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Design of Voice Interactive Industrial Control System

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Abstract: *In order to improve the intelligence and operation convenience of industrial control system, a voice interactive industrial control system based on MCU STM32 is designed. The system integrates SU-03T offline voice recognition module to recognize voice commands and voice announcements, and communicates and controls with the industrial host via Modbus communication protocol with RS485 interface. The circuit design of STM32 minimum system, SU-03T voice recognition circuit, RS485 level to TTL level circuit, and DC-DC power supply wide voltage power supply circuit are introduced. Test results show that the system can accurately respond to voice commands, control device operation, collect and voice broadcast data, and voice alarm in abnormal situations. The system innovatively realizes voice interactive control with industrial systems, demonstrating the great potential of human-computer interaction using voice interaction in industrial environments and providing new ideas for the intelligence of industrial control systems.*

Keywords: *Voice Interaction, Industrial Control, STM32, Modbus Communication Protocol, SU-03T Voice Recognition, Industrial Human-computer Interaction*

1. Introduction

Speech is the most natural and intuitive way of human communication and one of the important means of human-computer interaction. With the emergence of emerging natural language technology and the continuous maturation of existing technologies, intelligent speech technology has moved from the budding stage to the maturity stage [1], promoting large-scale commercialization of applications such as smart home, smart car, smart education, smart medical care and so on. Voice intelligent interaction can realize the understanding and response to the user's voice input, providing more convenient, efficient and intelligent services and experiences [2].

Industrial control system is a system used to control and monitor industrial production processes, which usually consists of sensors, actuators, controllers, communication networks, etc. The performance and reliability of industrial control systems directly affect the efficiency and quality of industrial production, therefore, the design and optimization of industrial control systems is an important topic in the industrial field. Traditional industrial control systems usually use physical buttons, touch screens, mice, etc. for human-computer interaction, which limits the level of intelligence of industrial control systems to a certain extent [3].

In this paper, the design of a voice-interactive industrial control system is proposed. The system combines voice recognition technology and Modbus protocol to apply voice control in industrial field and realize powerful scalability and compatibility through Modbus protocol. It realizes the control and monitoring of industrial equipment through simple voice commands.

2. System Design Overview

The voice-interactive industrial control system primarily consists of four components: a voice unit, a microcontroller unit (MCU), a TTL-to-RS485 unit, and a wide-voltage power supply unit. The system block diagram is shown in Figure 1.

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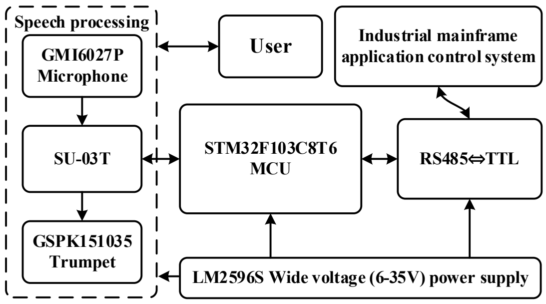

Figure 1: System chart

The system uses an STM32 MCU as the core controller and employs the widely-used Modbus communication protocol in the industrial field [4]. The physical layer communication with the industrial host is established through a TTL-to-RS485 level conversion circuit, ensuring stable and reliable communication and data exchange [5]. To adapt to the complex industrial power environment, the system is designed with wide voltage support, allowing for an input voltage range of 6 to 35V, thereby ensuring its usability in various industrial settings.

The voice unit, consisting of a microphone, speaker, and the SU-03T voice recognition chip, enables voice recognition and playback functions. Users can interact with the industrial system using natural language, making the monitoring and operation of industrial equipment more convenient and efficient.

3. Hardware Design

3.1. STM32 Minimal System Design

The STM32F103C8T6 is a 32-bit microcontroller based on the ARM Cortex-M3 core, capable of operating at frequencies up to 72 MHz, with a power supply range of 2.0V to 3.6V. It is characterized by high performance, low power consumption, and a rich set of peripherals and memory [6]. In this system, the STM32F103C8T6 microcontroller is used as the core controller, responsible for the overall system logic control, data processing, and communication with the host. The minimal system design utilizes an 8 MHz external crystal oscillator as the clock source to ensure system stability. The reset circuit adopts a low-level NRST reset design, facilitating the return of the microcontroller to its initial state, which is convenient for debugging. Additionally, the system is equipped with a power indicator, a BOOT circuit, power decoupling, and a linear regulator LDO to ensure stable power supply and provide necessary indication and protection functions. The STM32 minimal system schematic is shown in Figure 2.

