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Design of an Intelligent Drug Delivery AGV Cart Control System

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ABSTRACT: *With the increasing strain on medical human resources and the heightened risk of cross-infection, traditional manual drug delivery methods can no longer meet modern hospitals' demands for efficient and precise distribution. Intelligent drug delivery carts, leveraging their automated and contactless delivery capabilities, have emerged as a critical technological direction for transporting medical resources. This paper presents the design and implementation of an intelligent drug delivery cart system based on the STM32F103C8T6 microcontroller, aiming to enhance the accuracy, safety, and efficiency of pharmaceutical logistics through the integration of embedded control and IoT technologies, thereby providing a reliable solution for hospital digitalization.*

The intelligent drug delivery cart employs the STM32F103C8T6 as its core controller, integrating a five-channel infrared tracking module, infrared obstacle avoidance module, HX711 pressure sensor, and ESP8266 wireless communication module to achieve environmental perception and autonomous path tracking. The system identifies preset routes using five infrared sensors and detects pedestrians or obstacles in real-time via the infrared obstacle avoidance module. The pressure sensor monitors drug-loading status to trigger delivery workflows. Utilizing the Alibaba Cloud IoT Platform, users can remotely issue delivery commands or adjust target wards through cloud interfaces, enabling seamless human-machine interaction. The hardware design incorporates a main control circuit, sensor array, motor driver module, and user interface, featuring a compact layout and robust anti-interference capabilities. Software development, based on the Keil µVision5 environment, implements core functionalities such as path planning, obstacle avoidance decision-making, and drug status sensing. This design not only significantly reduces the workload of medical staff but also minimizes cross-infection risks through contactless delivery, offering robust technical support for smart hospital initiatives.

Test results demonstrate stable system performance in complex hospital environments, defined by variable lighting conditions (day-night illumination differences in wards), diverse floor materials (tiles, carpets), and dynamic obstacle density (crowded pedestrian flows). The system effectively alleviates medical staff burdens and reduces nosocomial infection risks, validating its practical value. Future enhancements could include deep learning algorithms for optimized path planning, RFID integration for drug traceability, or multi-agent collaboration to further improve system intelligence and scenario adaptability, advancing the technological foundation for smart healthcare.

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I. INTRODUCTION

With the rapid development of the medical industry, the efficiency and accuracy of hospital drug delivery have become key factors in enhancing medical service quality. However, traditional manual drug delivery models have long faced problems such as low efficiency, high error rates, and significant labor costs. Especially in crowded hospital environments, medical staff frequently travel between pharmacies and wards, consuming considerable time. The complexity of drug types and patient information also easily leads to delivery errors, potentially causing medication safety hazards. Particularly during special periods when personnel are often reassigned, the shortage of human resources within the medical system is further exacerbated[1,2].

This research utilizes the STM32F103C8T6 as the core controller to build an intelligent drug delivery robot system for hospital environments. The hardware system comprises five main modules: The path tracking perception layer uses TCRT5000 infrared sensors (detection range 1-57cm) and a five-channel TCRT5000 infrared reflective sensor module for obstacle detection and route tracking, respectively. The drug perception unit integrates an HX711 pressure sensor (accuracy ±1g) to ensure accurate drug delivery through a weight sensing mechanism. The drive control layer employs a TB6612FNG dual-motor driver module, supporting PWM speed control and emergency braking. The interaction terminal is equipped with a touchscreen and WiFi communication module, enabling command issuance from nursing stations and cloud data synchronization. The power management system, based on a 12V lithium battery pack and an LM2596 voltage regulator circuit, provides an operational endurance of up to 10 hours. For software design, the Keil software environment is used to implement cart functions including obstacle avoidance, path tracking, alarm triggering, and human-machine interaction.

