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Design of Control System for Household Disinfection Cabinet

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Abstract: With improved living standards, people pay more attention to health and safety, and household disinfection cabinets have become increasingly important in modern families. In the past, the disinfection cabinet mainly relied on simple mechanical switches; the operation was not flexible enough, and the disinfection effect was difficult to guarantee. Therefore, the traditional disinfection cabinet could not meet the needs of modern families. The system comprises a temperature and humidity monitoring module, LCD interface, physical key input, stepper motor driver, sound and light alarm system, relay, and Bluetooth wireless communication module. An intelligent disinfection cabinet with comprehensive functions and convenient operation was completed. By accurately controlling the temperature and humidity of the disinfection cabinet, the system can ensure the effectiveness of the disinfection process. The system can give the user feedback on the working state of the disinfection cabinet in real time with the LCD. Users can remotely control the disinfection mode, disinfection time, and system switch of the disinfection cabinet by independent buttons or a Bluetooth mobile phone app paired with the system, which significantly improves its convenience. In addition, the system is equipped with a temperature monitoring and protection mechanism. When the detected temperature exceeds the set threshold, the system will immediately trigger the sound and light alarm and send reminders to the user through the mobile phone app to ensure the safety of the use process.

1. Introduction

With the development of microelectronics technology and intelligent control technology, the intelligence and automation of household disinfection cabinets have become possible. Modern people's pursuit of a healthy quality of life is getting higher, and the requirements for food safety and tableware hygiene are also increasing [1-5]. Under the influence of public health events such as the novel coronavirus epidemic, people have a higher understanding of the health and safety of daily life. Household disinfection cabinets can effectively kill bacteria and viruses on tableware and reduce the risk of disease transmission. The requirements of environmental protection and energy saving are considered in the design of the new household disinfection cabinet. By optimizing the program

control, the operation state of high efficiency and low energy consumption is realized, which aligns with the concept of green life [6-10].

In the past, household disinfection cabinets mainly relied on simple mechanical switches, which were not flexible enough to operate, and the disinfection effect was difficult to guarantee. Therefore, traditional disinfection cabinets can no longer meet the needs of modern families. Nowadays, disinfection cabinet products that combine new technologies, such as intelligent control and client monitoring, can provide a more convenient and safer user experience [11-15]. In addition to household use, disinfection cabinets are widely used in catering, hospitals, laboratories, food processing, and other areas. The requirements of different environments make the design and function of disinfection cabinets more and more diversified. With consumers' increasing interest in smart home products, the market demand for disinfection cabinets with intelligent control functions has also increased. It has promoted the transformation of disinfection cabinets from traditional manual operation to automation and intelligence.

2. System working principle

After the system is started, the DHT11 temperature and humidity sensor begins to monitor the temperature and humidity of the internal environment of the disinfection cabinet. It transmits the collected data to the STM32 microcomputer in real time. LCD1602 liquid crystal display can display the current working state of the system in real time, such as temperature and humidity readings, disinfection mode, and residual disinfection time. Users can control the disinfection cabinet by independent key modules, such as starting the disinfection process, selecting different disinfection modes, setting specific disinfection times, or adjusting the upper limit of temperature. These operations are processed and executed by the STM32 microcomputer according to the received instructions.

During the disinfection process, when the user issues control commands or status queries using the Bluetooth app, the STM32 microcomputer will receive and process these instructions with the HC05 Bluetooth module. Users can remotely start or stop the disinfection process, select the disinfection mode, adjust the temperature, and set the disinfection time, providing great convenience. The system has a safety monitoring mechanism. When the temperature sensor detects that the temperature inside the disinfection cabinet exceeds the safety threshold, the microcomputer will close the heating plate and the ultraviolet disinfection lamp and open the exhaust system and the disinfection cabinet door with the relay. At the same time, the sound and light alarm circuit is triggered to remind the user to take corresponding measures and push the alarm notification with the Bluetooth app.

3. Hardware circuit design

3.1. Microcomputer control module

STM32F103C8T6 is a microcomputer based on the ARM Cortex-M3 core. Its package form is LQFP48. It has a variety of peripheral interfaces and excellent processing performance. It integrates 64 KB Flash storage space and 20 KB SRAM. It operates at clock frequencies up to 72MHz and supports various energy-saving modes, making it ideal for battery-powered devices. It is equipped with JTAG and SWD debugging interfaces, which are convenient for program writing and debugging. STM32F103C8T6 has many standard I/O ports, such as PA0-PA15, PB0-PB15. These ports can be used for various functions, such as input/output, external interrupt triggering, and analog signal input. In addition, the microcomputer has special communication interface pins, such as USART1 sending/receiving pins (PA9/PA10), USART2 sending/receiving pins (PA2/PA3), and I2C2 clock/data

pins (PB10/PB11). It also has analog signal input pins (PA4-PA7, PB0-PB1) for ADC and NRST pins for system reset.

