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Design of Intelligent Window Automatic Monitoring System Based on Microcontroller Control

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Abstract: To ensure the safety of residents' lives and property by using automatic opening and closing of ordinary windows, this article designs an intelligent window automatic monitoring system. The article proposes a software and hardware design scheme for the system, which comprises a microcontroller control module, temperature and humidity detection module, harmful gas detection module, rainfall detection module, human thermal radiation induction module, Organic Light-Emitting Diode (OLED) display module, stepper motor drive module, Wi-Fi communication module, etc. Users use this system to monitor environmental data such as temperature, humidity, rainfall, harmful gas concentrations, and human health. Users can control the opening and closing of windows through manual, microcontroller, and mobile application (app) remote methods, providing users with a more convenient, comfortable, and safe living environment.

Keywords: Smart window; Automatic monitoring; STM32 microcontroller; Mobile application

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1. Introduction

In the past, windows required residents to manually open and close them. Residents often have to close the windows themselves before going out to prevent illegal intrusion. When it rains, if the user does not close the window on time, the rain can enter and wet the room. If a room suddenly catches fire and the person involved is not paying attention while the window is closed, their life and property will be at risk. Therefore, smart furniture that can automatically assist people in handling these trivial matters has become particularly important. A smart window with an automatic monitoring system, equipped with functions such as rain, theft, and smoke prevention with the help of a Wi-Fi module, and remote control through a mobile application will provide great convenience in daily life.

2. Scheme design

The hardware of the intelligent window automatic monitoring system consists of a microcontroller control system module, a temperature and humidity acquisition module, a rainfall detection module, a harmful gas detection module, a human infrared sensing module, an alarm module, a driver module, and a Wi-Fi module [1].

The hardware components are further combined with software programming to achieve the required functions. The system diagram is shown in **Figure 1**.

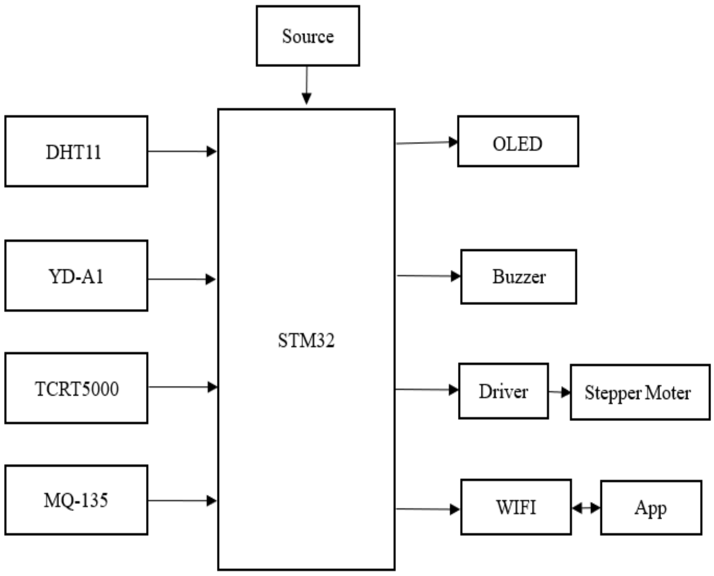

Figure 1. Composition block diagram of intelligent window automatic monitoring system

3. Hardware design

3.1. Microcontroller control module

The system adopts a microcontroller STM32F103C8T6, which has a 12-bit Analog-To-Digital Converter (ADC) and 37 General-Purpose Input/Output (GPIO) pins, providing digital processing of analog signals. This supports multiple communication interfaces, including Serial Peripheral Interface (SPI), Inter-Integrated Circuit (IIC), etc. The Receive (RX) and Transmit (TX) pins can be used to both burn programs and receive control instructions from the upper computer. The crystal oscillator circuit provides a stable clock source for the microcontroller, ensuring precise timing for its operations. The reset circuit can restore the entire system to its initial state, reload the program, and avoid system crashes.

