Analysis of the Indoor Comfort Control System Catering to the Environmental Needs of Elderly People Living Alone

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Abstract. With the acceleration of the social aging process, the health and quality of life of elderly people living alone have attracted increasing attention. This paper designs and implements an intelligent home environment control system specifically tailored for elderly people living alone. The system, centered around the STM32 microcontroller, collects real-time temperature and humidity data from digital sensors. Based on preset control algorithms, it automatically regulates executive devices such as fans, heating pads, dehumidifiers, and humidifiers to maintain a comfortable and healthy indoor environment. During the development process, an efficient workflow is adopted, which involves using Keil MDK for firmware development and combining it with Proteus, thus ensuring the reliability and correctness of the system. This system can effectively control the environmental temperature and humidity within the preset comfortable range. This project provides a reliable solution for improving the wellbeing of elderly people living alone and demonstrates significant application value in the field of smart elderly care.

Keywords: Smart Home, Elderly Care, STM32, Temperature and Humidity Control, Keil.

1. Introduction

With the acceleration of the aging process of society and the changes in family structure, the number of elderly people living alone is increasing. Elderly people living alone are a special group among the huge elderly population in my country. They have relatively weak risk avoidance ability and are more inconvenient to move [1]. Inappropriate living environments are prone to trigger health risks such as respiratory diseases, joint pain, and cardiovascular stress. In addition, due to their limited mobility and impaired senses, the elderly often have difficulty in promptly and efficiently controlling household devices. This further increases the risk of safety hazards. Therefore, by utilizing intelligent control technology, creating a more comfortable and healthy living environment for elderly people living alone holds significant social significance and value. This system improves the quality of life and health of the elderly population, and also alleviates the burden of raising the elderly for children living in different places.

This system is designed to develop and implement an intelligent home environment control system specifically for elderly people living alone. Its core function is to automatically adjust the indoor temperature and humidity. Currently, smart home monitoring systems can measure basic environmental data, but they still face challenges such as high costs, limited measurable data, lack of real-time control, lack of unified industry standards, and difficulties in cross-disciplinary collaborations [2]. So, the hardware part of the system is mainly composed of the following modules. Firstly, I have set up a temperature and humidity sensor to collect environmental data in real time and upload it. Secondly, the STM32 microcontroller will be responsible for data processing and judgment to issue instructions. The actuators of this system include fans, heating elements, dehumidifiers and humidifiers, which are used to specifically carry out control actions.

The core of the software part lies in the development of embedded programs. This system will use Keil as the integrated development environment, leveraging its excellent code editing, compiling, and debugging tools to write the system firmware. This program will be based on the C language and preset the temperature and humidity ranges suitable for the elderly in advance. The Hex file compiled by Keil can be directly loaded into the microcontroller in Proteus simulation model to realize the joint simulation of software and virtual hardware. The microcontroller will compare the real-time data from the sensors with the preset thresholds, and make decisions through the compiled and burned program, automatically driving the execution mechanism to operate. This will create a comfortable and stable living environment for the elderly living alone.

2. Overall hardware solution design

2.1. Scheme operating principle

The hardware working principle of this intelligent control system follows the closed-loop control logic of "perception - decision - execution": Firstly, the temperature sensor and humidity sensor serve as the perception front-end, converting the resistance or capacitance changes of their internal sensitive elements into precise digital signals and transmitting them to the microcontroller STM32; then, with the STM32 microcontroller as the decision core, running the firmware program developed in Keil, it compares the real-time data with the preset thresholds and makes decisions based on the control algorithm; finally, the microcontroller STM32 outputs signals through the GPIO port to drive the circuits, thereby controlling the actuators such as fans, heating elements, dehumidifiers, and humidifiers to start or stop or adjust the power, ultimately achieving precise and automatic control of the environmental temperature and humidity.

