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Smart Home Heating Control System Design

ZhiWen Xiao Yanting Ni*
School of Mechanical Engineering, Chengdu University, China
Corresponding Author: Yanting Ni

ABSTRACT: *With the increasingly severe energy crisis and environmental pollution, the traditional heating system is difficult to meet the needs of national energy conservation and emission reduction because of its low regulation efficiency and serious energy waste. Electric heating technology has become an important direction for the efficient use of energy due to its flexibility and low pollution characteristics [1], and the integration of embedded systems and Internet of Things technology provides technical support for intelligent temperature control. Based on the STM32F103C8T6 microcontroller, this project designs and implements a set of intelligent heating control system, which aims to improve the accuracy and intelligence level of temperature regulation, optimize energy efficiency, and provide a feasible solution for energy-saving heating in the home.*

The system takes STM32F103C8T6 as the core, uses DHT11 temperature and humidity sensor to collect environmental data in real time, and establishes wireless communication with OneNet cloud platform through the ESP8266 module to support remote monitoring and control functions. The system is designed with automatic control to dynamically adjust the desired temperature, and at the same time, combined with the PID control algorithm[2], the output angle of the SG90 servo is optimized to ensure accurate temperature adjustment[3]. The hardware design of the system includes the construction of the main control circuit, temperature and humidity sensor, communication module, servo control module and OLED display module, and the circuit connection is reasonable and stable. The software development is based on the Keil uVision5 environment, which realizes functions such as temperature and humidity data collection, cloud data interaction, PID algorithm calculation, and OLED data display. The system supports two modes: manual control and automatic control, and the user can dynamically adjust the target temperature by manually changing the steering gear angle or selecting the automatic mode to preset the temperature.

The test results show that the platform runs stably, the temperature error of DHT11 acquisition is less than ±2°C, and the PID algorithm makes the actual temperature stable within the range of ±0.5°C of the set value. This design realizes the intelligent control of temperature, significantly improves the regulation efficiency and energy utilization rate, and has good practicability and promotion value[4].

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I. INTRODUCTION

The smart home heating control system designed in this subject is based on the original heating equipment, adding WIFI wireless transmission, DHT11 temperature sensor and intelligent control system, with the help of the collaborative operation of these key parts, to achieve intelligent control of the entire heating process. After analyzing the research status of intelligent heating technology at home and abroad, the application trend of embedded system and Internet of Things technology in temperature control was determined, and it was decided to take STM32F103C8T6 as the core, combined with WIFI wireless communication and the overall design scheme of OneNet cloud platform. Through the analysis of functional requirements, the overall architecture of the system was designed, and the hardware design finally selected DHT11 temperature and humidity sensor, ESP8266 WIFI module, relay module, SG90 steering gear and OLED display module. The STM32 microcontroller controls each sensor of signal acquisition to achieve the required functions, and the WIFI module uploads the data collected by the microcontroller to the IoT cloud platform to realize data transmission and human-computer interaction. Finally, a complete test environment was built and the system was comprehensively tested. Including hardware module debugging, OneNet cloud platform function test and overall reliability test, the temperature and humidity acquisition accuracy, temperature control accuracy, communication delay and operation stability of the system are verified, and the design goal is achieved.

According to the main research content, the technical route is determined as follows:

This topic determines the overall technical route based on the requirements of the embedded smart home heating control system, which can be divided into hardware design and software design.

The hardware design is based on the STM32F103C8T6 minimum system, and the circuit connection of the main control circuit, temperature and humidity acquisition module, WiFi communication module, servo control module, OLED display module and button module is designed, which optimizes the anti-interference ability and power consumption, and ensures the stability and reliability of the hardware.

Systematic software development was carried out. In the Keil uVision5 environment, the code of functional modules such as temperature and humidity data acquisition, key status detection, cloud data interaction, PID algorithm calculation, and OLED display was written. The system supports manual control, automatic control, two modes, through the ESP8266 module and MQTT protocol to achieve data interaction with the cloud platform, combined with the PID algorithm to drive the SG90 servo to achieve accurate temperature regulation.