3.2. Temperature and humidity detection module

This design uses a temperature and humidity sensor DHT11 to collect the temperature and humidity of the environment, with a temperature measurement range of 0–50 °C and an error of ± 2 °C. The measurement range of humidity is 20%–90% Relative Humidity (RH), with an error of ± 5% RH [2]. Users can set a temperature and humidity threshold, and then the microcontroller compares the values detected by the sensor with the threshold, automatically controlling the opening and closing of the window. DHT11 adopts a single-bus communication protocol. After the microcontroller sends a reset signal, DHT11 switches from low-power mode to high-speed mode. After waiting for the host reset to complete, DHT11 sends a response signal and raises the bus to prepare for data transmission.

3.3. Human infrared sensing module

Using the principle of infrared reflection, when a certain part of the human body is in the infrared region, the infrared emitted by the infrared emitting tube is reflected to the infrared receiving tube due to the shielding effect of the human body. The signal is processed by the microcomputer in the integrated circuit and sent to the microcontroller [3]. After receiving the signal, the electromagnetic valve opens the valve core according to the specified command to control the opening and closing of the window. This design uses the TCRT5000 infrared reflective sensor to detect whether there is anyone outside the window. When someone is detected in the window, the analog signal is converted into an electrical signal and input to the ADC pin to initiate Analog-To-Digital (A/D) conversion to control the window to close and activate the buzzer for vibration and alarm.

3.4. Harmful gas detection module

By detecting the concentration of harmful gases through the MQ135 air quality sensor module, it is possible to detect harmful gases such as ammonia, sulfides, and benzene, with a detection range of 10–1,000 ppm [4]. The sensor adopts a socket communication protocol, which outputs the detected data as an analog signal to the microcontroller to detect the concentration of harmful gases in the air. When the detected concentration of harmful gases exceeds the threshold, the data is transmitted to the microcontroller through the three pins of the module for processing, and then the window is automatically closed and the buzzer vibration alarm is activated.

3.5. Rainfall detection module

A raindrop sensor is used to detect whether it is raining outdoors and automatically control the window to close. This prevents rainwater from entering the home and damaging the products inside. This module uses the YD-A1 raindrop sensor. When there are no water droplets on the detection chip, the Digital Output (DO) is high and the switch indicator light is off. When drops of water are detected (exceeding the set rainfall monitoring threshold), the DO output is low and the switch indicator light is on [5]. After brushing off the water droplets (below the set rainfall monitoring threshold), it returns to the DO output high-level state.

3.6. Display module

Using a 0.96-inch OLED as the display module, the data collected by each sensor is displayed. The main advantage of this module is its self-luminous properties, which are coated with a thin layer of paint on the outside of the module. When there is current passing through, it will automatically emit light. Its communication protocol adopts IIC, Serial Clock Line (SCL), and Serial Data Line (SDA). When SCL is transmitting data at a high level, the SDA cannot be flipped. When the SDL is low, the SDA can flip [6].

3.7. Driver module

The system uses a stepper motor to simulate window opening and closing. When someone is detected or the temperature, humidity, rainfall, and gas concentration exceed the threshold, the system automatically closes the window. Before controlling the rotation of the Direct Current (DC) motor, it is essential to understand the truth value table. IN1 and IN2 control one motor, with OUT1 and OUT2 connected to both ends of the motor, and IN3 and IN4 control the other motor. When the input terminal IN1 is low and the input terminal IN2 is high, the motor is in a forward rotation state. When the input terminal IN1 is high and the input terminal IN2 is low, the motor is in a reverse state [7]. When both inputs are at high voltage, the motor is in braking mode. This setup allows precise control over the motor’s direction and braking, facilitating effective window automation.

3.8. Wi-Fi module

The system achieves a Wi-Fi connection through the ESP8266 module. ESP8266 converts the received data into serial output, communicates with the microcontroller through the serial port (RX and TX), and achieves data transmission and control through transmission instructions [8]. Through the built-in ESP8266 Wi-Fi module, the smart window automatic monitoring system can connect to mobile applications and upload the collected data through the system. The 5-pin Transmit Data (TXD) of this module is connected to the sending pin and the receiving pin of the microcontroller [9]. The instructions issued by the mobile phone are transmitted to the microcontroller through this pin. The 3-pin Receive Data (RXD) of this module is the receiving pin, and the 7-pin RESET is the reset pin, which is used to restart ESP8266. The Chip Enable Pin (EN) is the enable port, and the high-level module is effective, while the low-level module is not working [10].

