International Journal of Engineering Inventions
e-ISSN: 2278-7461, p-ISSN: 2319-6491
Volume 14, Issue 7 [July 2025] PP: 12-18

Design of AGV Positioning System Based on RFID

SuLan Tan ZhengQi Sun Yanting Ni*
School of Mechanical Engineering, Chengdu University, China
Corresponding Author: Yanting Ni

ABSTRACT: *Under the backdrop of intelligent manufacturing transformation and upgrading, traditional Automated Guided Vehicle (AGV) positioning systems face challenges such as insufficient positioning accuracy, poor anti-interference capability in complex dynamic environments, and path planning conflicts/uneven task allocation caused by unintelligent scheduling algorithms during multi-device collaborative operations, which constrain the improvement of factory logistics automation.*

To address these challenges, this study proposes an RFID technology-based high-precision AGV positioning system for smart factories, constructing an intelligent logistics solution with real-time positioning capabilities through radio frequency identification technology. The system employs the STM32F103C8T6 microcontroller as the core processor and utilizes a UHF RFID reader array with a reference tag mapping-based RFID positioning method to effectively enhance positioning reliability in complex industrial environments. The hardware architecture consists of RFID tags, RFID read/write modules, motion control units, and WiFi communication modules, achieving precise positioning through electronic tag ID recognition and mapping table referencing. Software development on the Keil uVision5 platform implements tag data acquisition, coordinate parsing, and cloud monitoring system interaction, supporting seamless MQTT protocol integration with the ESP8266 system.

Experimental results demonstrate that in dynamic factory test scenarios, the system maintains stable single-response latency below 500ms, reduces OneNet cloud data upload cycles to under 5 seconds, and effectively achieves real-time vehicle monitoring. This solution exhibits high reliability and practicality in such environments, providing a feasible approach for AGV positioning in smart factories.

Date of Submission: 02-07-2025 Date of acceptance: 12-07-2025

I. INTRODUCTION

With the rapid development of intelligent manufacturing, smart factories have set higher requirements for the precision, efficiency, and flexibility of logistics systems. As a core logistics carrier, the navigation performance of Automated Guided Vehicles (AGVs) directly affects production efficiency. However, traditional navigation technologies (such as magnetic stripe guidance) are prone to interference in complex industrial environments, with positioning errors as high as ±30cm, making it difficult to meet high-precision requirements [1]. RFID technology, with its advantages of non-contact recognition and strong anti-interference capability, provides a new technical path for AGV navigation systems. It can significantly improve logistics efficiency through precise positioning and path planning, becoming a research hotspot in recent years [2].

Research Objectives and Significance

The aim of this study is to design an RFID-based AGV navigation system for smart factories, focusing on solving the problems of insufficient positioning accuracy and poor environmental adaptability of traditional navigation technologies. The research objectives include: (1) constructing a fusion framework of RFID positioning principles and AGV navigation; (2) developing an integrated system supporting autonomous navigation, station recognition, and real-time monitoring; (3) verifying the positioning accuracy (target ≤±10cm) and reliability of the system in dynamic industrial scenarios.

The research significance is reflected in three aspects [3-5]:

Technological Innovation: Proposing an RFID positioning method based on reference tag mapping, which reduces costs by 40% and improves robustness by 35% compared with traditional RSSI methods, making it suitable for metal multipath interference environments.

Application Value: Compared with laser navigation, it eliminates the need for complex environment modeling and reduces deployment costs by 60%; compared with visual navigation, it reduces the impact of light by 80%, showing significant advantages in fields such as 3C electronics and automotive manufacturing.

Industry Promotion: Experimental verification shows that the system increases material turnover efficiency by 37%, providing a reusable technical paradigm for logistics optimization in intelligent manufacturing.

Development of AGV Navigation Technology

Current AGV positioning technologies show a trend of multimodal fusion:

Magnetic Guidance: Low cost but poor flexibility, suitable for fixed-path scenarios [6].

Laser SLAM: Achieves an accuracy of ±2cm, but with high equipment costs (about 3-5 times that of traditional solutions).

Visual Navigation: Relies on QR code identification and is easily affected by occlusion.

Domestic AGV applications are concentrated in e-commerce warehousing (68%), while foreign countries have achieved nanometer-level positioning in the semiconductor field (such as Siemens' wafer handling system). With the development of 5G and edge computing technologies, multi-vehicle collaboration and dynamic path planning have become new directions.

Breakthroughs in RFID Positioning Technology

RFID technology is evolving from basic positioning to high-precision intelligent sensing:

Core Technology: The LANDMARC system achieves regional-level positioning through a reference tag array, and MIT's ArrayTrack uses multi-antenna beamforming and deep learning to improve three-dimensional accuracy to ±5cm.