2.2. Hardware overview

2.2.1 STM32 microcontroller

During the selection process of microcontrollers, this project conducted a comprehensive evaluation of Arduino, the classic AT89C52, and the STM32 series. Although Arduino is widely popular in entry-level applications due to its rich open-source ecosystem and user-friendly nature, its processing performance and efficiency in handling complex logic are limited. In scenarios where it is necessary to simultaneously process sensor data, run decision algorithms, and coordinate multiple actuators, it is unable to cope effectively. As for the early classic AT89C52 single-chip microcontroller, its architecture is simple, but its core drawback lies in the severe lack of resources, slow running speed, and high-power consumption. It lacks the hardware peripherals required for modern embedded development and is unable to support an efficient and reliable real-time monitoring and control system.

The STM32 microcontroller serves as the intelligent decision-making core of this system. Its working principle is as follows: Through its peripheral interfaces (such as I2C), it accurately acquires digital temperature and humidity signals from sensors. With its efficient processing capability based on the ARM Cortex-M core, it runs control algorithms in the firmware program developed with Keil in real time, comparing and making decisions based on the real-time data and preset thresholds. Subsequently, it outputs precise driving signals through the GPIO port to coordinate the operation of actuators such as fans and heating elements. Compared to Arduino or AT89C52, the significant advantage of STM32 lies in its outstanding computing performance, which ensures the real-time response capability and the carrying capacity for complex algorithms of the system. The rich peripheral resources provide a hardware foundation for the connection of multiple sensors and future function expansion. The advanced power management mechanism guarantees the energy efficiency for the device to operate continuously without interruption. Ultimately, its perfect combination of high performance, high integration, and high cost-effectiveness provides a stable and reliable core component for the entire control system.

2.2.2 Humidity and temperature sensor

In this system, humidity and temperature are two of the most common monitoring parameters this is because of the fact that not only humidity and temperature often represent crucial aspects of the monitored object, but also due to the abundance and ease of use of the sensors [3]. the core working principle of the digital temperature and humidity sensor is to convert the abstract physical quantities into precise digital signals that can be read by the microcontroller: The temperature sensor usually relies on a high-performance thermistor, whose resistance value will regularly decrease as the environmental temperature rises. By measuring this resistance change, the temperature value can be calculated; while for humidity measurement, capacitive sensitive elements are mostly used. The dielectric constant of the dielectric layer will linearly change with the number of water molecules adsorbed in the air, resulting in a change in the capacitance value between the electrodes. By detecting this capacitance value, the relative humidity can be calculated. The dedicated integrated circuit inside the sensor is responsible for amplifying, calibrating and compensating these weak analog signals, and then outputs stable digital signals via I2C and other methods. This integrated digital output method not only effectively avoids the drawback of analog signals being susceptible to interference during long-distance transmission, but also incorporates temperature compensation, ensuring high accuracy and reliability within the full range, ultimately providing accurate and reliable initial data input for the entire intelligent control system.

2.2.3 Actuators

The microcontroller outputs control signals through its GPIO ports to drive the relay switch circuit, thereby precisely controlling each actuator: After the circuit is activated, the fan can obtain power to rotate, increasing the air circulation speed to achieve cooling and auxiliary dehumidification; the heating element heats up directly using the thermal effect of the current; after the dehumidifier (condensation dehumidification module) is activated, its semiconductor cooling sheet lowers the surface temperature, causing water vapor in the air to condense into water droplets, thereby achieving dehumidification; while the humidifier is actually an ultrasonic atomization unit. Under the drive of the circuit, the ceramic sheet vibrates at a high frequency to instantly atomize water into micron-sized water mist and blow it into the air, effectively increasing the environmental humidity.

