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Design of a Closed-Loop Control-Based Intelligent Fan System Using STM32

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Abstract: With increasing demands for living comfort and rapid advancements in IoT technology, this paper designs and implements a smart fan system centered on the STM32F103C8T6 microcontroller. By integrating hardware components such as the DHT11 temperature and humidity sensor, SR501 human body infrared sensor, and MQ135 air quality sensor, the system establishes a diversified intelligent control framework combining manual operation, sensing, automatic adjustment, environmental control, and scheduling. Additionally, it incorporates an ASRPRO voice module and an ESP8266 WiFi module to enable data exchange via the MQTT protocol. A companion Android mobile app allows users to remotely adjust fan speeds, view environmental data, and set thresholds. The innovation of this system lies in its integration of multi-sensor data for intelligent environmental perception control, enhanced by voice and network technologies that improve interaction convenience. It not only provides users with a comfortable and convenient experience but also offers an innovative solution for the smart home sector, holding significant research value and broad application prospects.

Keywords: Smart Fan; STM32; Internet of Things; Multi-Sensor Fusion; MQTT Protocol.

1. Research Background and Significance

The ongoing socioeconomic development and rising living standards have elevated demands for comfort, convenience, and intelligence in home environments. Traditional single-function appliances like fans struggle to meet the diverse usage scenarios of modern households. Rapid advancements in IoT technology have matured various sensors, wireless communications, and intelligent control algorithms [1], laying a solid foundation for device interconnectivity and smart control. Against this backdrop, developing a multifunctional fan system integrating environmental sensing, intelligent decision-making, and remote control not only addresses clear market demand but also holds significant practical value for advancing smart home industry upgrades.

This research holds both theoretical reference value and practical application significance in the smart home domain. By integrating multi-source environmental sensor data, the system establishes an intelligent control framework based on real-time environmental awareness. It automatically adjusts fan operating modes according to temperature, humidity, air quality, and human activity status. This design not only enhances user convenience and environmental comfort but also achieves energy savings through intelligent operation strategies. Technologically, this research integrates microcontroller control technology, IoT communication protocols, and mobile application development [2], providing a comprehensive and feasible solution for upgrading traditional home appliances. It offers valuable reference and insights for the development of similar smart home products.

2. Development Tools

2.1. KEIL5

Keil uVision5 serves as the core integrated development environment (IDE) for developing the embedded program of the STM32F103C8T6 microcontroller in this project. It provides code editing, compilation, debugging, and simulation capabilities, efficiently converting C/C++ code into machine code executable by the microcontroller. Its built-in hardware debugging interface and real-time simulator support offline logic verification and online diagnostics, significantly enhancing development efficiency and program reliability.

2.2. Android Studio

Android Studio, serving as the development environment for the mobile app accompanying this project, is built upon IntelliJ IDEA and provides full-stack Android application development support. Leveraging its intelligent code editing, visual layout editor, and Android Virtual Device Manager, we efficiently completed user interface design and feature development. Comprehensive debugging tools ensured stable application operation across different terminals, ultimately enabling users to remotely control fans via their mobile phones.

3. Hardware Design

3.1. Overall System Architecture Design

Centered around the STM32F103C8T6 microcontroller, this project builds an intelligent fan system integrating environmental sensing, smart control, and remote management. The hardware integrates multiple sensors for temperature/humidity monitoring, human activity detection, and air quality assessment, complemented by a local interaction interface and voice recognition capabilities. A WiFi module establishes a stable data transmission channel, while PWM technology precisely drives the fan motor to enable multi-speed fan speed adjustment. The mobile application provides device pairing, parameter configuration, environmental data monitoring, remote control, and historical query functions, forming a complete smart environmental management ecosystem. This delivers an intelligent, personalized comfort experience for users. As shown in

Figure 1.