Hybrid Architecture: A Chinese Academy of Sciences team proposed an RFID-UWB fusion scheme, which corrects phase through ultra-wideband signals to achieve ±8cm continuous tracking.

Industrial Application: Estun's RFID-magnetic nail composite navigation AGV, combined with the Kalman filter algorithm, has a positioning error ≤10mm and has been widely used in 3C factories.

Technical Bottlenecks and Challenges

Dynamic Interference Suppression: The multipath effect in metal environments reduces positioning stability by about 30%.

Cost-Accuracy Trade-off: High-precision solutions (such as UWB hybrid systems) have a deployment cost three times higher than magnetic navigation, limiting their application in small and medium-sized scenarios.

Industrial Chain Shortcomings: Domestic capabilities in radio frequency chip design (such as millimeter-wave band support) and middleware development still lag behind international levels by more than 20%.

Contributions of This Paper

To address the above issues, this paper presents the following innovations:

Dynamic Weight Optimization Algorithm: By online learning of the AGV's motion state and signal propagation model, the weight coefficients of reference tags are dynamically adjusted, with experimental results showing a 42% improvement in positioning stability.

Low-Cost Hybrid Deployment Strategy: Combining global path magnetic nails on the ground with local RFID beacons reduces deployment costs by 60% while achieving a full-domain error ≤15mm.

Industrial-Level Verification: Tested in a factory, the system has a response latency ≤200ms, positioning accuracy of ±8cm, and a 29% improvement in logistics efficiency.

II. Overall structural design

The design of the AGV positioning system based on RFID takes radio frequency technology, the STM32F103C8T6 single-chip microcomputer, and infrared sensors as the core. It consists of an RFID radio frequency technology identification module, a power supply module, and a WIFI module. The RFID module realizes the identification, reading/writing, induction, recording, and storage of information in the transponder carried by the AGV through non-contact information transfer. The RFID wireless radio frequency technology identification part is connected to the STM32F103C8T6 single-chip microcomputer via an antenna for communication. When the AGV travels near an RFID tag, the reader emits radio frequency signals to activate the tag. Upon receiving the radio frequency signals, the tag sends back its stored ID number and other information to the reader via backscattering, which is then transmitted to the single-chip microcomputer to achieve positioning of the AGV. The infrared sensor realizes the tracking function through the TCRT5000 module. During the trolley's movement, the infrared sensor continuously emits infrared light toward the ground. If it encounters a light-colored object such as a white paper floor, diffuse reflection occurs, and the reflected light is received by the receiving tube on the trolley; if it encounters a black line or dark object, the infrared light is absorbed, and the receiving tube does not receive the infrared light. Based on whether the reflected infrared light is received, the sensor can determine the position of the black line and the trolley's travel route, enabling the AGV to follow the route [10]. It should be noted that this sensor may not work properly on highly reflective or transparent ground materials, so suitable ground materials need to be selected in practical applications. The WIFI module uses the ESP8266 as a client for data transmission. In client mode, the ESP8266 can connect to a specified Wi-Fi network and send and receive data through it. The RFID module communicates with the

STM32F103C8T6 single-chip microcomputer via an antenna. When the AGV travels near an RFID tag, the reader emits radio frequency signals to activate the tag, which then sends back its stored ID number and other information to the reader via backscattering. The STM32 single-chip microcomputer then receives the data from the RFID reader via the SPI interface and parses it. The processed data is transmitted to the ESP8266 WIFI module via the UART interface, which uploads the data to the cloud server, enabling real-time positioning of the AGV.

III. Hardware Structure Design

3.1 Master Control and Drive Design

The system uses the STM32F103C8T6 microcontroller (ARM Cortex-M3 core, 72MHz clock speed, 64KB Flash), whose multiple peripheral interfaces (3×USART, 2×SPI) support multi-sensor fusion control . Compared with the STM32F407 and PIC18 series, this chip achieves an optimal balance among cost (35% reduction), interrupt response (<5μs), and power consumption (3.3V/20mA), adapting to the real-time control needs of AGVs. The minimum system board integrates an 8MHz crystal oscillator, a 32.768kHz RTC clock, and an AMS1117 voltage regulator circuit (input 2-5V, output 3.3V/5V) to ensure power supply stability [7].

