as strings (e.g., "\$carA,A2B,<distance_cm>\r\n") and transmitted via USART1 to the ZigBee module.

4.4. ZigBee Communication:Coordinator (IAR Z-Stack)

Manages network setup/maintenance and serial data forwarding. Routes commands from the host PC to target AGVs and relays sensor data back to the PC. Key configurations include network layer initialization, binding table management, and the GenericApp_ProcessEvent() handler.

4.5. End Nodes

Join the network, receive coordinator-relayed commands, and transmit sensor data. Serial data from STM32 is sent via AF_DataRequest(), while incoming coordinator messages are forwarded to STM32 over UART. Random Priority Conflict Resolution Algorithm:

4.6. Trigger Condition

Activates when ultrasonic sensors detect a distance <40cm for consecutive measurements.

4.7. Random Number Generation

Uses the sum of the last four distance readings (sum_dist) as a seed for srand(sum_dist), generating a random priority value (0 or 1) via rand() % 2. Decision Exchange: AGV1 sends the inverted random number (1-randNum) to AGV2 (e.g., "\$carA,INVER:X\r\n"). Priority Determination: AGV1 proceeds if randNum == 1, otherwise waits. AGV2 proceeds if received X == 1, otherwise waits. Recovery Mechanism: The low-priority AGV resumes movement once the distance exceeds 40cm.

This translation maintains technical accuracy while adapting terminology for international audiences. Key components like GPIO configurations, TIMx functions, and ZigBee protocols are preserved, along with the logical flow of the conflict resolution algorithm.

5. Verification and Analysis

To verify the system's functions and performance, a physical platform was built and a series of tests were carried out: Trajectory Following: By adjusting the height and sensitivity of the TCRT5000, the AGV can stably travel along the preset black trajectory line [10], as shown in Figure 1.

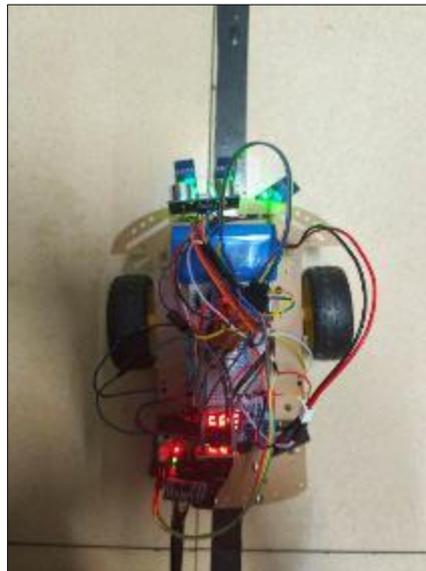


Figure 1 AGV Tracking Diagram

5.1. Ultrasonic Ranging

The measurement accuracy and stability of HC-SR04 at different distances were verified, and the data were accurately displayed through the serial port and the host computer.

5.2. ZigBee Communication

The serial port debugging assistant was used to test the data transmission between the coordinator and the terminal node, verifying that the transparent transmission function is stable and error-free.

5.3. Host Computer Functions

The Qt host computer successfully achieved the following: sending start/stop commands ("@PC,carX,1/0\r\n"); real-time receiving, parsing, and displaying the ranging information returned by the AGV. The host computer interface is shown in Figure 2.



Figure 2 Host Computer Debugging Diagram

5.3.1. Collaboration and Avoidance Verification

The core test scenario involved two AGVs traveling towards each other to a preset intersection, with the experiment repeated 20 times:

5.3.2. Trigger Reliability

The ultrasonic sensors reliably activated the avoidance process when the distance was <40 cm.

5.3.3. Decision Effectiveness

The random priority decision-making mechanism successfully resolved conflicts in all tests without collisions. The average response time for the decision-making process (parking, generating/exchanging random numbers, determining priority) was approximately 185 ms.

5.3.4. Passage Order

Priority determination conformed to randomness (each AGV had a ~50% probability of priority).

5.3.5. Restart Operation

After the distance recovered to >40 cm, the waiting AGVs correctly restarted trajectory following. The process is shown in the Figure 3.

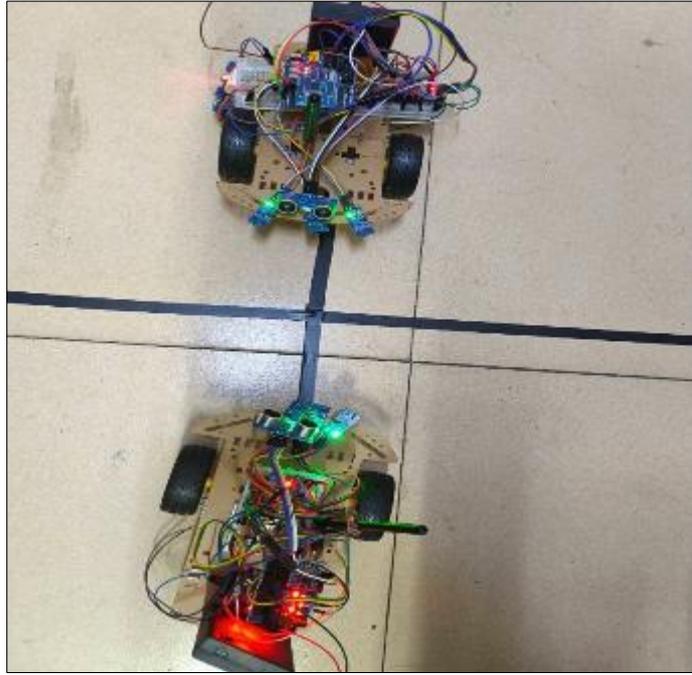


Figure 3 Physical Diagram of AGV Avoidance Decision at Intersection After Startup

6. Conclusion

This paper designs and implements a dual-AGV collaborative calling system based on the STM32F103C8T6 microcontroller and ZigBee wireless communication technology. Through modular hardware design, the system integrates infrared trajectory following, ultrasonic obstacle avoidance, motor drive, and low-power wireless communication functions. A distributed random priority dynamic avoidance strategy is innovatively proposed and implemented, effectively solving the conflict problem of dual AGVs at preset path intersections. The host computer software developed based on Qt provides an intuitive monitoring and command issuance interface.

Experimental verification shows that: 1. The system can stably receive commands from the host computer to achieve synchronous startup and autonomous trajectory following of dual AGVs; 2. The ZigBee communication network has a delay of less than 50 ms and a packet loss rate of less than 0.5%, ensuring reliable transmission of commands and status information; 3. The random priority avoidance mechanism triggered by ultrasonic ranging successfully avoided collisions in 20 intersection encounter tests, with an average decision response time of approximately 185 ms, demonstrating the effectiveness of the strategy.

This system features low cost, high reliability, and easy implementation, providing a practical solution for small-scale AGV collaborative applications in industrial logistics scenarios. Future work can focus on the following directions: Expanding to support collaboration of three or more AGVs and researching more complex conflict resolution algorithms (such as combining simple path planning); Integrating precise positioning technologies like UWB to achieve real-time AGV trajectory display on the host computer;

Enhancing environmental adaptability, such as dealing with dynamic obstacles; Optimizing random number algorithms or introducing lightweight negotiation protocols to improve decision-making efficiency.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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