3.2. Temperature and humidity sensor module

As shown in Figure 1, with the sensor's second pin (single bus, serial data) connected to the PA8 port of the microcomputer, the DHT11 sensor can be directly connected to the microcomputer. The PA8 port is a data interface for sending and receiving serial data. After the system is powered on, the PA8 port obtains the sensor's environmental temperature and humidity digital information. The microcomputer analyzes and processes the data according to the communication protocol to obtain the sensor's temperature and humidity readings. When the microcomputer issues a start-up command, the PA8 port sends data in serial form from the DATA pin, and the sensor is switched to high-speed transmission mode. Based on single bus technology, data transmission is complete with only one I/O port. A 10k pull-up resistor is added between the sensor's second and first pin (VCC power supply). It ensures signal transmission stability, meets communication protocol requirements, and enhances the circuit's anti-interference ability. In practical applications, the resistance value of the pull-up resistance is usually between 5k-10k, and the specific resistance value can be adjusted according to the actual circuit. The first pin of the sensor is connected to the 5V power supply, the second pin is connected to the PA8 port of the microcomputer, and the third pin is suspended.

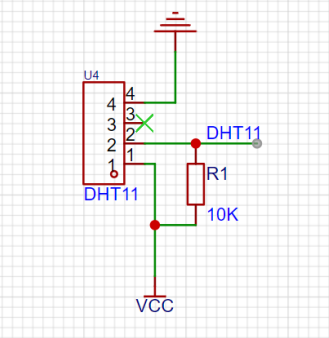

Figure 1: DHT11 circuit.

3.3. Bluetooth communication module

HC-05 Bluetooth communication module is a compact wireless device for data exchange between wireless devices. It has the advantages of low energy consumption, simple pairing, and good compatibility. It can be divided into classic Bluetooth and Bluetooth Low Energy (BLE) versions. It comprises an RF unit, baseband processor, memory, various interfaces, and antennas. It is widely used in mobile phone accessories, automotive electronics, medical equipment, smart home systems, and industrial automation.

With the serial port control pin of the main control chip crossed with the Bluetooth module, the connection between the central control chip and the HC-05 Bluetooth module is realized. The Bluetooth module has the characteristics of data transmission transparency, so the Bluetooth module can seamlessly relay the signal emitted by the serial port of the main control chip. The serial port of the main control chip can be regarded as a unique serial port with wireless transmission capability. Bluetooth communication is divided into host and slave. The Bluetooth module is configured as the slave by default and can be set as the host by the AT command.

Figures 2 and 3 show that the EN and STATE pins are suspended, and the VCC and GND pins are connected to the power supply. The TXD serial port pin is connected to the microcomputer's PA10 (RXD) I/O port, and the RXD pin is connected to the microcomputer's PA9 (TXD) I/O port.

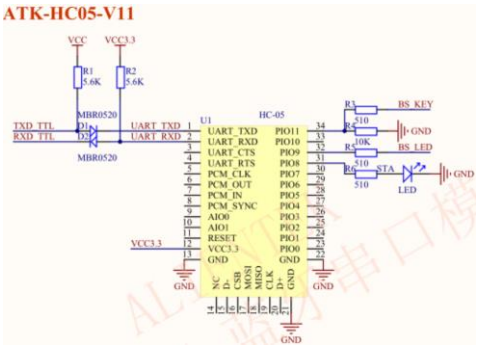

Figure 2: HC-05 schematic diagram.

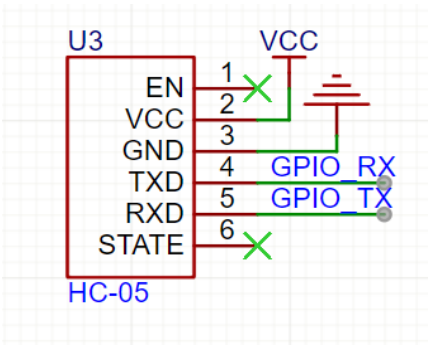

Figure 3: HC-05 circuit.

The system can be connected to the mobile phone app with the Bluetooth communication module. The main operation steps are: (1) Open the mobile phone app and click the 'Connect Bluetooth' button, and the surrounding Bluetooth devices will be automatically detected and listed in the interface. (2) When the device named 'JDY-31-SPP' is found, the system will pop up a password pairing dialog box when the device is selected, and the default password is '1234'. (3) After the Bluetooth is successfully connected, the app home page will automatically pop up a dialog box, and the text 'Bluetooth is successfully connected' can be seen in the app. Users can transmit data through the app and the Bluetooth communication module, which will be synchronized to the mobile phone app in real time.