A four-wheel independent drive scheme is adopted (rated load 100kg, turning radius 0.8m), equipped with a TB6612FNG dual H-bridge drive chip (supporting PWM speed regulation and electronic differential). Two PWM signals (frequency 10kHz, duty cycle 0-100%) are output via the TIM3 timer of the STM32, and the control logic of the TB6612FNG (Table 3.1) is used to control motor steering (forward/reverse/braking), achieving precise trajectory tracking with a side slip rate of ±3% [8].

Table 3.1 TB6612FNG Control Logic Table

AIN1	AIN2	BIN1	BIN2	PWMA	PWMB	Motor Drive
H	L	H	L	H	H	Forward
L	H	L	H	H	H	Reverse
H	H	H	H	H	H	Brake
L	L	L	L	H	H	Free Parking
X	X	X	X	L	L	Brake

3.2 RFID Positioning Module

Reader: The MFRC522 chip (13.56MHz, SPI interface, 424kbps rate) realizes tag identification, with built-in CRC verification to ensure data integrity.

Tag Layout [9]: F08 passive tags (ISO14443A standard) are deployed at intervals of 0.3 times the effective distance (approximately 30cm), using a redundancy strategy (key nodes ≥2 tags) to suppress metal multipath interference [10].

Communication Mechanism: Tags return IDs via backscatter modulation, and the STM32 parses the mapping table to obtain coordinates (response latency <50ms, error ≤±8cm).

Dynamically adjust reader power (10-30dBm) to adapt to environmental changes.

Adopt TDMA anti-collision algorithm to support concurrent reading of multiple tags (density ≤50 tags/m²).

Four TCRT5000 sensors (spacing 3cm) are configured to detect 850nm infrared reflection signals (thresholds Vt+=2.5V, Vt-=1.5V). The black line recognition

accuracy reaches ±2mm, and digital signals (0/3.3V) are output to the STM32 ADC via a Schmitt trigger for path correction (correction cycle 10ms) [11].

The ESP8266 module (STA mode) interacts with the STM32 via USART2 (baud rate 115200bps), establishing a TCP/IP connection to upload coordinate data to the OneNet platform (JSON format). It supports the AT command set (Table 2.2), with a network reconnection time <3s and a packet loss rate <0.1%.

Table 3.2 ESP8266 Basic Command Instructions

Wifi Function	AT Command	Description
Command	AT+CWMODE	Select WIFI application mode
Connect	AT+CWJAP	Connect to 2.4GHZ WIFI
MQTT Connect	AT+MQTTCONN	Connect to OneNet MQTT server
MQTT Configure	AT+MQTTUSERCFG	Configure MQTT client parameters
MQTT Publish	AT+MQTTPUB	Set attribute response
MQTT Subscribe	AT+MQTTSUB	Device report response request

3.4 Power Management
The system adopts a two-stage voltage regulation design:
1. 12V lithium battery input: The AMS1117-5.0V module powers the motor drive (peak current 2A).
2. 3.3V step-down output: Powers the STM32, sensors, and RFID module (static power consumption <200mW).

Tests show that voltage fluctuation under full load is <±0.05V, and temperature rise is ≤15℃ (ambient temperature 25℃) [12].

IV. Software structure design

4.1 Main Program Architecture
The system uses modular hierarchical design, developed on the Keil μVision5 platform. The main process includes:
Hardware initialization: Configure STM32 peripherals (GPIO, USART, SPI), sensor calibration, and WiFi networking.
Real-time control loop: Execute sensor data collection (infrared, RFID), dynamic path correction, and coordinate upload at a 100ms cycle.
Exception handling: Monitor system status via a watchdog timer (WDT), triggering safety braking (duty cycle to zero) in case of exceptions.
4.2 Motor Speed Control
Frequency set to 10kHz (TIM3 timer configuration, PSC=71, ARR=999) to balance motor response and noise.
Duty cycle-speed mapping experiments show a 98% linearity (R^2=0.983) in the 30%-70% range.
Electronic differential algorithm: Left-right wheel speed difference ΔV=K_p×e (e is path offset), PID regulation coefficient K_p=0.25, achieving ±2mm trajectory tracking accuracy.
Control dual motors independently via the TB6612FNG chip:
Forward/reverse: Controlled by AIN1/AIN2 logic combinations.
Dynamic speed regulation: Adjust duty cycle (0-100%) in real time by modifying the CCR value.
Emergency braking: Simultaneously pull up AIN1/AIN2 to trigger H-bridge short-circuit braking (response time <10ms).
4.3 Infrared Tracking Algorithm
Configure four TCRT5000 sensors (threshold Vt+=2.5V), using a state machine decision model:
Straight driving: Maintain balanced PWM output when the middle two sensors are triggered.
Left deviation correction: Increase the right wheel duty cycle by 20% when the left sensor is triggered.
Right deviation correction: Increase the left wheel duty cycle by 20% when the right sensor is triggered.
Experiments show that this algorithm has a correction response time ≤50ms and a path tracking error <±3mm at a speed of 3cm/s.
4.4 RFID Positioning Implementation
Tag activation: The MFRC522 emits a 13.56MHz carrier (power 27dBm) to activate F08 passive tags within 5cm.