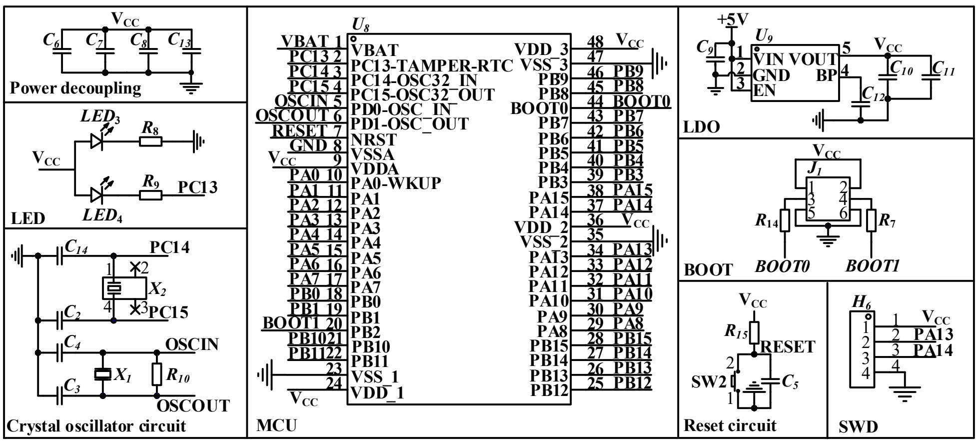

Figure 2: STM32 minimal system schematic

3.2. SU-03T Voice Recognition Circuit Design

The SU-03T is a low-cost, low-power, compact offline voice recognition module that can be quickly applied to products requiring voice control [7]. It supports direct voice control without the need for networking or smartphones, and includes features such as customizable startup prompts, wake-up words, and command words. The module achieves sound capture and voice playback through a built-in mono AB class amplifier and an electret microphone. The SU-03T schematic is shown in Figure 3.

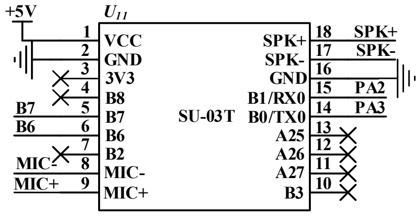

Figure 3: Schematic diagram of the SU-03T

3.3. RS485 to TTL Level Conversion Circuit Design

The RS485 to TTL level serial communication circuit utilizes the dedicated transceiver chip MAX485. The function of the RS485 to TTL level serial communication circuit is to convert the differential signal of RS485 into a TTL logic signal, or convert a TTL logic signal into an RS485 differential signal, thereby enabling communication between devices with different level standards [8]. The schematic diagram of the RS485 to TTL conversion is shown in Figure 4.

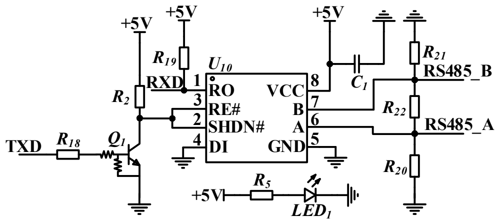

Figure 4: RS485 to TTL schematic diagram

3.4. DC-DC Power Supply with Wide Voltage Circuit Design

The design employs the LM2596S buck switching regulator, which features high efficiency, low heat generation, and low ripple characteristics [9]. It is suitable for various power conversion applications, capable of converting a DC input voltage ranging from 4.5V to 40V into a DC output voltage between 1.2V and 37V, with a maximum output current of 3A. The input power interface is connected to the power input end of the circuit board, receiving an input voltage between 6V and 35V, and then achieving a 5V output through this circuit design. The power schematic diagram is shown in Figure 5.