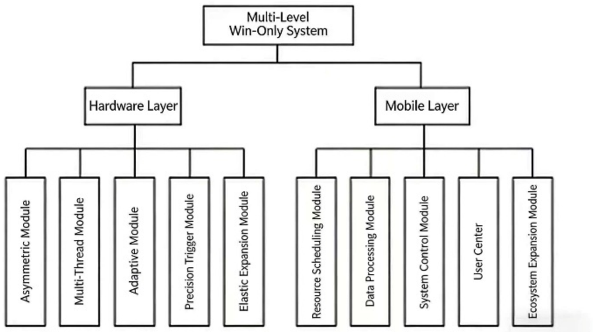

Figure 1. Overall Structural Design

3.2. System Module Design and Implementation

3.2.1. Main Control Module

The main control module employs the STM32F103C8T6 microcontroller, powered by 3.3V. This module centers on the STM32F103C8T6 microcontroller. The chip operates on a 3.3V power supply, with a backup power source connected to the VBAT pin to sustain RTC operation. Its clock circuit combines a high-speed external crystal oscillator with a 32.768kHz low-speed crystal oscillator, providing reference frequencies for the system core and real-time clock respectively. The chip manages various peripheral devices through its rich built-in peripheral interfaces: multiple ADC channels collect analog signals from sensors such as temperature, humidity, and air quality; USART, SPI, and I²C modules handle Wi-Fi communication, display driving, and sensor data reading respectively; Dedicated PWM output ports enable stepless speed control of DC motor fans. Additionally, multiple general-purpose I/O ports handle button detection and status indication. Together with specialized pins like WAKEUP (wake-up) and BOOT0 (boot selection), these form a complete system control architecture, as shown in Figure 2.

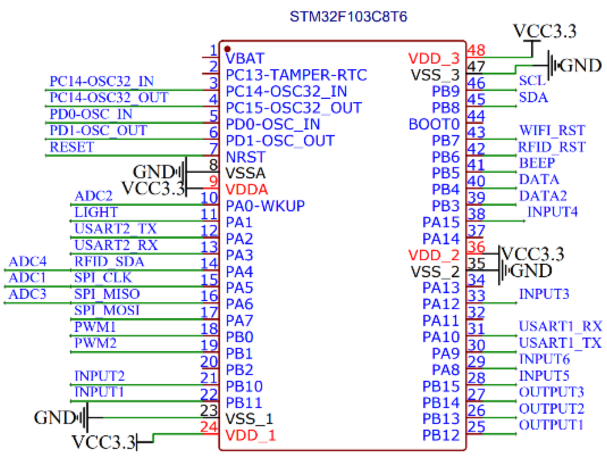

Figure 2. Main Control Module Connection Diagram

3.2.2. Temperature and Humidity Sensor

The DHT11 sensor operates on a 3.3V supply, with its DATA pin connected to power via a 10kΩ pull-up resistor. Based on a single-bus communication protocol, this sensor periodically outputs a 40-bit digital signal containing temperature and humidity data. The main control chip accurately acquires environmental parameter data by parsing specific timing signals. The sensor's NC pin remains unconnected and unused.

3.2.3. Human Presence Detection Module

The SR501 infrared human presence sensor operates on 5V DC power and functions based on pyroelectric infrared sensing principles. Upon detecting human activity, its output generates a 5V high-level signal transition. Since the main control chip's I/O ports operate at 3.3V logic levels, this signal must be processed through a level-shifting circuit (such as a resistor divider or level-shifting chip) before being input to the main control chip to trigger an interrupt. This enables intelligent start/stop control of the fan. The module's sensing distance is adjustable between 3-7 meters, with a detection angle of 120 degrees. The delay time can be set via the onboard potentiometer. [3]

3.2.4. Voice Module

The ASRPRO voice module operates on 5V power. Its INPUT1 and INPUT2 pins connect to the UART TXD/RXD pins of the main control chip. Due to differing voltage levels, a level-shifting circuit is required to establish serial communication. This module incorporates a high-precision voice recognition algorithm that converts user commands into corresponding control signals and feeds them back to the main controller via the serial port, enabling voice interaction functionality.