II. Overall structural design

The smart home heating control system designed in this project is based on the current electric heating equipment, and adds wireless transmission technology, temperature sensor and intelligent control platform module to realize the intelligence of the heating process. Through WIFI communication technology, long-distance wireless transmission of environmental data can be realized, and the temperature of the space where the user is located can be reflected in real time, so as to meet the needs of human comfort to the greatest extent. The real-time data collected is transmitted by the WIFI module to the IoT cloud platform for analysis and processing, and supports the synchronous interaction between a variety of terminal devices and the cloud platform, so as to realize long-distance monitoring and accurate regulation of heating equipment. In addition, the system uses the PID control algorithm to optimize the temperature output of the electric heating equipment, which effectively improves the control accuracy and system performance.

The system is mainly composed of two parts: the collection node and the OneNet IoT cloud platform. Sensors are deployed at critical locations to collect environmental parameters, including temperature and humidity. Through WIFI wireless communication technology [5], the temperature and humidity sensor nodes (the number of installations is determined according to the heating area) transmit the collected data to the OneNet IoT cloud platform in real time. At the same time, the terminal node can receive instructions issued by the cloud platform to accurately control the environment [6]. The OneNet cloud platform is responsible for storing and displaying ambient temperature and humidity data, and providing real-time information feedback to users through the APP client.

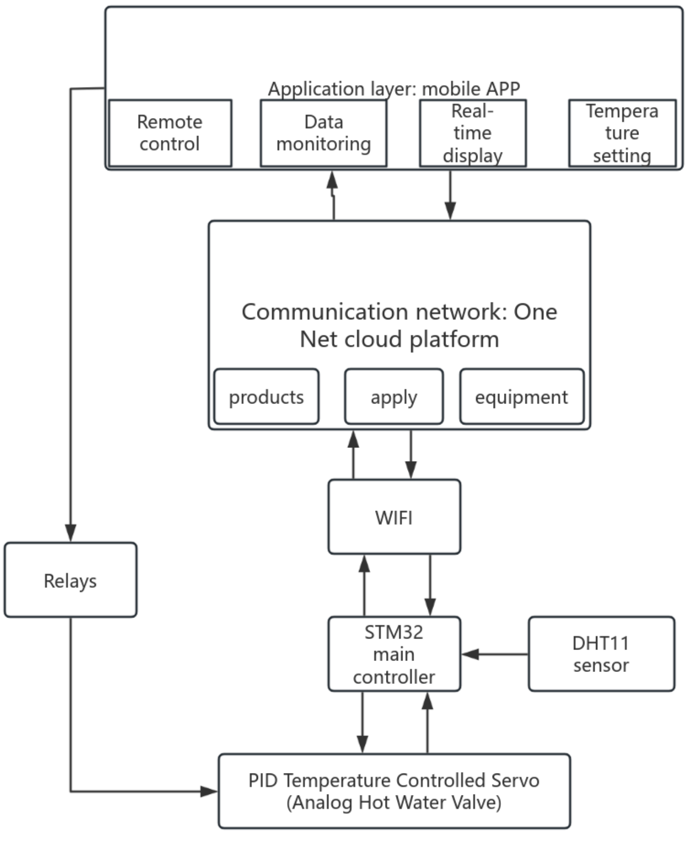

Figure 1 Overall design of smart home heating control system

III. The overall hardware framework of the smart home heating control system

The intelligent furniture heating control system designed in this project has many functions such as temperature and humidity data collection, remote control and wireless communication. It uses a STM32F103C8T6 microcontroller as the core processing unit, and by connecting an external temperature and humidity sensor, it can obtain temperature and humidity data of the indoor environment in real time [7]. The obtained sensor data will be encapsulated into MQTT packets with the help of the WIFI wireless communication module, and then transmitted to the OneNet IoT cloud platform. The execution of control commands relies on external relay modules and servo modules [8]. In this chapter, the hardware design scheme and its working principle will be introduced in detail, and the completion of the circuit design of each functional module will be displayed, and the overall hardware architecture is shown in Figure 2.