The core objectives of the system are: (1) To enhance medical efficiency and safety. The robot can operate 24/7, shortening single delivery times through path optimization. The contactless delivery mode reduces the risk of cross-infection within the hospital. Precise obstacle avoidance and drug perception functions minimize human operational errors, ensuring patient medication safety. (2) To optimize medical resource allocation and improve human resource utilization. By interfacing drug traceability functions with the Hospital Information System (HIS), real-time sharing of delivery data is achieved, aiding in refined hospital management. (3) To promote the intelligent transformation of healthcare, facilitating the application of artificial intelligence, IoT, and other technologies in medical scenarios. Accumulated achievements in sensor fusion and autonomous navigation algorithms can be extended to areas such as disinfection robots and surgical assistant robots. (4) To generate social and economic value by reducing hospital operational costs. Enhancing patient satisfaction through fast and accurate delivery services shortens patient waiting times and improves the medical experience.

II. Overall System Design

The primary tasks of the STM32-based intelligent drug delivery cart are:

The intelligent drug delivery cart can autonomously navigate complex hospital environments with high pedestrian traffic by following pre-set routes using its intelligent path tracking module.

The obstacle avoidance function of the intelligent drug delivery cart enables it to detect obstacles in the surrounding environment in real-time and stop. After the obstacle in front of the cart is removed, the cart can resume path tracking. This requires solving problems related to obstacle avoidance and path tracking, ensuring the cart can obtain the positional relationship between obstacles and the moving cart[3].

The HX711 pressure sensor used by the intelligent drug delivery cart detects weight, determining whether drugs are placed on the cart or have been removed based on weight changes.

In summary, the main role of the STM32-based intelligent drug delivery cart is to achieve autonomous path tracking, obstacle avoidance, and drug delivery functions within the hospital environment. This enhances nurse work efficiency while ensuring the safety of the cart itself and surrounding pedestrians in the hospital setting.

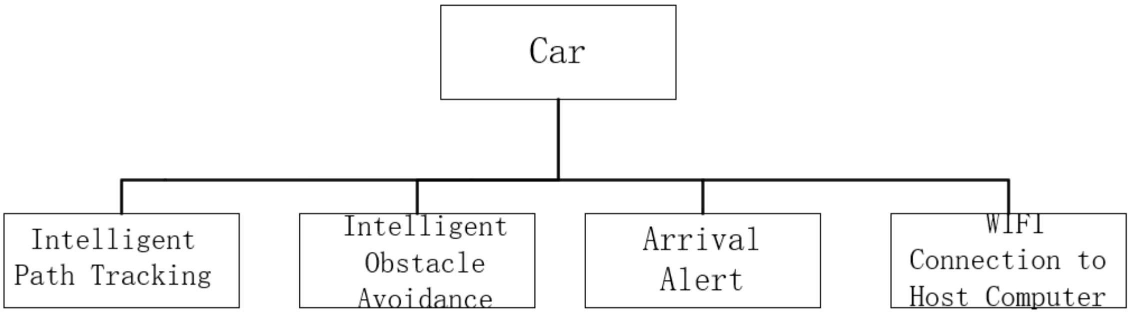

Figure 1.1 Overall System Structure Diagram

(1) Main System Functions and Composition

The system mainly consists of the following modules, as shown in Fig. 1.2:

