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Design of Temperature Control System Based on STM32 and Tuned PID Algorithm

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***Abstract*—The design of this paper is to solve the problems of poor stability and low control accuracy of traditional temperature control system in industry, agriculture and even daily life. This paper is a design of temperature control system based on STM32 microcontroller and self-tuning PID (proportional-integral-differential) algorithm. The system mainly includes temperature acquisition module, mode adjustment module, display module and temperature control module. The temperature acquisition module uses a temperature sensor to monitor the ambient temperature in real time, which is converted into a digital signal by ADC and fed back to the main control chip. The temperature control module processes the temperature signal through the PID algorithm designed by the target set value and the actual ambient temperature, calculates the control quantity according to the set target temperature, and outputs it to the execution module through the PWM signal, so as to realize the precise control of the heater and the temperature control. The results show that the temperature control system based on STM32 and tuning PID algorithm can quickly respond to temperature changes, has high control accuracy and stability, can maintain the target temperature under different environmental conditions, and is suitable for various application scenarios that need accurate temperature control.**

Keywords—stm32 microprocessor; self-tuning pid algorithm; temperature control; pwm signal

I. INTRODUCTION

Nowadays, the importance of temperature control is increasingly prominent in industrial and agricultural production and daily life. For example, chemical industry, metallurgy, biology, pharmacy and living environment all need real-time temperature monitoring and control[1]. With the continuous progress of science and technology, the application prospect of high-precision temperature controller is more and more extensive. Influenced by the improvement of science and technology, people's requirements for living environment are constantly improving. They are no longer just satisfied with the use of air conditioners, but hope that indoor temperature control can be more convenient, fast and intelligent. However, the traditional temperature control system often needs manual adjustment, which is not only time-consuming and labor-intensive, but also has low control accuracy.

In order to solve these problems, this paper designs an intelligent temperature control system. The system adopts STM32F103C8T6 as the controller, and uses the tuned PID algorithm to control the temperature[2]. Because PID algorithm is simple and effective, it is widely used in temperature control in industrial field. The system designed in this paper not only has the basic functions of real-time measurement of environmental temperature, temperature parameter setting and temperature adjustment, but also can monitor the temperature in real time, which has strong practicability.

II. SYSTEM OVERALL DESIGN

In this paper, an intelligent temperature control system is designed, which takes STM32F103C8T6 as the main controller and adopts DS18B20 temperature acquisition module to collect the ambient temperature in real time. After the temperature acquisition module obtains the ambient temperature, the analog temperature value is converted into digital value through A/D conversion, and the real-time temperature value is displayed on the display module.

The system can not only display the temperature in real time, but also have intelligent adjustment function. By comparing the real-time temperature with the preset target temperature, the system accurately calculates the required control parameters by using the adjusted PID algorithm to generate the PWM wave signal of the driving circuit, so as to control the work of the heating plate or the cooling plate[3]. The heating plate is used to raise the ambient temperature, while the cooling plate is used to lower the ambient temperature. By this way, the ambient temperature can quickly reach and stabilize at the preset target temperature. The mode adjustment module can change the working mode of the system, and the overall block diagram is shown in Fig 1.

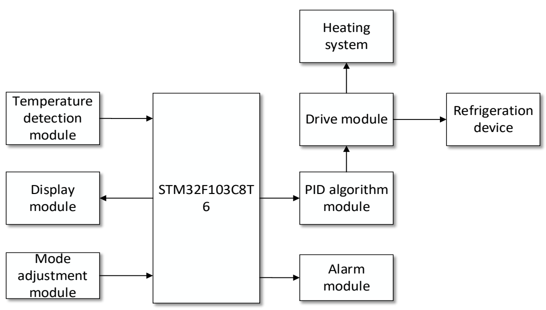

Fig. 1. Overall block diagram.

The system has the characteristics of simple structure and perfect function, and can realize high-precision temperature control. At the same time, the design of the system also has strong expansibility, which can be expanded and adjusted according to different application scenarios, so it has a wide application prospect in modern industrial and agricultural production and daily life. Through the actual test, it is proved that the system can achieve the expected function well and has strong practical value to today's society.

III. HARDWARE DESIGN OF MAIN MODULE

A. Main control

The system designed in this paper takes STM32F103C8T6 as the main control chip. The STM32F103C8T6 has many advantages in the temperature control system. Based on the high-performance processing ability of ARM Cortex-M3 core and rich peripheral interfaces, such as USART, SPI, I2C, etc., it is easy to connect with the temperature sensor DS18B20 and the display module OLED[4]. Built-in 12-bit high-precision ADC ensures the accuracy of temperature acquisition data, and multiple timers support PWM output to realize accurate control of heating and cooling modules. Its low power consumption is suitable for long-running applications, and rich software libraries and development tools simplify the development and debugging process. STM32F103C8T6 also has powerful real-time processing ability and high reliability, which is suitable for application scenarios that require high temperature control accuracy, and it has strong expansibility and high cost performance, and rich community support further reduces the development difficulty[5].