3.4. Relay control module

The relay control module circuit is composed of the relay, NPN triode, voltage regulator diode, resistor, and light-emitting diode. The microcomputer's PB7, PB8, and PB9 pins are connected to the transistor's Q2, Q3, and Q4 base extremes. The microcomputer can control the transistor's conduction and cut-off state by outputting high- and low-level signals to realize the switching function.

The loads driven by the relay control circuit include an ultraviolet disinfection lamp, a heating element, and an exhaust fan. The control principle of these loads is similar. Taking the control principle of the ultraviolet lamp as an example. When the disinfection task starts, the control loop will supply power to the relay coil. After the coil is energized, a magnetic field is generated to attract the armature action. The relay's normally open contact is closed to connect the primary circuit, and the ultraviolet disinfection lamp starts to work. After the disinfection is completed, the control circuit will cut off the current of the relay coil, and the magnetic field generated by the coil disappears. The armature is reset through the spring, and the contact is disconnected. The primary circuit is interrupted, and the ultraviolet disinfection lamp stops working.

3.5. Independent key module

The system has six independent keys. The first key can switch to disinfection mode (there are three kinds). The second key can control the door's opening/closing. The third key is the start/cancel key. The fourth key is the exhaust fan's open/close key. The fifth key is the plus key. The sixth key is the minus key. The microcomputer's PB12-PB15, PA11, and PA1 pins are respectively connected to the six independent keys.

3.6. Stepper motor driver module

The stepper motor is driven by the ULN2003 chip to open/close the cabinet door. ULN2003 is a high-voltage, high-current Darlington transistor array that integrates seven NPN-type Darlington transistors. Each transistor's front stage is connected to a 2.7k base resistance to ensure the transistor

is directly connected to the TTL and CMOS logic circuits at a voltage of 5V. Therefore, the chip has a strong current driving function. In the process of use, it is necessary to pay attention to matching the appropriate driving voltage and current to the chip and consider the stepper motor's heat dissipation problem to ensure its regular operation.

ULN2003 driving chip is shown in Figure 4, and the stepper motor is shown in Figure 5.

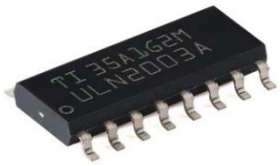

Figure 4: ULN2003 driving chip.

Figure 5: Stepper motor.

3.7. Motor driving module

ULN2003 can be directly connected to the I/O ports of the microcomputer. By sending control signals, the microcomputer drives the stepper motor to rotate 90 degrees to open/close the disinfection cabinet door. The PB5, PB4, PB3, and PA15 pins of the microcomputer are respectively connected to the 1, 2, 3, and 4 pins of ULN2003. The 13-16 pins of ULN2003 are connected to the stepper motor, the 8 pin are connected to GND, the 9 pin are connected to VCC, and the other pins are suspended.

3.8. Sound and light alarm module

A sound and light alarm circuit is included in the system. The primary function of the circuit is to send out sound and light alarm information to remind the user after receiving the microcomputer signal. When the ambient temperature inside the disinfection cabinet exceeds the threshold, the system stops working, the circuit sounds, and the indicator light flashes. The circuit will emit sound and light prompts for the user's various operations. The circuit comprises a buzzer, a triode amplifier circuit, two 1k resistors, and an LED indicator. The PB6 pin of the microcomputer is connected to the base pole of the triode of the circuit by a 1k resistor. When the microcomputer gives a high-level signal, the triode will be conducted to make a sound, and the LED indicator light is turned on.

4. Physical operation

As shown in Figure 6, the system is in the normal working state after the power supply is turned on. The LCD1602 displays the current temperature (26 ℃), humidity (53%), system mode (M1), disinfection time (10s), temperature upper limit threshold (35 ℃), and system working state (OFF) information.

Figure 6: The typical working state of the system.

Press the first button of the key circuit the first, second, and third times, and the system will enter the disinfection mode selection. The LCD1602 and the mobile phone app will synchronously display the M1, M2, and M3 modes. The system is in modes 1, 2, and 3, and the disinfection time is 10 seconds, 15 seconds, and 20 seconds, respectively. When the disinfection cabinet is not working, the disinfection time can be changed by the independent buttons and the mobile phone app.

As shown in Figures 7 and 8, when the second button of the key circuit is pressed, the stepper motor is driven to rotate positive and negative to open/close the cabinet door. When the cabinet door is opened/closed, the opening indicator light and the LED indicator light will be turned on/off. The disinfection cabinet cannot be disinfected when the door is opened and can only be disinfected when it is closed. The cabinet door can be controlled by the independent key or the mobile phone app.