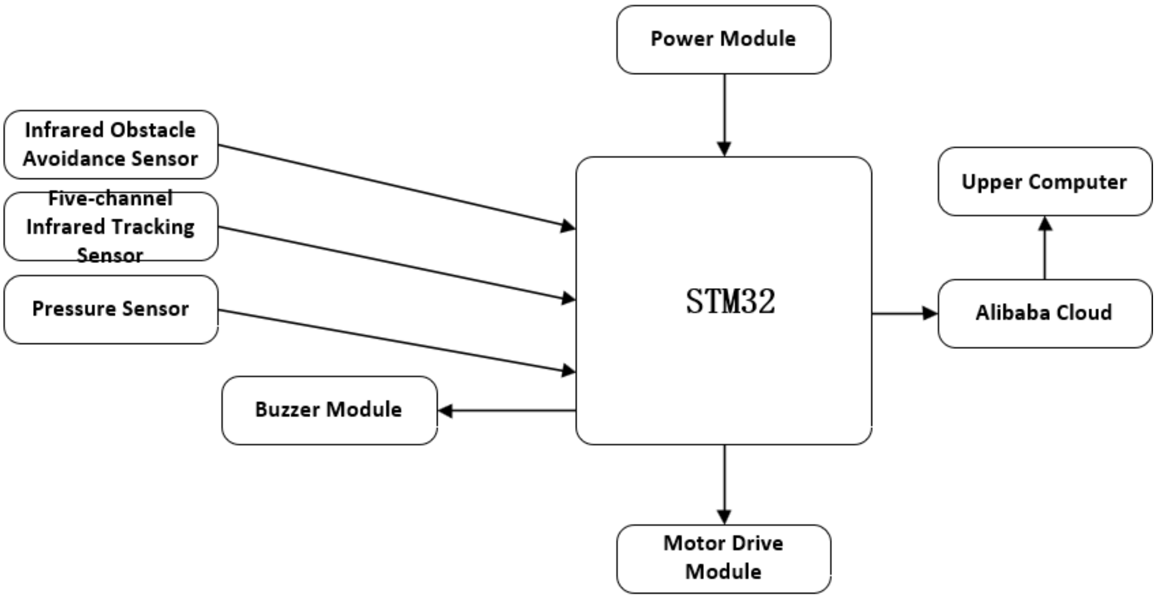

Fig. 1.2 Structure Diagram of Intelligent Drug Delivery Cart

Main Controller: STM32F103C8T6 microcontroller, primarily used for sensor data acquisition, drive control, logic operations, and task scheduling.
Drive Module: TB6612FNG module, used to drive the four motor modules, controlling the cart's steering and speed via PWM.
Pressure Module: HX711 module, used to detect whether drugs are placed on the cart.
Path Tracking Module: Five-channel infrared path tracking module, used to detect the tracking path.
Obstacle Avoidance Module: Infrared obstacle avoidance module, used to detect obstacles.
Buzzer Module: A buzzer is used to alert patients when drugs arrive.
Power Module: Powered by a 7.4V lithium battery, stepped down to 5V using an LM2596S buck module to power other modules.

(2) **System Workflow**

The main workflow of the intelligent drug delivery robot is as follows: Power is supplied to the cart, and all modules are initialized. The cart then enters standby mode at the nursing station. The cart's pressure sensor begins determining whether drugs have been placed on it. Once drugs are placed, the host computer issues a command, and the cart starts path tracking. Upon reaching the designated ward, the cart's buzzer sounds an alarm to alert the patient in the room to retrieve the drugs. The pressure sensor then determines whether the drugs have been taken. Once it detects that the drugs have been removed, the cart returns along the original route. The main workflow of the cart system is shown in Fig. 1.3.