B. Temperature acquisition module

The temperature acquisition module adopts DS18B20 digital temperature sensor, which has obvious advantages and excellent measurement accuracy. This module uses the digital output characteristics of DS18B20 to simplify the design and improve the accuracy of measurement. The single bus interface design of the sensor allows communication with the main control chip through a data pin. Its wide working voltage range, strong anti-interference ability and low power consumption make it suitable for various voltage levels and complex industrial environments[6]. The wiring schematic diagram of the temperature acquisition module is shown in Fig 2.

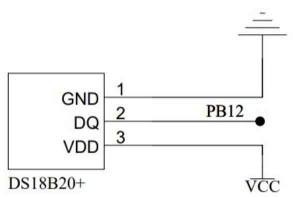

Fig. 2. Schematic diagram of temperature measuring module.

C. Display module

The display module adopts OLED display screen as the core display component, which is responsible for displaying the ambient temperature, set value and operation mode in real time. Its fast response time and high resolution ensure the smooth update and accurate display of temperature data and system status. At the same time, the thin and light design of OLED display screen and the simple I2C or SPI interface simplify the system integration process[7]. The wiring diagram of the display module is shown in Fig 3.

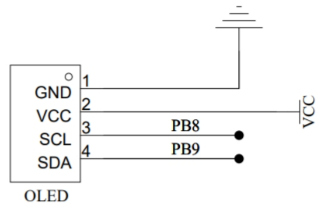

Fig. 3. Schematic diagram of display module.

D. Temperature control module

The temperature control module uses STM32 and the tuned PID algorithm to accurately adjust the working state of PTC heater and TEC cooler to ensure the ambient temperature is stable within the set range.

In the heating module, PTC heater is controlled by L298N drive module. Because the working voltage of single chip microcomputer is not enough to directly drive the 12V PTC heater, L298N double H-bridge driver module is adopted to deal with the high voltage load[8]. Through the PWM signal generated by single chip microcomputer, the heating power is accurately controlled. When the ambient temperature is lower than the set minimum value, the system starts the heating module to raise the temperature to the set range, thus maintaining the stability of the environment.

In the cooling module, the L298N driver module is used to handle the driving demand of 12V. The PWM signal generated by single chip microcomputer regulates the current to TEC cooling plate through L298N, thus realizing accurate cooling[9]. When the ambient temperature is higher than the set maximum value, the system starts the refrigeration module to reduce the temperature to the set range.

IV. SOFTWARE DESIGN

The software design of temperature control system mainly includes four main parts: temperature acquisition program design, mode adjustment program design, heating program design and cooling program design.

A. Design of temperature acquisition program

The design of temperature acquisition is the basis of our other module design. The real-time temperature acquisition on site is mainly collected by DS18B20 temperature sensor, and the collected temperature is converted into digital quantity, and then sent to CPU for subsequent operation, and the measured real-time data is displayed on OLED. At the same time, the thin and light design of OLED. When designing the temperature acquisition program module, steps such as port initialization, command writing and command reading must be carried out. The flow chart of the temperature acquisition program is shown in Fig 4.

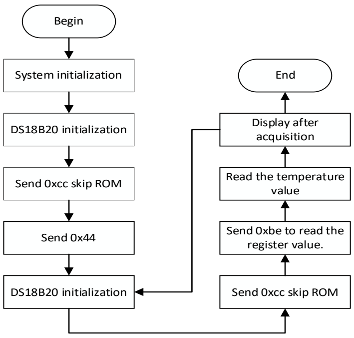

Fig. 4. Temperature acquisition process.

B. Mode adjustment program design

The mode adjustment module is mainly used to adjust the working mode of the actuator, adjust the set point temperature to an appropriate threshold, and the working mode is changed to the heating mode, and when the set point is also adjusted to another threshold, the working mode is changed to the cooling mode. Mode adjustment is mainly completed by the key circuit, and the set value can be increased or decreased according to the state of different keys, thus changing the working mode of the actuator. The program flow of mode adjustment is shown in Fig 5.