3.2.5. Communication Module

The ESP8266 Wi-Fi module operates on a 3.3V power supply and communicates with the main control chip via serial links using its TXD and RXD pins. The CH_PD enable pin must remain high. The RST and WIFI_RST pins handle system reset and communication reset, respectively. The module receives AT commands through the serial port to configure network settings and transmit data. It supports multiple operating modes, including STA and AP, to accommodate flexible networking requirements.

3.2.6. Display Module

The display module utilizes a 0.96-inch OLED connected to the main controller via an I²C bus. SCL handles clock synchronization, while SDA facilitates data transmission. Powered by 3.3V, the main controller drives the OLED through the I²C protocol to stably display text, graphics, and other information. This design effectively meets the system's diverse display requirements.

3.2.7. Air Quality Module

The MQ135 gas sensor operates at 3.3V. Its AO pin outputs an analog voltage signal proportional to the concentration of harmful gases in the environment. The main controller acquires this signal through ADC1 channel. Since sensor output is affected by ambient temperature and humidity, software-based data calibration and compensation are required to convert it into meaningful gas concentration ratios.

4. Software Design

4.1. Overall Software System Design

The smart fan system builds an IoT control architecture based on Wi-Fi technology. It achieves network connectivity via an ESP8266 module, collects real-time data from multiple sensors, and displays it locally on an OLED screen. Simultaneously, it synchronizes data to mobile devices using the MQTT protocol, enabling remote monitoring of environmental parameters. The system integrates six control modes: Manual Mode supports direct operation; Sensing Mode uses infrared sensors to activate when people enter and deactivate when they leave; Auto-adjust mode increases fan speed by one level for every 2°C temperature rise; Environment control mode intelligently activates/deactivates based on humidity and air quality parameters; Timer mode supports preset operation durations; Voice mode accurately responds to voice commands. This integrated system—combining data acquisition, transmission, and intelligent control—upgrades functionality from basic ventilation to smart environmental management. Remote monitoring and parameter configuration via a mobile app demonstrate the successful application of IoT technology in smart home solutions. [4]

4.2. Bidirectional Closed-Loop Data Interaction System

A high-efficiency data synchronization mechanism between the mobile app and hardware ensures consistent user experience. The system continuously collects environmental parameters via high-precision sensors and transmits data in real time using Wi-Fi communication protocols. Users can access fully synchronized environmental information—including temperature, humidity, and air quality—either on the real-time data interface of the mobile app or the OLED display of the hardware unit. Simultaneously, any adjustments made to operational thresholds via the app are immediately reflected on the OLED screen. This design establishes a bidirectional closed-loop data interaction system, effectively ensuring the real-time accuracy of data displayed across both interfaces. As shown in Figure 3.

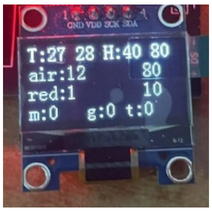

Figure 3. OLED Display Data

4.3. Status Monitoring and Data Analysis Interface Design

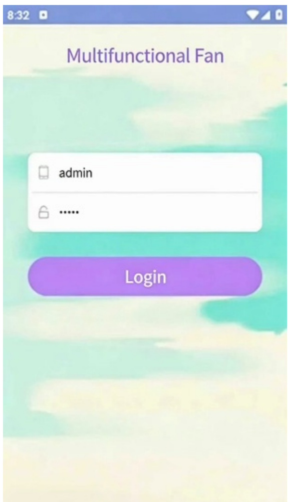

Figure 4. Login Interface

The system establishes its first security barrier through a rigorous login interface. Users must input a pre-set username and password for identity verification. The system performs real-time validation of the input information, granting access to the main interface upon successful verification. This identity verification mechanism, designed around the combination of username and password, builds a comprehensive data security protection system: after the user completes the information input and passes system verification, they are automatically redirected to the system's main interface, thereby ensuring the security of device management. As shown in Figure 4.

Within the mobile application, the system offers flexible environmental control through mode switching and fan speed adjustment functions. Within the Control Center interface, users can select from five operational modes—Manual Mode, Sensing Mode, Auto Adjust Mode, Environmental Control Mode, or Timed Mode—based on their needs. Fan speed can be adjusted in real time via the gear buttons. This comprehensive control mechanism enables users to choose the most suitable operating mode for specific environmental conditions, effectively meeting diverse usage requirements and ensuring the system creates a more comfortable and pleasant indoor environment. As shown in Figure 5.