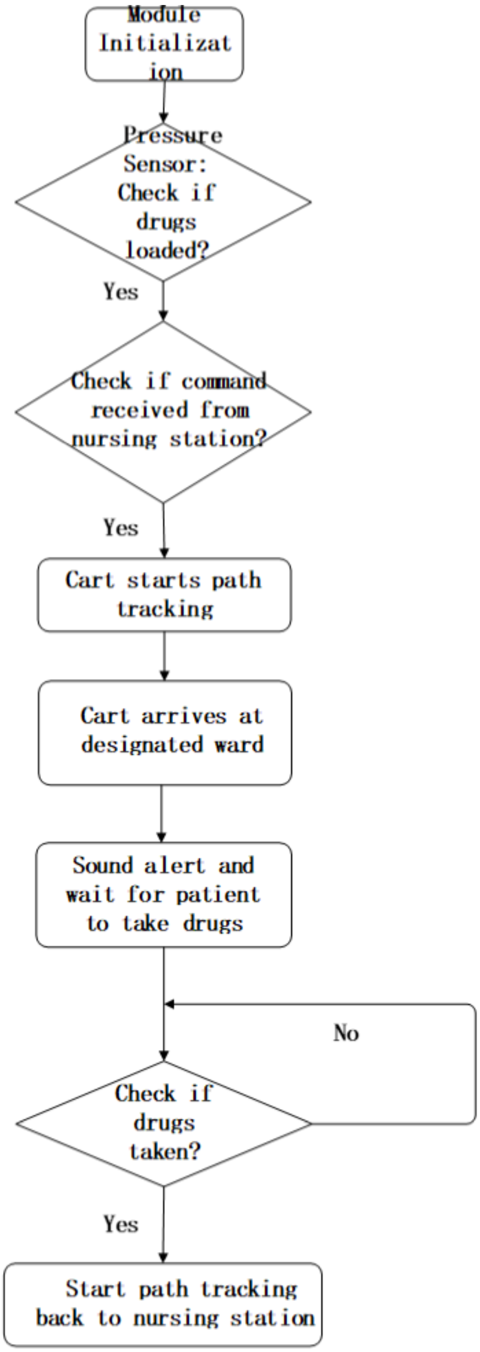

Fig. 1.3 Main Workflow Diagram

III. Hardware Structure Design

(1) Microcontroller Hardware System

The microcontroller selected for this cart is the STM32F103C8T6. Compared to traditional 51-series microcontrollers, the STM32F103C8T6's architecture and high operating frequency significantly enhance data processing efficiency, making it suitable for real-time control (such as parallel multi-sensor acquisition). It possesses built-in function libraries and supports C programming[4], whereas 51 microcontrollers are prone to performance bottlenecks in real-time tasks. Furthermore, the STM32's rich peripheral set (such as hardware PWM, ADC, multiple communication interfaces) allows direct driving of motors and reading sensor data, reducing the need for external expansion chips. In contrast, 51 microcontrollers require substantial peripheral support, increasing circuit complexity and cost. The STM32's low-voltage operation and power modes are better suited for battery-powered mobile devices. Therefore, the STM32F103C8T6 is a suitable choice for products with strict power consumption requirements[5].

In summary, the core main control board selected for the intelligent drug delivery cart designed in this paper is the STM32F407VET6 (Note: *Inconsistency with previous mention of STM32F103C8T6, translated as written*). It features a 32-bit high-performance ARM core operating at 72 MHz; memory includes 20 KB RAM and 64 KB FLASH; it contains 37 general-purpose I/O pins, 2 ADC channels (12-bit precision), and 3 UART interfaces[4].

(2) **Power Module**

The LM2596S was chosen for the power module. This LM2596S voltage regulator module offers many advantages, such as high efficiency and low power consumption. The module incorporates switching frequency design to reduce energy loss. It provides flexible output regulation and a wide input voltage range (2.5V~35V), compatible with various power sources and meeting different load demands. This intelligent drug delivery cart uses the LM2596S voltage regulator module for appropriate power voltage conversion. The LM2596S module has an input voltage range of 2.5V~35V and an output voltage range of 1.25V~35V, satisfying the 5V requirement of our intelligent drug delivery cart.

(3) **Motor and Drive Module**

The cart selects DC geared motors as its power core. This motor solution not only offers high load-carrying capacity but also operates stably under conditions of varying speed and signal instability. It exhibits significant load characteristics, greatly enhancing the cart's stability. While PWM can be used to control motor speed, directly using PWM waves to change the voltage across the motor terminals to achieve forward, reverse, and stop is often complex and offers low real-time performance, imposing a burden on the STM32 main control chip. Therefore, the intelligent drug delivery cart designed in this paper uses a motor driver chip to implement driving and speed control functions. The selected motor driver chip is the TB6612FNG driver IC. Its internal MOSFET-H bridge structure can withstand large currents and features dual-channel output circuitry capable of driving two motors simultaneously.

（4） **Obstacle Avoidance Module**

This intelligent drug delivery cart requires obstacle avoidance in the specific conditions of a hospital. The component used is an infrared photoelectric reflective sensor. The infrared photoelectric reflective sensor module mainly consists of an infrared emitting diode (IR LED), an infrared receiving transistor (phototransistor), a comparator circuit, and an adjustable potentiometer. The obstacle avoidance principle of the infrared photoelectric reflective sensor is primarily based on the emission and reflection characteristics of infrared light. It judges whether there is an obstacle ahead by determining the reflective characteristics of the surface color.

（5）**Path Tracking Module**

This intelligent drug delivery cart requires autonomous path tracking in the specific conditions of a hospital. The module used for autonomous path tracking is a five-channel TCRT5000 infrared sensor. The five-channel TCRT5000 infrared sensor is composed of 5 independent TCRT5000 modules. The principle of using infrared photoelectric sensors for path tracking relies on the differing reflective capabilities of black and white objects to infrared light. The sensor drives its internal photodiode or phototransistor using the received reflected infrared light of varying intensity, generating corresponding electrical signals of different strengths. The internal current-to-voltage conversion circuit then converts this current into high/low-level electrical signals for use by the microcontroller (here mentioned as STC89C52, translated as written) to complete the intelligent path tracking process[6].