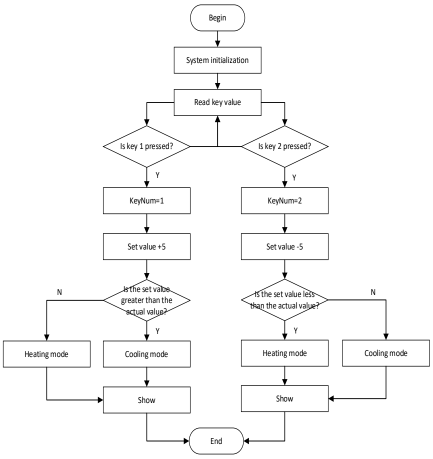

Fig. 5. Mode adjustment process.

C. Heating program design

The design of the heating program should be based on the first two program modules. Before heating, it is necessary to read the relationship between the current ambient temperature value and the set temperature value. When the ambient temperature value is lower than the set value, the program will control the heating module to heat to approach the set value according to the PWM wave output by PID algorithm. When the ambient temperature is higher than the set value, the PWM duty ratio is 0 and the heating module stops working. The flow chart of the heating program is shown in Fig 6.

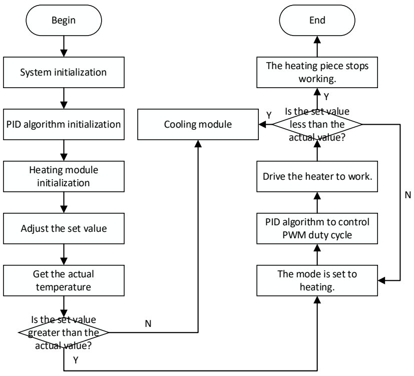

Fig. 6. Heating program flow.

D. Cooling program design

The goal of cooling program design is to control the refrigeration module to cool down by controlling the output PWM wave through PID algorithm according to the relationship between the current ambient temperature and the set temperature. When the ambient temperature value is higher than the set value, the program will control the output PWM wave according to the PID algorithm to control the refrigeration module to cool down to get close to the set value; When the ambient temperature is lower than the set value, the PWM duty ratio is 0, the refrigeration module stops working, and the cooling program flow is shown in Fig 7.

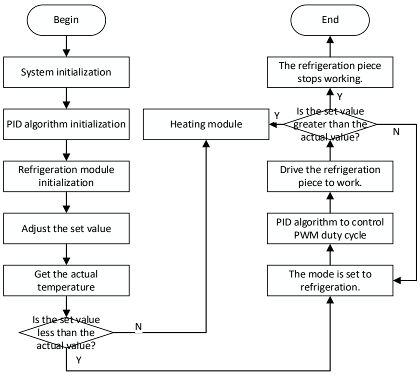

Fig. 7. Cooling program.

V. PID CONTROL ALGORITHM

A. The basic principle of PID algorithml

PID controller is a kind of feedback controller widely used in industrial control system, which optimizes the response of the system by adjusting three parameters: proportion, integration and differentiation. The function of PID algorithm in temperature control system is to make the actual temperature of the system approach the set temperature quickly and smoothly by adjusting the control quantity. The block diagram of conventional PID controller is shown in Fig 8.

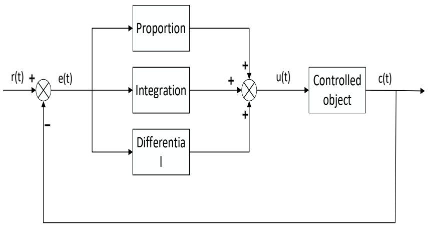

Fig. 8. PID principle block diagram.

In the figure, r(t) is the set value, e(t) is the difference between the set value r(t) and the feedback value c(t), and u(t) is the control quantity after proportional, integral and differential operations, and then acts on the controlled object. As can be seen from the figure, PID controller is a linear controller, and its differential equation is:

$$u(t) = K_p\left[e(t)+\frac{1}{T_i}\int_0^t e(t)dt+T_d\frac{de(t)}{dt}\right] \tag{1}$$

Transfer function of PID controller:

$$\frac{U(S)}{E(S)} = K_p + \frac{K_p}{T_i}\times\frac{1}{s} + K_p T_d \times s \tag{2}$$

Digital PID controller:

$$\Delta u(k) = K_p\Delta e(k) + K_i e(k) + K_d\left[\Delta e(k) - \Delta e(k-1)\right] \tag{3}$$

Where K_p is a proportional system, T_i is an integral time constant, and T_d is a differential time constant. When the proportional gain K_p increases, the system response will become faster. However, if K_p is too large, it may lead to system instability. When the integral gain K_i increases, the steady-state error can be eliminated. However, if the K_i is too large, the system response may be too slow, and it may easily cause overshoot and oscillation. When the differential gain K_d increases, the system is more sensitive to the change of error, and can predict the change trend of error, which can restrain oscillation and overshoot. If K_d is too large, the system may be too sensitive to noise and produce high-frequency oscillation.