3. Software Design Analysis

3.1. Software process analysis based on Keil

Keil development tool is a tool for embedded development. In terms of software design, this system is based on Keil as the core platform. The software process of this system is carried out in the Keil MDK environment. Keil MDK is an excellent development software for ARM processors, especially for STM32 series processors [4]. Firstly, complete the basic configuration of the project, initialize the system clock and key peripherals using STM32CubeMX, including configuring the I2C interface for sensor communication and the GPIO pins for controlling the actuator; then enter the modular coding stage, establish modules such as sensor.c (containing the SHT30 data reading function), control.c (temperature threshold comparison algorithm), and actuator.c (encapsulating relay drive function) in Keil, and build the closed-loop control logic of "reading sensor data → executing PID control algorithm → driving the actuator" in the main function; then generate the executable file through compilation, first import Proteus for virtual simulation verification of basic functions, and then conduct hardware online debugging via ST-Link, correct logical errors and optimize performance; finally, burn the debugged program onto the STM32 chip to achieve independent deployment and stable operation of the system.

3.2. Use Proteus for simulation

This system uses the Proteus software as the simulation platform, and its workflow constitutes a complete "design - verification - optimization" closed loop. The specific operation method is as follows: Firstly, in the Proteus ISIS interface, build the simulation circuit based on the previous hardware design scheme. The core of this circuit includes the STM32 microcontroller model, the temperature and humidity sensor model, as well as the components such as the motor and LED that simulate the actuators such as the fan, heating plate, and humidifier controlled by the single-chip microcontroller. Then, load the firmware file (.hex format) generated in Keil into the virtual STM32 chip. After starting the simulation, the operator can actively adjust the temperature and humidity parameters of the virtual sensor to simulate real environmental changes, thereby dynamically and intuitively observing the response process of the entire system: For example, when I increase the temperature value, I can see that the symbol representing the motor starts to accelerate rotation, while monitoring the changes in the output value of the MCU.

The advantage of Proteus is its excellent integration and flexibility: It can fully verify the correctness and coordination of the design before actually manufacturing the hardware, which not only can expose and solve potential circuit design flaws and program logic errors in advance, but also greatly reduces development costs and operational risks. In addition, it can simulate extreme environmental conditions (such as high temperature and high humidity), and support advanced debugging functions such as single-step running and setting breakpoints, enabling us to analyze the system behavior more deeply and optimize the control algorithm.

4. Analysis of typical cases

4.1. Home temperature control system cases

Song completed the design and implementation of the smart home temperature control system before. The overall concept of this system is to first identify the user's status to determine whether there is someone in the room. When there is a person, the status bit is 1. When the user enters the room, the system will measure the temperature in real time, compare it with the set value, and decide whether to turn on the air conditioner. This system selected the firmware library package FWLib V3.4, which contains CMSIS files. Later, it was transplanted to the UC/OS-II system and used HTML to build a Web server. Secondly, for the human recognition aspect, the NRF24L01 wireless communication module was selected to achieve efficient data collection. The temperature sensor selected was the DS18B20, which monitors the bus level. A high bus level indicates 1, and a low bus level indicates 0. Finally, the system achieved the function of maintaining or turning off the air conditioner based on the actual status controlled remotely [5].

Pan designed a remote-control system for home temperature and humidity based on STM32. He selected the STM32F103C8T6 chip as the main control chip for the device end, used the DH T11 digital temperature and humidity sensor for data collection, adopted the ESP8266 Wi-Fi integrated module to establish a connection between the wireless network card and the module, used two LED lights, through their on-off to display the increase or decrease of temperature and humidity, set STM32's Boot to 1, connected PB10 and PB11 to the URXD and UTXD of the ESP8266, and connected 3.3V VCC and GND to complete the UART connection; connected DHT11's DATA to PA7 and connected VCC and GND; the LED light module connected to PA4 and PA5 and powered it; L298N's IN1, IN2, and ENA were respectively connected to PB4, PB5, and PB6, and connected two DC motors to OUT1~OUT4, and powered them by a 12V battery. Finally, through the connection between the single-chip microcontroller and the Wi-Fi module, after simulation, the remote-control function for the surrounding environment of the home temperature and humidity can be realized [6].