（6）**Pressure Module**

The HX711 is a 24-bit A/D converter chip specifically designed for high-precision electronic scales[7]. This chip integrates a regulated power supply, on-chip clock oscillator, and other peripheral circuits required by similar chips, offering advantages such as high integration, fast response speed, and strong anti-interference capability[7]. This part consists of a weight sensing chip, strain gauges, and a tray. Its circuit is a sensor circuit based on the Wheatstone bridge principle, composed of the bridge and an amplifier[8]. When the cart's HX711 pressure sensor detects pressure, it indicates drugs are on the cart. When no pressure is detected, it indicates drugs are not on the cart.

（7）**Alert Module**

When the intelligent drug delivery robot delivers drugs to a ward, it emits an alarm sound to alert the patient. This is implemented using an active buzzer. The cart uses a low-level triggered active buzzer. Its core lies in the built-in oscillation and drive circuits, controlling the circuit's on/off state via an external low-level signal to produce sound output. When the external control signal outputs a low level, the drive circuit conducts, applying the power supply voltage to the buzzer's internal circuit. Low-level triggering avoids the risk of false triggering.

A base pull-down resistor ensures the transistor reliably turns off. Additionally, to prevent the buzzer from burning out due to excessive current, the transistor's pull-up resistor also serves a current-limiting function. Its core advantages are simple control and high reliability.

（8）**Communication Module**

This intelligent drug delivery cart uses a communication module to achieve wireless communication between the STM32 microcontroller and the host computer. After comparing multiple options, a WiFi wireless communication module was selected as the bridge between the cart and the host computer. Various modules were considered, such as Bluetooth, ZigBee, and WiFi. Although Bluetooth offers low power consumption, low cost, flexible connection, and ease of use, its short transmission distance and weak penetration led to its rejection. ZigBee offers low power consumption, low latency, and a transmission distance suitable for the cart's application scenario, but its low transmission rate and complexity in interfacing with IP protocols were drawbacks. WiFi communication technology features long-distance transmission and strong penetration, enables high-speed transmission over relatively long distances, and offers high bandwidth, low power consumption, and high security, making it the optimal choice for the intelligent drug delivery cart designed in this paper[8].

The wireless communication module selected for this intelligent drug delivery cart is the ESP8266-01S module. This is a low-cost, highly integrated WiFi module introduced by Espressif, widely used in IoT and embedded wireless communication fields.

IV. Software Structure Design

（1）**Motor Drive**

PWM signals are generated using TIM4 Channel 1 (PB6) and Channel 2 (PB7). The configuration involves: enabling the GPIO port clock, defining and configuring the GPIO initialization structure (Mode: Alternate Function Push-Pull Output (GPIO_Mode_AF_PP); Output Speed: 50MHz), initializing GPIOB. Configuring TIM4 timer using the internal clock source, defining and configuring the timer base parameter initialization structure (Clock Division: TIM_CKD_DIV1 (no division); Counter Mode: Up (TIM_CounterMode_Up); Period: 99 (i.e., ARR value of 100-1); Prescaler: 35 (i.e., 36-1); Repetition Counter: 0), then initializing TIM4.

These configurations collectively implement PWM signal output settings for controlling motor speed and direction. Adjusting the prescaler and period values changes the PWM frequency and duty cycle.

（2）**Path Tracking**

The path tracking module of this intelligent drug delivery cart uses infrared photoelectric sensors. An infrared photoelectric sensor consists of an infrared emitting diode and a receiving transistor. When infrared light is reflected back from an object, the receiving transistor detects the signal. If the reflecting surface is black, it absorbs more infrared light, resulting in a weak signal at the receiver; white surfaces reflect more, resulting in a strong signal. Therefore, when the infrared receiver detects the weak infrared light reflected from a black line, it generates an electrical signal. This signal can be read by the STM32, and based on the written program, enables the cart to perform autonomous path tracking[9]. Typically, multiple sensors (e.g., one on the left and one on the right) are used during cart tracking to determine position by detecting the black line. If the cart deviates from the black line, the sensor output levels change, and the control system adjusts the motor direction. For example, if the left sensor detects the black line and the right sensor does not, the cart may need to turn left.