B. Parameter self-tuning of PID controller

PID parameter self-tuning is a process to optimize the control effect by automatically adjusting proportional, integral and differential parameters, and its quality directly affects the system performance. The self-tuning method uses the algorithm to automatically find the optimal PID parameters and realize the expected control goal. The system introduces the Z-N tuning method.

Ziegler-Nichols parameter tuning method is one of the classical PID parameter tuning methods, which is mainly used to determine the parameters of PID controller to optimize the performance of control system[10]. The system puts forward the setting method of response curve method.

The response curve method determines the step response curve of the system through experiments, calculates the critical proportional band and critical period of the system, and then determines the PID parameters. For most projects, an inertia link and a pure lag link can be used for approximate description, so the transfer function of the controlled object is:

$$G(s) = \frac{K}{Ts+1}e^{-as} \tag{4}$$

Where K is the system gain, T is the inertia time constant and a is the lag time. The setting and formula of PID parameters are as follows:

$$K_p = \frac{1.2T}{Ka} \tag{5}$$

$$T_i = 2a \tag{6}$$

$$T_d = 0.5a \tag{7}$$

Two transfer functions are selected to verify the control effect of the response curve method. The transfer functions of the two controlled objects are:

$$G_1(s) = \frac{1}{s+1}e^{-s} \tag{8}$$

$$G_2(s) = \frac{1}{3s+1}e^{-s} \tag{9}$$

According to the formula, the PID parameters of two transfer functions can be calculated.

Model 1:

$$K_p = 1.2,\quad T_i = 2,\quad T_d = 0.5 \tag{10}$$

Model 2:

$$K_p = 3.6,\quad T_i = 2,\quad T_d = 0.5 \tag{11}$$

Because the differential integrals of the two transfer functions are the same and the proportional coefficients are different, through simulation, we can get the response curves of the two transfer functions when the input signal is a step signal as shown in Fig 9.

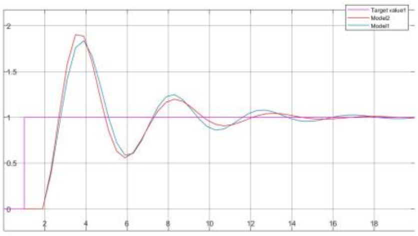

Fig. 9. PID controller response curve.

It can be seen from the figure that when K_p is different and T_i and T_d are the same, although the response time is reduced, it can be clearly seen that the overshoot of the system response will also increase at this time, so a control system with small overshoot and fast response time can be obtained by choosing a suitable K_p.

If K_p is kept constant and the values of T_i and T_d are changed appropriately, the transfer functions of the two controlled objects are:

$$G_3(s) = \frac{1}{s+1} e^{-0.7s} \tag{12}$$

$$G_4(s) = \frac{1}{s+1} e^{-0.8s} \tag{13}$$

Model 3:

$$K_p = 1.2\ ,\quad T_i = 1.6\ ,\quad T_d = 0.4 \tag{14}$$

Model 4:

$$K_p = 1.2\ ,\quad T_i = 1.4\ ,\quad T_d = 0.35 \tag{15}$$

Through Simulink simulation, it can be seen that due to the decrease of integral, the steady-state error of the system will increase, but the response speed of the system will increase, while the decrease of differential will reduce the noise sensitivity of the system. The response graph is shown in Fig 10:

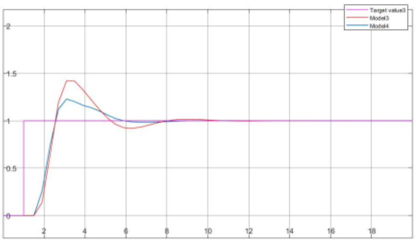

Fig. 10. PID controller response curve.

It can be seen from the figure that model 4 has smaller overshoot and faster response time than model 3, so a PID controller with smaller overshoot, shorter adjustment time, weaker oscillation and better control performance can be obtained by appropriately reducing T_i and T_d.

VI. CONCLUSIONS

In this study, we designed and implemented an intelligent temperature control system based on STM32F103C8T6. The system collects real-time temperature through DS18B20 temperature sensor, and uses tuning PID algorithm to accurately control the heating and cooling modules, thus realizing accurate temperature adjustment. The system uses OLED display screen to display the ambient temperature, set value and working mode in real time, which enhances the readability of the user interface and the convenience of operation. The intelligent temperature control system has simple structure, complete functions, practicability and application prospect, and provides an efficient solution for modern temperature control. In the future, we can further optimize performance and expand functions to meet a wider range of needs.

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