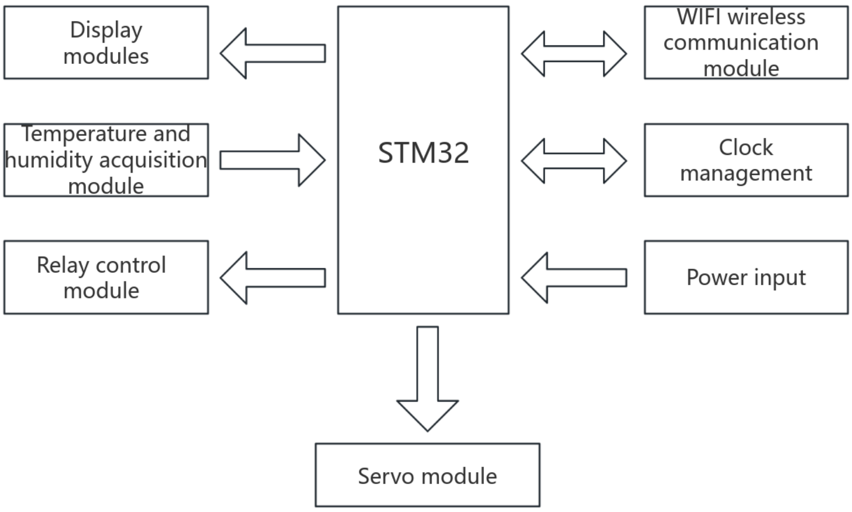

Figure 2 Hardware architecture of smart home heating control system

Reset circuit design

The reset circuit is a key design to ensure reliable operation of the system, and its main function is to force the main control chip back to the preset initial state. Due to the uncertainty of the working state of the microcontroller at the moment of power-on, and the abnormal crash phenomenon may occur during the program execution, the design necessity of the reset circuit is particularly prominent. At present, the system adopts two typical reset implementation methods:

Manual Reset: Triggered by an external key, when the NRST pin is pulled low when the key is pressed, triggering a hardware reset sequence;

Automatic Power-On Reset (POR): Based on the RC charge-discharge principle, the capacitive delay effect is used to keep the reset pin high enough to ensure that the chip is initialized through the capacitive delay effect when the power is turned on.

Crystal oscillator circuit design

The clock circuit is designed according to the requirements of the STM32F103C8T6 technical manual, which requires a crystal oscillator (referred to as crystal oscillator) to provide a reference clock signal to the microcontroller. The chip supports dual clock source configuration scheme, internal clock mode: the chip uses a built-in RC oscillator, which has the advantage of simple circuit structure; External clock mode: It is realized by an external crystal resonator, and this scheme is selected for this design.

This design significantly improves the timing reliability of the data acquisition system by optimizing the clock signal quality (square wave duty cycle 45-55%).

STM32F103C8T6 The design of the minimum system peripheral circuit [9] mainly includes the design of the processor power supply circuit, the clock circuit and the reset circuit, and the minimum system is shown in Figure 3.