4.2. Humidity control system cases

Zhang et al. designed and fabricated an intelligent dehumidifier for air conditioners based on the STM32 single-chip microcontroller. They used a low-power embedded microcontroller, STM32F103C8T6, for temperature and humidity sensors, and the AM2302 temperature and humidity module for communication. The infrared emitter diode and VS1838B infrared receiver tube were used as the communication module. This system collects environmental data through the AM2302 temperature and humidity sensor. When the detected value exceeds the preset threshold, the microcontroller will control the air conditioner to start dehumidification through the infrared emitter tube, and send a shutdown command when the environmental parameters return to normal. Then, the system enters a sleep state, and restarts the detection after 1 hour. The system also has four indicator lights for power, humidity, startup, and infrared signal reception and learning status. Finally, through multiple random experiments in different environments, this device has stable performance and safety reliability, and can monitor the indoor humidity in real time and respond accordingly [7].

Yu et al. designed an intelligent dehumidification wardrobe system based on a single-chip microcomputer. The wardrobe environment is monitored by temperature and humidity sensors. When the humidity exceeds the set threshold, users can remotely manually start the dehumidification device through a mobile phone APP (the principle is to make humid air flow through a cooling chip to condense and dehumidify). Thus, intelligent control of the wardrobe humidity can be achieved. The temperature and humidity sensors use DHT11. The settings of the dehumidification module enable the sensors to collect the temperature and humidity information of the wardrobe at a certain frequency, and then determine whether it exceeds the set threshold. The software is developed based on the Android operating system using the JAVA and Eclipse environment, and a full-bridge bidirectional DC/DC converter operating in the BUCK mode equivalent to the main circuit is designed. Through experimental verification, when the load power is changed artificially, the above converter can timely adjust the working state to ensure the stable operation of the power grid, and ultimately realizes the combination application of the sensor and the JAVA program, achieving intelligent dehumidification [8].

4.3. The temperature and humidity control system in agriculture cases

Zhang and others designed an intelligent environmental monitoring system with the STM32 microcontroller as the core. This system collects environmental data through the DHT11 (or SHT11/AM2302) temperature and humidity sensor, and uses the WiFi module ESP8266 to upload the data to the mobile APP or the LabVIEW upper computer for remote monitoring. When the environmental data exceeds the set threshold, the STM32 will automatically control the actuator: through the L298N motor drive module, it controls the DC motor to complete actions such as opening and closing the roller shutter, or through the relay module, it controls equipment such as the ventilation fan and water pump. Experimental verification shows that this system can achieve automatic and remote adjustment of environmental humidity [9].

Yan et al. designed an intelligent mushroom room temperature and humidity control system. Each production workshop is managed through a control system composed of an RS485 bus. The optimal program control algorithms for various mushrooms are pre-stored in the central control machine, and the monitored parameters are input into the single-chip microcomputer of each workshop through the bus. By comparing the actual values with the threshold values, instructions are given to turn on or off the electric heaters, humidifiers, and ventilators. The DS18B20 is used to measure temperature, the HIH3610 is used to measure humidity, and the measured values are input into the single-chip microcomputer through the 12-bit serial A/D converter TLC25432. The single-chip microcomputer uses the AT89C2051, achieving the temperature and humidity control of the intelligent mushroom room [10].

5. Conclusion

This thesis focuses on the health and well-being issues of elderly individuals living alone, and designs and implements an intelligent home environment control system centered on the STM32 microcontroller. The system integrates high-precision digital temperature and humidity sensors, which can continuously monitor environmental parameters and precisely control the actuators through relay drive circuits. At the software development level, the project has established an efficient workflow using Keil as the integrated development environment and Proteus as the simulation verification platform. This not only ensures the clarity and maintainability of the code through modular programming, but also fully verifies the correctness and reliability of the system functions through the joint simulation technology of software and hardware. This system can efficiently maintain the indoor temperature and humidity within the preset comfortable range. The value of this research lies not only in its terminal functions, but also in its systematic design methodology and clear targeting. The system successfully applies the Internet of Things and intelligent control technologies to the specific scenario of home-based elderly care, providing a practical technical solution for smart elderly care, and has profound significance for the increasingly severe social aging phenomenon.

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