4. System software design

The system software design is divided into two main parts, the automatic monitoring program and the mobile app remote control program. The automatic monitoring program compares the pre-set parameter threshold with the data collected by the sensor module, thereby automatically controlling the opening and closing of windows. The mobile app remote control program is used to remotely monitor environmental parameters, set thresholds, and control the opening and closing of windows. The overall system process is shown in **Figure 2**.

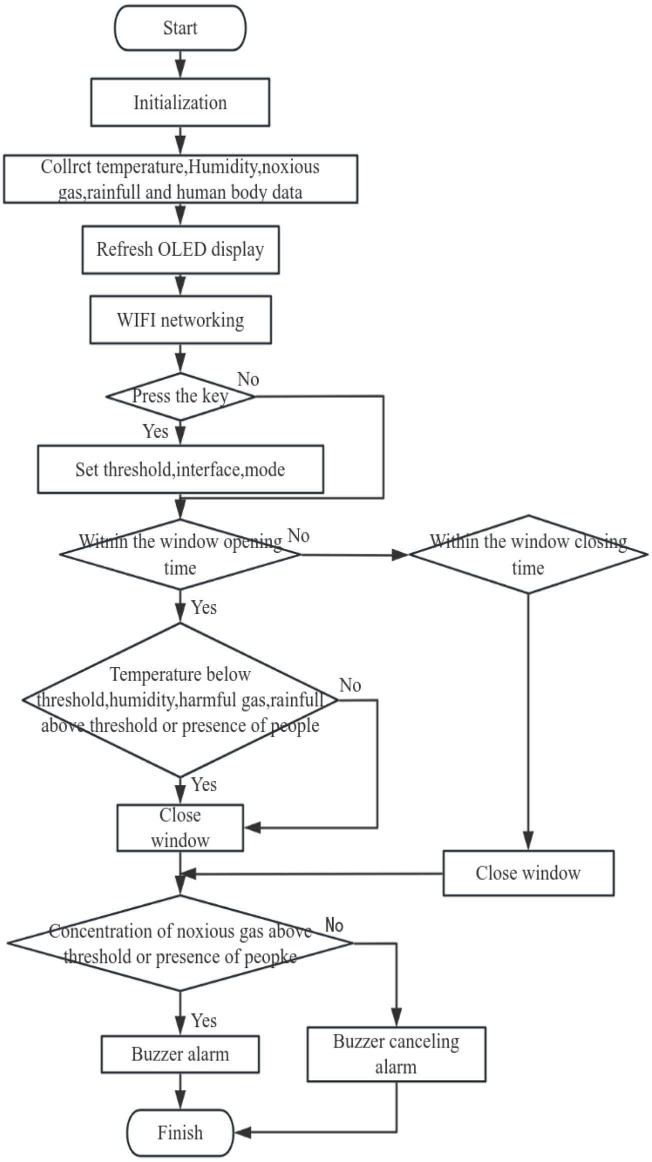

Figure 2. Overall system flow chart

4.1. Automatic monitoring program

By calling functions to drive sensors for environmental data collection, and through A/D conversion, analog signals such as temperature and humidity, harmful gas concentration, rainfall, and human infrared signals are converted into digital electrical signals, laying the foundation for later data processing. Convert the collected digital electrical signals into 01 signals compatible with the microcontroller, transmit them to the processor for data processing, and refresh the OLED display [11]. The obtained data is compared with the pre-set threshold. If the stepping motor module does not run within the window closing time, the window will remain closed. When the window is open, if the temperature is below the threshold, harmful gas concentration is detected, rainfall is greater than the threshold, and outdoor people are detected, the microcontroller will control the stepper motor drive to automatically close the windows. The system software design achieves automatic control of stepper motors through data collection, data processing, and motor drive.

4.2. Remote control program for mobile app

The programming and app connection of ESP8266 is a crucial part of the system, which is responsible for establishing communication with mobile apps and achieving remote control, data transmission, and reception. The ESP8266 module first establishes a connection with the Wi-Fi network, obtains Internet access rights, and establishes a connection through the Application Programming Interface (API) provided by the app [12]. The connection process includes login verification to ensure secure communication. STM32 sends control commands or device status data to the ESP8266 module, which encapsulates it as a Hypertext Transfer Protocol (HTTP) request and sends it to the mobile app through an interface. The mobile app receives an HTTP request from ESP8266, processes the request, and returns the corresponding response. ESP8266 will parse the response data and transmit it to the microcontroller [13]. The mobile app is installed on a client's mobile and uses the Socket communication protocol. Through the wireless ESP8266 module, it sends and receives data from the STM32 microcontroller, including collected environmental data such as temperature, humidity, and harmful gas concentrations. It can also set thresholds to remotely control the opening and closing of windows [14]. The functional block diagram of the app is shown in **Figure 3**.