The code logic described:

If GPIOA.6, GPIOA.7, GPIOA.12, and GPIOB.1 are all high (1), call Go_Ahead() to move forward.

If GPIOA.6 and GPIOA.7 are low (0), while GPIOA.12 and GPIOB.1 are high (1), call Self_Left() to rotate left in place.

If GPIOA.6 and GPIOA.7 are high (1), GPIOA.12 is low (0), and GPIOB.1 is high (1), call Turn_Left() to turn left.

If GPIOA.7 is high (1) and others are low (0), call Turn_Right() to turn right.

If GPIOA.6 is high (1) and others are low (0), call Self_Right() to rotate right in place.

（3）**Pressure Detection and Obstacle Avoidance**

The pressure detection part of this intelligent drug delivery cart, determining whether drugs are placed on it, uses the HX711 pressure sensor. It judges the presence of drugs based on whether pressure is detected. When the cart's pressure sensor senses pressure, it determines that drugs are on the cart. When no pressure is sensed, it determines drugs are not on the cart.

When the intelligent drug delivery cart encounters a person blocking its path while tracking, the cart stops and waits for the pedestrian to move aside. When the cart reaches the designated ward door, it also stops, and the buzzer sounds an alert to prompt the patient to retrieve the drugs.

（4）**Wireless Communication**

After connecting the Wi-Fi wireless communication module to the microcontroller and powering it on, the module starts working. The process involves: initializing the serial port, enabling global interrupts on the microcontroller. When a signal is output, it enters the global interrupt, then enables the serial port interrupt. When data needs to be sent, it enters the serial port interrupt[10]. Subsequently, the timer is started, the serial port working mode is set, and finally, the timer initial value is set, completing the entire process. The serial port facilitates communication between the microcontroller and the ESP8266 wireless communication module.

V. Verification and Analysis

To realize the preset functions of the intelligent drug delivery cart, it is recommended to lay a loop of black tape on the light-colored flooring surface of hospital corridors or pharmacy areas as the navigation track. This path should form a continuous closed loop, ensuring clear and stable boundaries of the tape at straight sections and turns to provide a high-precision directional reference for the cart's motion control system. For testing the obstacle avoidance function, common hospital equipment (such as infusion stands, medicine cabinets) or temporarily placed obstacles (e.g., traffic cones) can be utilized. The infrared module should detect obstacles ahead in real-time and trigger avoidance actions.

Five infrared path tracking sensors are mounted underneath the cart. During installation, attention must be paid to the distance between these sensors and the ground; neither too far nor too close, with an optimal height of approximately 1cm~3cm. After installation, the sensitivity of each sensor should be adjusted. During debugging, ensure there is no delay when the cart's infrared tracking modules simultaneously detect the black line. If delays occur, adjust them using the potentiometers.

After assembling the cart's path tracking module, place the cart on the pre-arranged route to begin tracking. First, select a route on the small application interface. The interface is shown in Fig. 4.1.

Fig. 4.1 Route Selection Interface

Then place the drugs on the cart and observe whether the cart follows the designated route. As shown in Fig. 4.2.

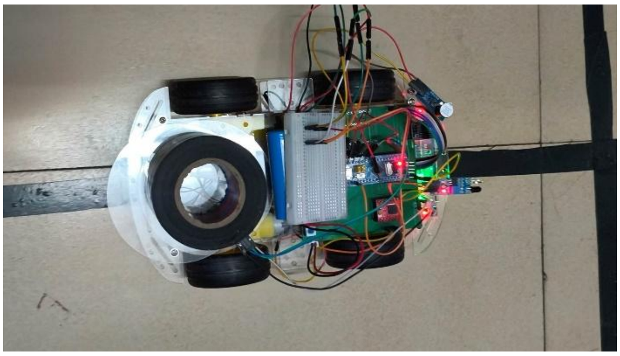

Fig. 4.2 Cart Moving Straight

An infrared obstacle avoidance sensor module is installed on the front of the cart. When an obstacle appears ahead on the path, the cart should stop moving forward, wait for the obstacle to move away, and then resume movement. As shown in Fig. 4.3, the cart stops upon encountering an obstacle and waits for it to be removed.