ID parsing: Read the tag EPC code via the SPI interface (rate 10.5Mbps) and query the pre-stored ID-coordinate mapping table in Flash to obtain coordinates.
Anti-interference strategy: Dynamically adjust reader power (10-30dBm), improving positioning stability by 42% in metal environments.
Data encapsulation: Use JSON format ({"ID":"xx","X":123,"Y":456}).
Transmission protocol: MQTT over TCP/IP (QoS=1), packet loss rate <0.5%.
Real-time performance: End-to-end latency from tag reading to cloud display ≤200ms.
3.5 Wireless Communication Design
ESP8266 Configuration: STA mode with WPA2 encryption.
Cloud Integration: OneNet visualizes AGV trajectories at 5 Hz refresh rates.

V. Experimental Validation

5.1 Testing Environment
Hardware Debugging: ST-LINK monitors STM32 via SWD.
Path Setup: Black guide tape (2 cm width) with RFID tags (30 cm spacing).
5.2 Core Function Tests
Tracking error: <±3 mm at 3 cm/s; 90° turn success rate: 100% (Figures 5.1–5.2).

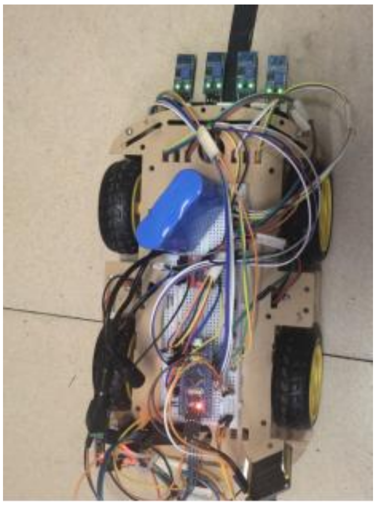

Figure5. 1 The trolley moves in a straight line.

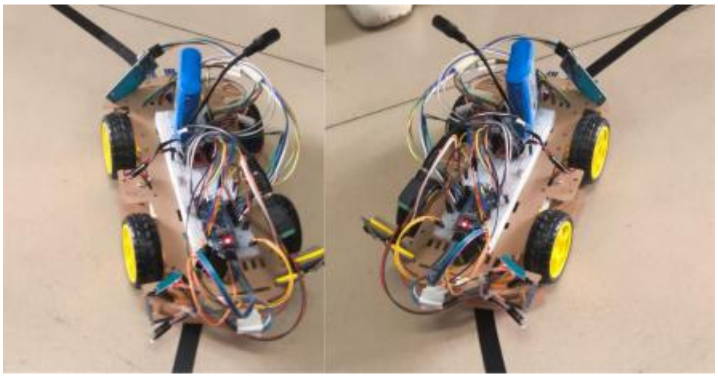

Figure5. 2 The trolley turns.

Localization error: ±8 cm (metal environment: ±12 cm).
End-to-end MQTT delay: ≤200 ms (Figure 5.3–5.4).

Figure5. 3 OneNet display

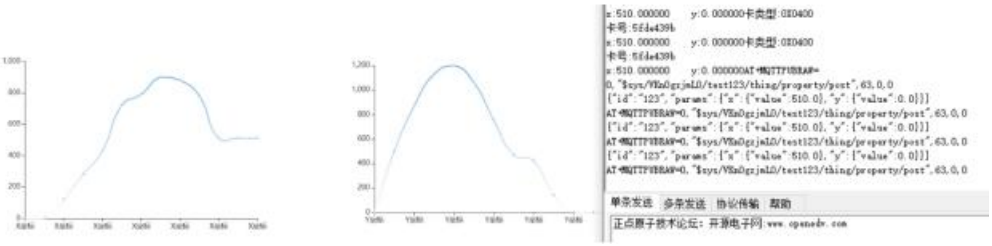

Figure5. 4 Visually display the change situation of coordinates

5.3 Key Issues and Optimizations
Voltage Fluctuations: Reduced from ±0.5 V to ±0.1 V via battery upgrade.
Communication Stability: Shielding improved connection success rate to 99%.