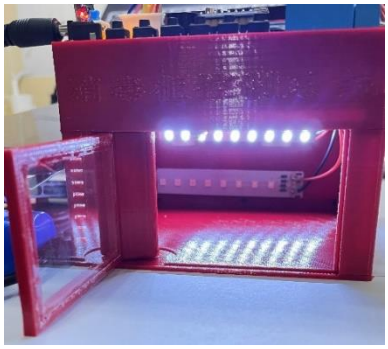

Figure 7: The cabinet door opened.

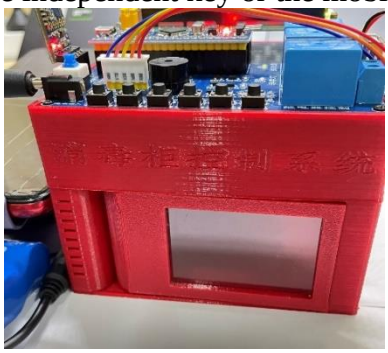

Figure 8: The cabinet door closed.

As shown in Figures 9 and 10, when the third button of the key circuit is pressed, the disinfection can be started or stopped. Press the button during the disinfection process, and the disinfection is stopped. The disinfection can also be controlled by the mobile phone app. When the disinfection is ongoing, the disinfection indicator light is turned on. The LCD1602 and the mobile phone app will synchronously display 'ON', indicating that it is being disinfected, and display 'OFF' when it is not disinfected.

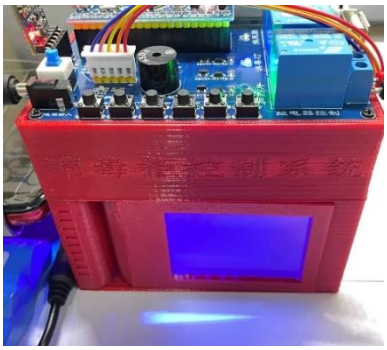

Figure 9: Disinfection ongoing.

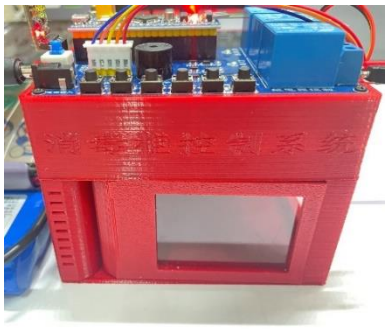

Figure 10: Disinfection stopped.

Press the fourth button of the key circuit, and the exhaust fan will be turned on/off. In the case of excessive polluted gas or high temperature inside the disinfection cabinet, the exhaust fan can be opened by the key circuit or the mobile phone app, and the fan state indicator light will be turned on. When the temperature inside the disinfection cabinet exceeds the threshold, the system will automatically open the exhaust fan.

The key circuit's fifth and sixth keys (short press) are the plus and minus keys of the disinfection time, respectively. When the system is not disinfected, the disinfection time can be changed synchronously by pressing keys or using the mobile app. The key circuit's fifth and sixth keys (long press for 3 seconds) are the plus and minus keys of the temperature threshold, respectively. Users can synchronize the temperature threshold by pressing keys or using the mobile phone app.

The system has an intelligent control function. When the temperature inside the disinfection cabinet exceeds the threshold, the system stops disinfection, opens the cabinet door, opens the exhaust fan, and sends an alarm reminder through the sound and light alarm circuit. The mobile phone app will display the alarm prompt information: 'Warning! The temperature is too high. Please deal with it!'.

5. Conclusions

The STM32 microcomputer is the core component. The system comprises a temperature and humidity detection module, LCD, physical key input, stepper motor controller, relay switch, sound and light prompt system, Bluetooth wireless transmission interface, and power management unit. The temperature and humidity data inside the disinfection cabinet is collected by the DHT11 temperature and humidity sensor, and the environmental conditions inside the disinfection cabinet are monitored in real time. The current temperature and humidity, disinfection mode, disinfection time, temperature threshold, system working status, and other information are displayed on LCD1602. Users can control the system's start/stop, disinfection mode, cabinet door, and exhaust functions with independent buttons or the Bluetooth mobile phone app. The disinfection time and temperature threshold can be set by the independent buttons or the Bluetooth mobile phone app. The system has an intelligent safety control function. When the temperature exceeds the set threshold, the system will stop working in time and issue sound and light alarm prompts. It improves disinfection efficiency, safety, and user experience, and it makes family lives more convenient and safer.

Acknowledgments

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