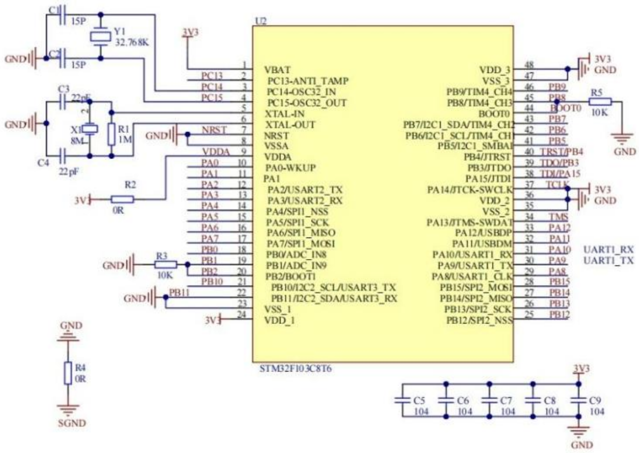

Figure 3 STM32F103C8T6 Minimal system

WIFI wireless communication module circuit design：

Wi-Fi technology (IEEE 802.11 standard) enables wired-to-wireless signal conversion through wireless access points (APs), and its physical layer uses OFDM modulation technology to provide transmission rates of up to 9.6Gbps (Wi-Fi 6) in the 2.4/5GHz band. In practice, the coverage radius is significantly affected by the building structure: up to 100 meters in open environments, and 10-30 meters in multi-walled interiors.

This project uses a ESP8266 module based on Espressif's ESP8266EX chip[10], integrated with a 32-bit Tensilica L106 processor, clocked at 80MHz (can be overclocked to 160MHz), supports IEEE 802.11b/g/n protocol, operates in the 2.4GHz band, and has a maximum transmission rate of 72.2Mbps. The module provides 8 pins, including power (VCC, GND), serial (TXD, RXD), and control pins (EN, RST, GPIO0, GPIO2), with an operating voltage of 3.0V to 3.6V, a typical current of 70mA, and a quiescent current of about 10μA in low-power mode. ESP8266 Supports STA (station mode), AP (access point) and mixed mode. The chip circuit for ESP8266 is shown in Figure 4.

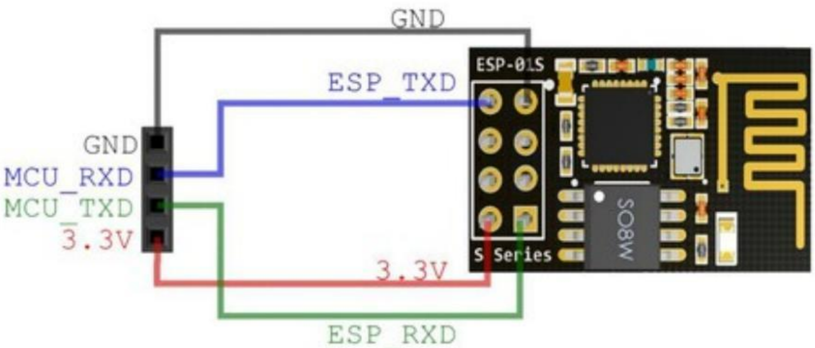

Figure4 Chip current diagram of ESP8266-01S

Servo module circuit design：

The servo module is at the heart of the intelligent temperature control platform for precise temperature regulation, which regulates the heating or cooling effect by controlling the angle of the output device, such as a valve or damper. The SG90 miniature servo is used in this design, which is widely used in embedded systems due to its small size, high cost performance and easy control. The SG90 is driven by a STM32F103C8T6 PWM signal, combined with a PID control algorithm, and dynamically adjusts the angle based on the DHT11 sensor data.

The SG90 servo module circuit is designed to be simple and efficient, with high accuracy and fast response to meet temperature regulation needs, and PWM control is seamlessly integrated with STM32's TIM3 in a single pin. However, the SG90 has limited torque (1.8kg·cm) and is not suitable for high-load equipment. The life of plastic gears is short, and the frequency of action needs to be limited. This project extends life through PID optimization (10 adjustments per second <).

In summary, the SG90 servo module provides accurate output control capabilities for the intelligent temperature control platform through reliable circuit design and PWM drive, supports local and remote temperature management, and enhances the intelligence and practicability of the system [11].