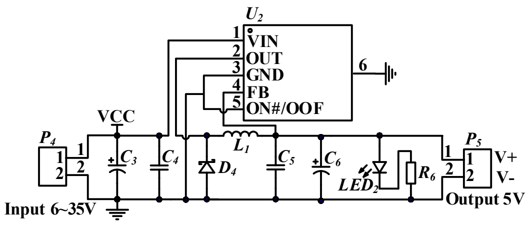

Figure 5: Power schematic diagram

4. System Software Design

4.1. System Software Main Flow Design

After the system is powered on, communication with the industrial control host is established using the Modbus RTU protocol through the physical layer RS485. The voice unit starts recognizing speech, and once a voice command is detected, the voice unit immediately sends the command to the MCU via the serial port. Upon receiving the command, the MCU processes the data and updates the slave register data based on the results. Then, the MCU sends a response frame to the industrial host, which

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uses this response frame to control industrial equipment. Simultaneously, the MCU sends commands to the voice unit via the serial port to enable voice broadcasting. In this way, comprehensive voice-interactive control of industrial equipment is achieved. The main flow diagram of the system software is shown in Figure 6.

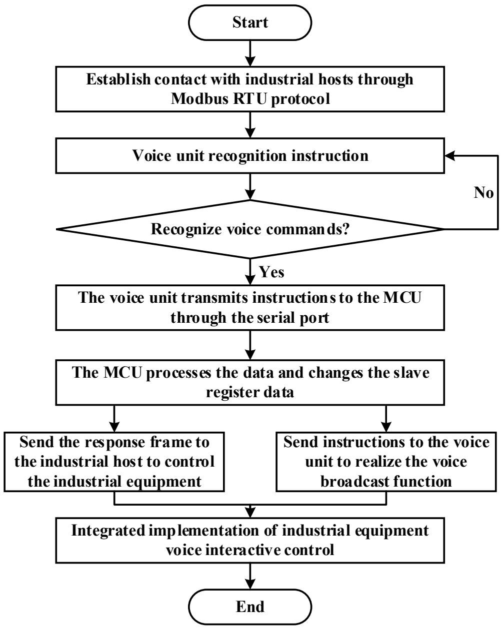

Figure 6: System software main flow diagram

4.2. Modbus RTU Communication Frame Processing

The Modbus RTU communication frames can be divided into two types: request frames sent by the master and response frames sent by the slave. The general format of the frame is fixed and includes an address field, function code, data, and error check. The general Modbus frame is shown in Figure 7.

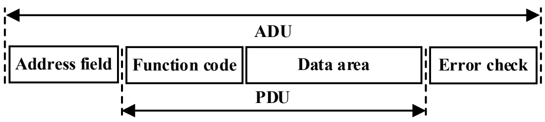

Figure 7: General Modbus frame

Upon receiving a complete Modbus RTU data frame, the slave needs to process the communication frame, which includes request frame parsing, request frame processing, and sending response frames [4, 10]. The flow chart of the communication frame handler is shown in Figure 8.

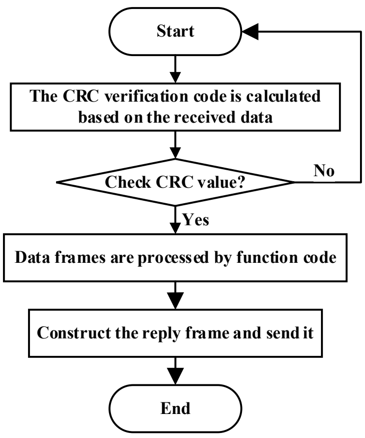

Figure 8: Communication frame handler flow chart

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5. System Testing

5.1. Speech Recognition Testing

A validation set containing various speech samples, including male and female voices as well as speech segments in noisy environments, was used. To test the stability and robustness of the voice module, the training set was appropriately disturbed to simulate variations in the dataset in actual applications. The experimental data on speech recognition accuracy are shown in Table 1.