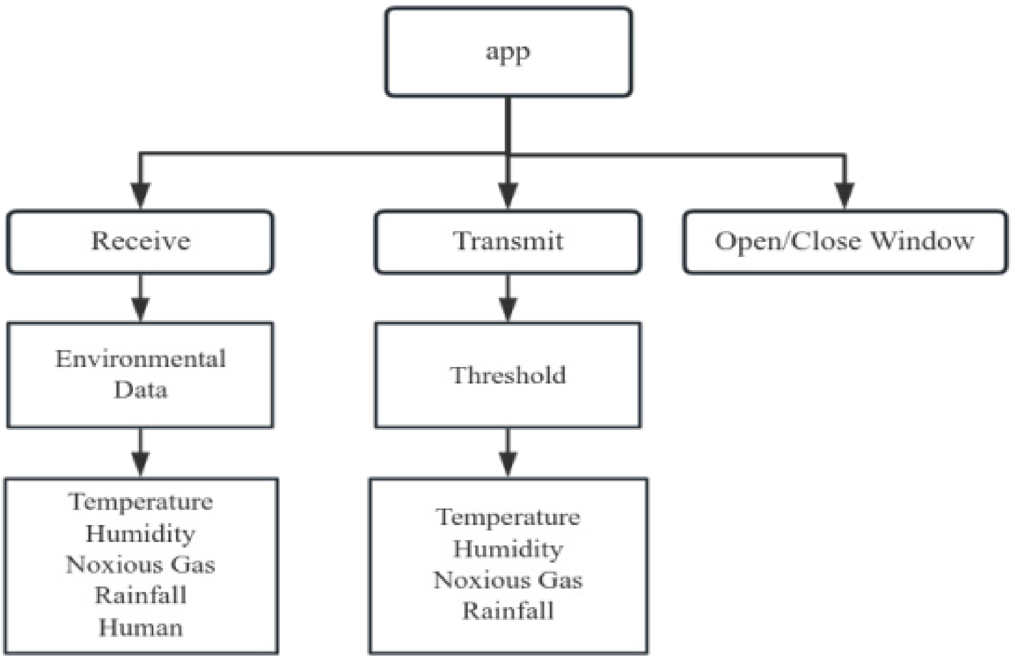

Figure 3. App function block diagram

5. System testing

Hardware debugging is an important stage in the development process of an intelligent window automatic monitoring system. Firstly, ensure that all hardware devices are properly connected. This includes connecting STM32 microcontrollers, sensors, drivers, Wi-Fi modules, OLED displays, and such. Check the wiring, pins, and connectors to ensure they are securely connected without any looseness or poor contact. After the system is powered on, a series of initializations will be carried out, and the OLED screen will begin to collect data. The content displayed in one to four lines is temperature, humidity, rainfall, and gas concentration. Press the S2 button to switch the interface. The first line displays whether the human body is present or not, and the second line displays whether the window is open or closed. Real-time transmission of data is sent to the user's mobile phone via Wi-Fi. Open the mobile hotspot, set the device name to "wlkj", and the password to "99999999". At this point, you can connect to the hardware.

6. Epilogue

This article is based on the design of an intelligent window automatic monitoring system with multiple sensors. The system uses STM32 as the main controller and utilizes various sensors to collect indoor environmental data, including temperature and humidity, harmful gas concentration, rainfall, and human body detection. The system is ultimately displayed on an OLED screen and has functions such as an abnormal alarm, automatic control of window opening and closing, and wireless communication. At the same time, to improve the level of human-computer interaction, manual threshold setting, remote monitoring, and control have been added, making the system functions more diverse and promoting intelligent measurement devices to enter daily life [15].

Disclosure statement

The authors declare no conflict of interest.

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