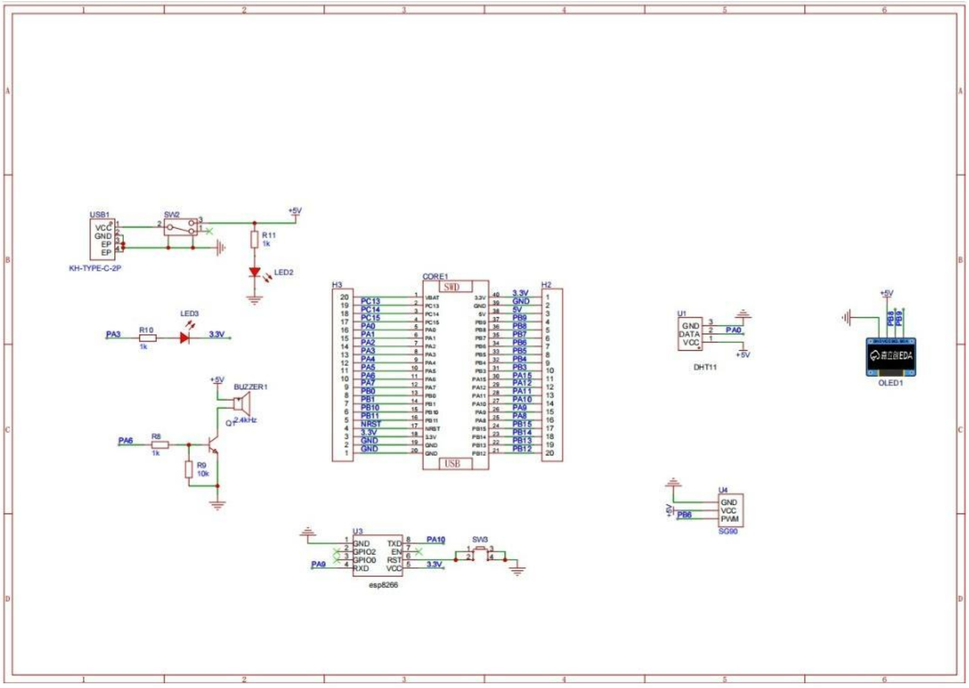

Figure5 Overall circuit diagram

IV. Software structure design

The core function of the smart home heating control system depends on the software design, and its performance directly affects the overall performance of the system. This chapter will elaborate on the system software design scheme, which mainly includes the following three key parts: development environment configuration, cloud platform parameter setting, and program design of each functional module [12]. Adopting a modular design approach [13], the following functional modules are emphatically developed: temperature and humidity data acquisition [14], WIFI wireless transmission, relay drive, human-computer interaction display, and servo control based on PID algorithm[15]. The complete software architecture design is shown in Figure6.