Table 1: Speech recognition accuracy experiment data

Command Statement	Male Voice (No Interference)	Female Voice (No Interference)	Noisy Environment	Wake-Up After Standby
Open the water pipeline	100%	100%	85%	100%
Close the return pipeline	100%	100%	81%	97%
Current temperature	100%	100%	82%	100%
Start the circulation pump	100%	100%	87%	99%
Open the exhaust fan	100%	100%	86%	98%
Turn on the LED light	100%	100%	83%	100%

According to the experimental data, the system demonstrates extremely high speech recognition accuracy, reaching 100% in an interference-free environment. Although accuracy decreases in a noisy environment, it still remains above 80%. To address the decline in accuracy under noisy conditions, a microphone array with multiple microphones arranged in an array is considered, utilizing beamforming technology to enhance target speech, suppress environmental noise, and adding noise reduction algorithms such as adaptive filtering and spectral subtraction in the software to reduce the impact of background noise.

5.2. Modbus RTU Communication Testing

To test the connectivity, data transmission accuracy, communication speed, and stability of the Modbus RTU communication system, as well as the compatibility of the voice-interactive industrial control system with different devices, a Modbus RTU communication experimental system was constructed. The master in the experimental system was connected to the communication line via an RS485 to USB interface and used Modbus Poll software to simulate the master in Modbus RTU communication. The slave part consisted of the industrial voice-interactive system and several devices with RS485 interfaces capable of Modbus RTU communication. The schematic diagram of the communication experiment system is shown in *Figure* 9.

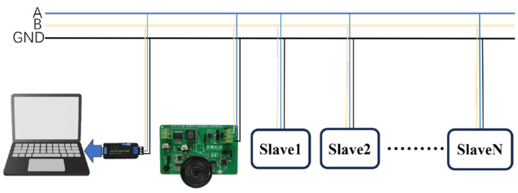

Figure 9: Schematic diagram of communication experiment system

Through the constructed Modbus RTU communication experimental system, the Modbus Poll software allowed observation of the number of request frames sent by the master, the number of erroneous frames, and the status of the slaves. Different function codes were used to record data transmission. The Modbus Poll debugging interface is shown in Figure 10.

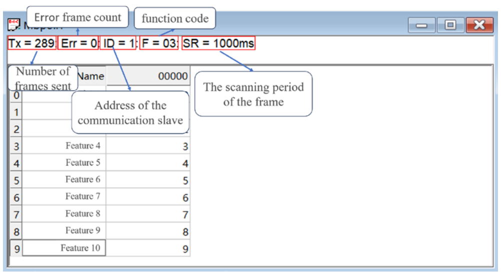

Figure 10: Modbus Poll debugging interface

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The testing of the experimental system verified that the communication connectivity between the master and the voice-interactive industrial control system is excellent, ensuring high accuracy and fast response in data transmission. The high matching degree between the request frames sent by the master and the response frames sent by the system indicates the accuracy of data transmission. In terms of communication speed and stability, the system exhibited fast and stable communication speed, with good consistency in response to continuous requests.

Additionally, the system's compatibility with different devices was tested, and the results showed that the system could successfully perform Modbus RTU communication in a multi-slave environment and retrieve data normally. No anomalies were detected by monitoring the error frame count and slave status information provided by the Modbus Poll software, demonstrating the system's good operating condition and confirming its reliability and practicality. This lays a solid foundation for the future development and optimization of industrial control systems.

6. Conclusion

The design of the voice-interactive industrial control system successfully integrates advanced voice recognition technology with the Modbus communication protocol, effectively introducing voice interaction into the industrial control domain. The system utilizes the RS485 interface at the physical layer, combined with UART idle interrupts and DMA at the software layer, to implement Modbus RTU communication, alongside a wide-voltage DC-DC power supply design. These elements ensure the system's usability and reliability across various industrial environments.

In basic functionality tests, the system demonstrated excellent voice recognition accuracy and robustness, maintaining high recognition rates even in noisy environments. The Modbus RTU communication tests further confirmed the system's connectivity and high data transmission accuracy.

In summary, the voice-interactive industrial control system not only meets the demand for intelligence and automation in modern industrial production, but also has good portability and economy, providing new ideas and solutions for the development of industrial control systems. In the future, with the further development and optimisation of the technology, the system is expected to be applied in a wider range of industrial fields and promote the realisation of Industry 4.0.

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