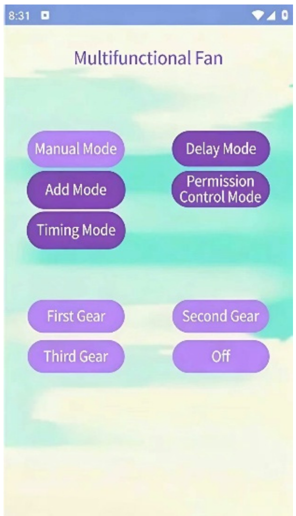

Figure 5. Control Center Interface

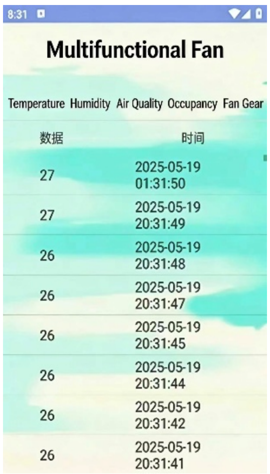

Figure 6. Historical Data Interface

For data management, the system provides a professional historical data query interface. It displays multiple historical parameters—including temperature, humidity, air quality, occupancy status, and fan speed—in an integrated chart format. All data includes precise timestamps down to the second, enabling users to trace environmental trends over any period. This feature not only delivers intuitive data visualization but also provides reliable support for analyzing environmental patterns and optimizing equipment operation strategies, demonstrating the system's intelligent capabilities in data application. As shown in Figure 6.

5. Conclusion and Outlook

This study successfully designed and implemented a multifunctional intelligent fan control system based on the STM32F103C8T6. Through multi-sensor data fusion and intelligent control algorithms, it established a comprehensive environmental perception and adaptive regulation system. The system integrates six control modes, automatically selecting the optimal operating strategy based on environmental parameters and user requirements, significantly enhancing the environmental adaptability and user convenience of traditional fans. Simultaneously, through deep integration of IoT communication technology, a stable and reliable remote monitoring system has been established, offering users diverse interaction methods. This provides valuable technical references and practical experience for the development of smart home environmental regulation devices.

Future work will focus on in-depth exploration in the following areas: (1) Introducing machine learning algorithms to further optimize control strategies by learning user habits and uncovering environmental patterns, achieving truly intelligent personalized regulation; (2) Expanding sensor types to include monitoring of environmental parameters such as light intensity and PM2.5, enhancing the system's environmental perception dimensions and accuracy;(3) Exploring collaborative mechanisms among multiple devices to build a unified intelligent environmental control system, enabling coordinated control of fans, air conditioners, humidifiers, and other appliances; (4) Optimizing energy management strategies to further reduce system standby power consumption and improve energy efficiency; (5) Enhancing system security by refining user authentication mechanisms and implementing encrypted data transmission to protect user privacy and data integrity.

References

[1] Zhang Jia, Li Yibo, Zhou Fan, et al. Research on R&D Innovation Strategies for Intelligent Agricultural Machinery Based on IoT Technology: Taking Rice Transplanter as an Example [J]. China Agricultural Machinery Equipment, 2024, (08): 41-43.

[2] Li Ping, Cai Jianjun, Liu Fah. Exploring the Reform Path of the 1+X System for IoT Application Technology Specialty Clusters Toward Integration [J]. China Vocational and Technical Education, 2020, (26): 16-22.

[3] Meng Chen, Li Min, Li Aichuan. I2C Bus Digital Temperature and Humidity Sensor SHT11 and Its Application in Microcontroller Systems [J]. Foreign Electronic Components, 2004, (02): 50-54.

[4] Gao Wa, Chen Rui. Application of IoT Technology in Smart Home Product Design [J]. Furniture, 2021, 42(06): 13-17. DOI: 10. 16610/j.cnki.jiaju.2021.06.003.