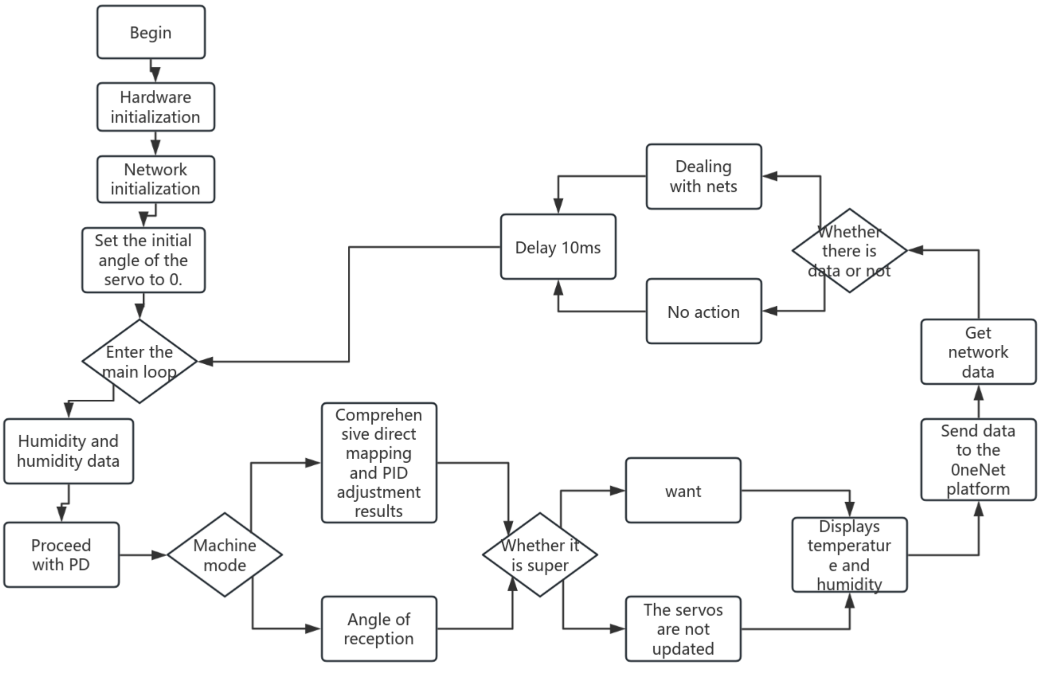

Figure 6 Software design architecture

Design of PID control algorithms：

Principles of PID algorithm：As a classical closed-loop feedback control method [16], the PID control algorithm realizes the precise adjustment of the controlled quantity through the synergy of proportional (P), integral (I), and differential (D). The core principle is to calculate the deviation between the output of the system and the set value in real time, and dynamically adjust the control quantity according to the change trend of the deviation, and finally make the system reach a stable state. This control method has a wide application value in the field of industrial process control by virtue of its simple structure and strong adaptability. The implementation principle of the control system can be seen in the block diagram structure shown in Figure 7.

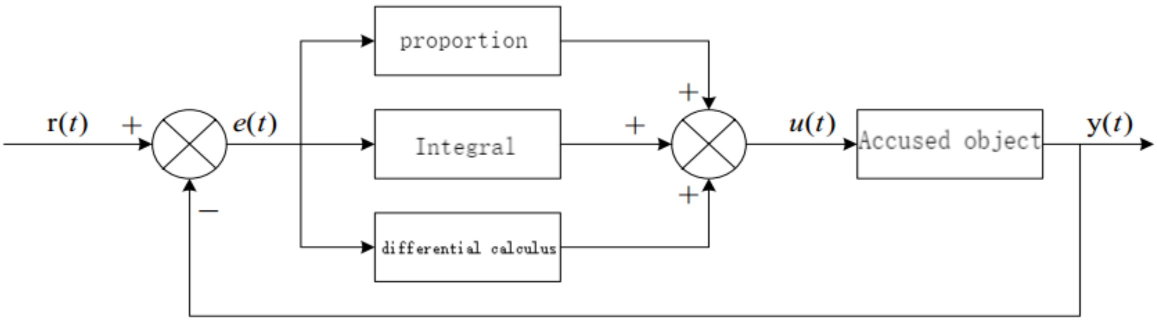

Figure 7 PID control schematic

PID control is to process the error value e(t) to obtain the control quantity u (t), and finally make the feedback value continue to tend to the set value until the error is 0.

$$(4.2)u(t) = K_P[e(t) + \frac{1}{T_i}\int_0^t e(t)\,dt + T_d\frac{de}{dt}]$$

(4.2) where Kp is the scale coefficient,Ti is the integral coefficient, and Td is the differential coefficient. These three coefficients have different roles in PID control:

(1) Scale factor: The scale factor amplifies the current error and generates a control output, so that the system can quickly move closer to the set value. KP determines the response speed, the higher the value, the stronger the system's response to the error.

(2) Integration coefficient: The integration coefficient accumulates historical errors, generates control outputs, eliminates steady-state errors, and ensures that the actual temperature is ultimately equal to the set value. The Ti is effective against small errors that persist over a long period of time.

(3) Differential coefficients: Differential coefficients generate control outputs according to the error rate of change, predict error trends, and suppress overshoot and oscillation. Td Enhance the system's responsiveness to rapid change.