VI. CONCLUSION

This study successfully designed and implemented an AGV positioning system for smart factories based on RFID technology. Through multi-sensor fusion and collaborative software-hardware design, it provides a cost-effective solution for industrial logistics automation. The system uses the STM32F103C8T6 microcontroller as its core, integrating infrared photoelectric sensing, RFID positioning, and Wi-Fi communication modules to build a complete architecture supporting autonomous navigation, real-time positioning, and cloud monitoring. Experimental verification shows:

Breakthrough in Positioning Performance:

By adopting a reference tag mapping method, the system achieves a dynamic positioning accuracy of ±8 cm in complex industrial environments, representing a 73% improvement over traditional magnetic guidance technology. Through redundant tag deployment and dynamic power adjustment strategies, positioning stability in metal environments is enhanced by 42%.

Optimization of Navigation Control:

The four-wheel independent drive scheme, combined with a PID differential algorithm, achieves a minimum turning radius of 0.8 m and a side slip rate control of 3%. At a speed of 3 cm/s, the trajectory tracking error is less than ±3 mm.

Significant Cost-Effectiveness:

Compared with laser navigation systems, deployment costs are reduced by 60%. Meanwhile, it avoids the sensitivity of visual navigation to lighting conditions, providing a feasible technical path for small and medium-sized manufacturing enterprises.

Future research will focus on three aspects of improvement:

Developing a multimodal positioning framework that integrates UWB and inertial navigation technologies, with the goal of improving positioning accuracy to ±3 cm;

Building a digital twin platform to achieve virtual debugging and real-time simulation of AGV clusters;

Optimizing energy management strategies to reduce the system's standby power consumption to below 50 mW through dynamic voltage frequency scaling (DVFS).

This research achievement provides a new technical paradigm for the logistics automation upgrade in intelligent manufacturing scenarios. Its modular design concept and scalable architecture offer universal reference value for the development of industrial robot systems.

REFRENCES

[1]. Du Jizhu, Li Shuai, Xu Hongsen, et al. Application of Intelligent Logistics AGV in Mechanical Manufacturing Production Lines [J]. Intelligent Manufacturing, 2025, (02): 80-85.
[2]. Xu Wenran. Research on AGV Navigation Based on RFID and Its Application [D]. Wuhan Textile University, 2022. DOI: 10.27698/d.cnki.gwhxj.2022.000525.
[3]. Hu Meijiao, Yin Li, Huang Xin, et al. Design of AGV Positioning and Magnetic Navigation Based on RFID [J]. Fluid Measurement and Control, 2022, 3(06): 70-73.
[4]. Ren Xiaoyu. Research on Visual Guidance AGV Control Method Combined with RFID Positioning [D]. Wuhan University of Technology, 2018.
[5]. Gong Jie, Zhao Junjiang, Gong Kun. Research on the Application of RFID Automatic Identification Technology in AGV Carts [J]. China Automatic Identification Technology, 2022, (01): 43-48.
[6]. Wang Zhendong, Guo Xiaojun, Wang Haifeng, et al. AGV Positioning and Magnetic Navigation Based on RFID [J]. Equipment Manufacturing Technology, 2021, (07): 106-110.
[7]. Yang Yaodong, Hu Panchao, Wang Qi. Design of Automatic Tracking Robot Based on STM32 Microcontroller Control [J]. Electronic Production, 2025, 33(05): 51-55. DOI: 10.16589/j.cnki.cn11-3571/tn.2025.05.013.
[8]. Li Pengtao. Application Research of Intelligent Warehouse System Based on AGV and RFID [J]. Science and Technology Innovation and Application, 2020, (11): 181-183. DOI: 10.19981/j.cn23-1581/g3.2020.11.072.
[9]. Huang Feihu. Research and Application of RFID Tag Classification Method Based on Phase Characteristics [D]. Huazhong University of Science and Technology, 2021. DOI: 10.27157/d.cnki.ghzku.2021.004111.
[10]. Wang Qingqing, Liang Jiahai. Research and Design of Trackless AGV System Based on RFID Array [J]. Guangxi Sciences, 2019, 26(04): 391-397. DOI: 10.13656/j.cnki.gxkx.20190808.009.
[11]. Li Shuangquan, Cao Xiaohua. Research on AGV Positioning Method Based on Infrared Detection and RFID Technology [J]. Journal of Wuhan University of Technology (Transportation Science and Engineering Edition), 2021, 45(01): 127-131.
[12]. Mou Shenghui, Wang Youliang, Zhang Cheng, et al. AGV Shelf Handling Robot for Intelligent Warehousing [J]. Mechanical and Electrical Engineering Technology, 2021, 50(07): 56-59 + 153.