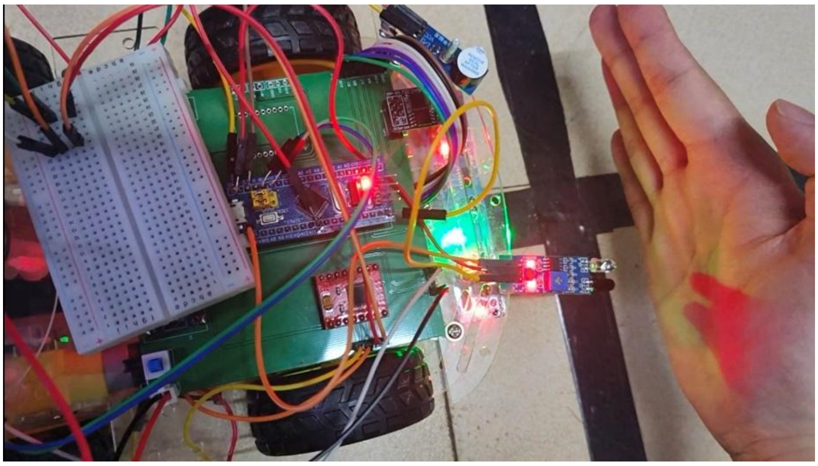

Fig. 4.3 Cart Encountering an Obstacle

After removing the obstacle, the cart continues tracking along the planned route. When the cart reaches the target ward, it first stops and then the buzzer sounds an alert to prompt the patient to retrieve the drugs. After the patient removes the drugs, the cart returns along the original path. The cart arriving at a ward is shown in Fig. 4.4.

Fig. 4.4 Cart Arriving at the Designated Ward

VI. Conclusion

This cart, with the STM32F103C8T6 microcontroller as its core controller, successfully implements functions such as autonomous path tracking, dynamic obstacle avoidance, drug placement monitoring, and cloud interaction through the combination of multi-sensor fusion and IoT technology. During the drug delivery process, the cart can detect obstacles, stop moving when encountered, and sound an alert via the buzzer upon reaching the designated ward. The cart then returns along the original route. During both delivery and return, the cart navigates autonomously and turns smoothly. However, the intelligent drug delivery cart is not without flaws. For instance, the current path tracking module is still limited to fixed paths. Future improvements could include using a lightweight YOLOv5s model for real-time recognition of dynamic obstacles (like moving hospital beds). Secondly, the mechanical structure lacks integrated drug sorting functionality, requiring manual pre-loading, which limits full automation. When conditions permit, an MFRC522 RFID module could be integrated into the bottom of the drug box to read passive RFID tags on drug packaging, enabling cloud synchronization of drug batch and expiry information. Tag data would be uploaded to the Alibaba Cloud database via ESP8266 and interfaced with the hospital HIS system to ensure medication safety. Thirdly, the cart currently only delivers drugs for one patient per trip. Future versions could deliver drugs for multiple patients, potentially using ZigBee networking technology to establish a master-slave communication framework. A master robot could coordinate

3-5 slave robots for collaborative delivery using dynamic task allocation algorithms. Finally, adapting to more diverse scenarios (like operating rooms, isolation wards) could involve designing a sterile housing with a UV disinfection module. Optimizing the path planning algorithm is also crucial; options like PID control, A* algorithm, or fuzzy control were considered. PID control offers high real-time performance and low hardware overhead, is suitable for fixed path tracking, and has low computational requirements, making it well-suited for the STM32's resource constraints.

This research, through the integration of embedded technology and IoT platforms, validates the practicality and feasibility of the intelligent drug delivery cart in hospital scenarios. The system demonstrates significant advantages in cost, efficiency, and safety, providing a technical reference for the intelligent transformation of healthcare. In the future, with advancements in artificial intelligence and edge computing, intelligent drug delivery systems are expected to become an important component of smart medical infrastructure, promoting the development of medical services towards higher efficiency and safety.

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