PID Parameter Settings：In the process of PID parameter tuning, the system refers to the parameter settings of industrial experience [17], and it is necessary to balance the response speed and stability. After multiple tests, the set parameters are (Kp=30.0), (Ki=0.3), (Kd=5.0). In addition, three special treatments have been made for PID calculation.

Integral limiting: Prevents the accumulation of integral items from being too large and causes the system to overshoot or oscillate, which is called integral saturation. The code is shown in Figure 8.

Output Limiting: Ensure that the output is within a safe and effective range, and avoid oversized or too small control signals. The code is shown in Figure 9.

Combination of direct mapping and PID control: The final calculation of the servo angle adopts a combination of direct mapping and PID control, and sets the weight ratio (direct mapping accounts for 80% and PID adjustment accounts for 20%), achieving a balance between fast response and stability. The code is shown in Figure 10.

```
if(pid->SumError > 20) pid->SumError = 20;
if(pid->SumError < -20) pid->SumError = -20;
i_term = pid->Ki * pid->SumError;
```

Figure 8 Integral Limiting Code

```
    if (output > pid->MaxOutput) {
        output = pid->MaxOutput;
    } else if (output < pid->MinOutput) {
        output = pid->MinOutput;
    }

    return output;
}
```

Figure 9 Output Limiting Code

```
final_angle = direct_angle * 0.8f + pid_output * 0.2f;
```

Figure 10 Setting the Weight Ratio Code

V. Verification and Analysis

Remote Control Test：

The user can select the working mode of the heating system through the APP interface, and when the automatic mode is selected, the servo will perform PID operation according to the preset temperature and the temperature and humidity data collected by DHT11 to accurately control the servo to control the hot water output: when the manual mode is selected, the user can directly adjust the rotation angle of the servo to control the hot water flow.

Servo control test in automatic mode: the preset temperature is 27.5, and the servo operation is observed by adjusting the external temperature. The outside temperature rises from 28°C to 34°C, the servo angle rises from 115° to 144°, and the hot water flow decreases. The test results show that in automatic mode, the temperature control system controls the steering gear angle stably and reliably, and the operation results are shown in Figure 11.

Figure 11 The result of the automatic mode

Servo control test in manual mode: Enter the servo angle (e.g. 75 degrees) directly on the mobile app, and the system will ignore the current temperature and fix the valve directly at this angle. The test results show that in the manual mode, the temperature control system controls the steering gear angle stably and reliably, and the operation results are shown in Figure 4.2.

Figure 4.2 Result of manual mode

VI. CONCLUSION

Focusing on the actual needs of smart home heating control system, this paper designs and constructs a solution for home automatic heating system. By combining the Internet of Things cloud platform, wireless communication and PID control technology, the intelligent regulation and control of the heating system is realized. The system includes temperature and humidity data collection, data transmission and equipment linkage functions, supports remote monitoring and alarm mechanism, and can optimize the heating time and temperature adjustment according to user settings, so as to effectively reduce heat loss. Major achievements include the following:

Through the investigation of the technical status inside and outside the field of intelligent heating, the research objectives and key design points are defined, which lays a theoretical foundation for the subsequent technology development work.

According to the functional requirements, the overall structure of the system was planned and constructed, and at the same time, the type selection and modular configuration of the core key technologies such as wireless communication and Internet of Things cloud platform were carried out.

The core components of the system hardware circuit have been completed, including STM32F103C8T6 as the main control chip, integrated DHT11 temperature and humidity sensor, ESP8266WiFi module, SG90 servo, OLED display and power module.

Based on the existing hardware, a software part has been developed and implemented to realize the remote monitoring and operation functions of the heating system. The ESP8266WiFi module is combined with the OneNet cloud platform to transmit the temperature and humidity information collected by the DHT11 sensor through the MQTT protocol, which realizes data monitoring and linkage operation between devices.

The PID control algorithm is introduced to achieve accurate temperature control. \(0.5在≤^{\circ }C\), the predetermined design standards were achieved.

A test platform was built to evaluate and verify the data collection performance, ESP8266 communication performance, and overall stability of DHT11. The study showed that the system was running stably and meeting the expected design standards.

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With the help of the long-distance communication characteristics of WiFi technology, the system is added to the OneNet cloud platform, which realizes the efficient control of data monitoring and remote control, showing good practicability and innovation value. The verification results show that the system works stably and meets the requirements of smart home heating, which confirms the feasibility of the plan. In the future, higher precision sensors may be required to enhance the accuracy of temperature regulation, while optimizing network fault tolerance strategies can improve system stability. In addition, the integration of 5G communication technology or the adoption of more advanced control strategies (such as fuzzy PID control method) can be explored to enhance the efficiency and intelligence level of the system, so as to lay a more solid foundation for energy conservation and emission reduction and the popularization and application of smart homes.

REFRENCES

[1]. Cui Yan. Siemens: Energy Contract Management Leads the New Concept of Green and Energy Saving: An Interview with Shao Kangwen, General Manager of Building Technology Group, Infrastructure & Cities of Siemens[J]. Electrical Manufacturing, 2014, (02): 14-17.

[2]. Wang Zhihua, Li Ming. Research on Temperature Control Technology Based on Internet of Things in Smart Home System[J]. Automation Technology and Application, 2020, 39(05): 68-72.

[3]. Li Xiaohong, Chen Wei. Internet of Things Technology and Its Application in Smart Home[J]. Application Research of Computers, 2021, 38(03): 123-128.

[4]. Smith J, Brown T. Smart Home Heating Systems: A Review of IoT-Based Solutions[C]//Proceedings of the 2020 International Conference on Smart Technologies. IEEE, 2020: 112-118.

[5]. Chen Li, Wang Gang. Application of ESP8266-based WiFi communication module in smart home[J]. Application of Electronic Technology, 2019, 45(07): 56-60.

[6]. Zhao Ming. Research on Application of PID Control Algorithm in Temperature Control System[J]. Control Engineering, 2018, 25(06): 789-793.

[7]. Liu Fang, Zhang Lei. Application of OneNet IoT Cloud Platform in Remote Monitoring System[J]. Internet of Things Technology, 2020, 10(04): 34-38.

[8]. Zhou Hua. Research on Energy Saving Optimization Strategy of Smart Home Heating System[J]. Building Science, 2022, 38(02): 89-94.

[9]. Zhang Qiang, Liu Yang. Design and application of embedded system based on STM32[M]. Beijing: Publishing House of Electronics Industry, 2019: 45-67.

[10]. Yang Y, Li J. Qiang. Design of Smart Home Remote Control System Based on WiFi[J]. Computer Measurement and Control, 2021, 29(03): 56-61.

[11]. Li Hua, Sun Qiang. Design and implementation of smart home system[M]. Shanghai: Shanghai Jiao Tong University Press, 2018: 78-92.

[12]. Wang Lei. Principle and application of Internet of Things technology[M]. Beijing: Tsinghua University Press, 2020: 102-125.

[13]. Zhang Wei, Sun Li. Research on the Application of Embedded Systems in Smart Homes[J]. Microcomputer and Application, 2019, 38(06): 45-49.

[14]. HE Fang, LIU Jie. Design and Implementation of Smart Home Environmental Monitoring System[J]. Sensors and Microsystems, 2020, 39(04): 78-82.

[15]. Sun M, Wang Fang. Application progress of Internet of Things technology in smart home[J]. Science and Technology and Innovation, 2021, (05): 34-37.

[16]. Li Gang, Zhang Hong. Optimal Design of Temperature Control System Based on PID Algorithm[J]. Process Automation Instrumentation, 2019, 40(07): 23-27.

[17]. Liu Yang, Chen Xiao. Research on energy-saving technology of smart home[J]. Energy Saving Technology, 2022, 40(03): 15-20.