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Analog-Based Temperature Control System

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Abstract: In order to solve the problems of large volume and Bang-Bang control of temperature control system in process control experimental teaching, a temperature control scheme based on analog quantity was proposed. The temperature system uses STM32 as the controller, DS18B20 collects the temperature, uses the positional PID algorithm to calculate the duty cycle of the PWM, converts the PWM into analog output to the solid-state voltage regulator through the PWM to voltage module, realizes the continuous control of the heating rod by changing the input voltage of the heating rod, and finally draws the temperature curve through MATLAB and analyzes the control effect. This scheme effectively solves the problems of large volume of process control instruments and large steady-state error of Bang-Bang control. Experiments show that when the system reaches stability, the steady-state error is less than 0.6%, which has a good control effect.

1. Introduction

In many fields such as electric power, chemical industry, petroleum, metallurgy, aerospace, machinery manufacturing, grain storage, wine production, etc., temperature is one of the most important parameters to characterize the state of the object and process. The temperature control is also diverse, and the classic Bang-Bang control is actually a kind of on-off control, also known as time-optimal control, which means that within the allowable control range, the control output switches from one boundary value to another, and the system takes the shortest time to switch from one state to another. However, Bang-Bang control may have overshoot and oscillation at the beginning of the control, resulting in oscillation and instability of the output variables, and is not suitable for systems that require finer control. Analog control can optimize the way of switching control, among which, temperature control is widely used in analog control, such as constant temperature water tank, temperature control greenhouse, etc., all need to control the temperature in real time. The analog-based temperature control system uses the temperature of the DS18B20 temperature sensor received by the single-chip microcomputer to calculate the PWM duty cycle through the positional PID algorithm, so as to adjust the voltage to control the adjustment scheme of the power of the heating rod, and the water temperature can be continuously and accurately controlled in real time. In the experimental teaching, the water temperature process control instrument itself is larger, especially some equipment with larger power and more complex functions, which may need to occupy more installation space, and the hardware equipment of this system can also optimize the use of space.

2. The overall control scheme of the system

When the microcontroller receives the water temperature measured by the DS18B20 temperature sensor, the duty cycle of the output PWM is adjusted after processing by the PID algorithm. Then, the output voltage of the PWM to voltage module is controlled by inputting PWM with different duty cycles. Then, the output voltage of the PWM to voltage module is input to the solid-state voltage regulator, so as to realize the continuous control of the voltage of the heating system. The flow diagram of this temperature control system is shown in Figure 1. Through this voltage analog control method, the power of the heating rod can be continuously adjusted, so as to reduce the oscillation and steady-state error of the system temperature, achieve a more accurate final temperature, and better meet the needs of temperature control.

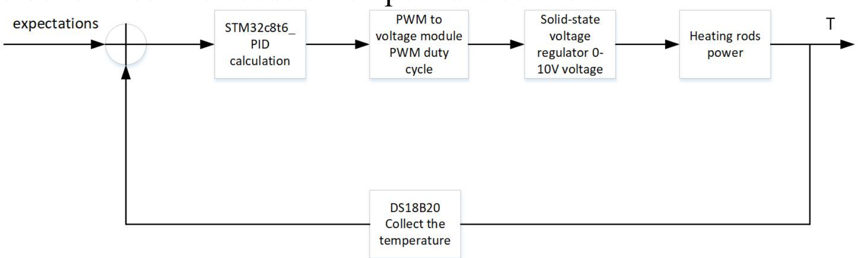

Figure 1 Flow chart of the temperature control system

3. System hardware composition

The hardware of the analog-based temperature control system is mainly divided into four main modules: STM32c8t6 microcontroller core control module, temperature acquisition module, analog conversion module and heating module.

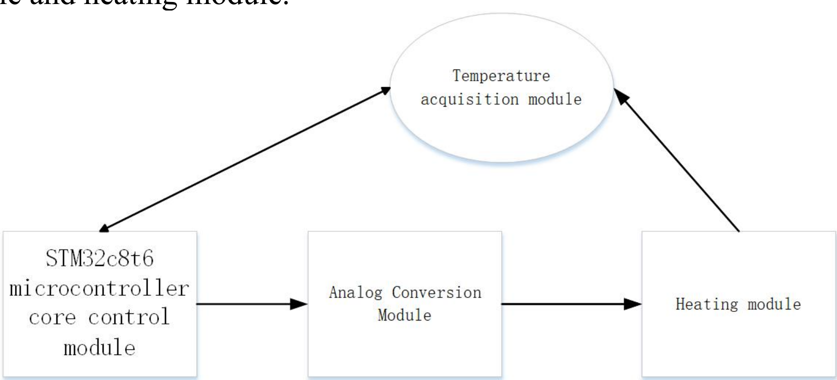

Figure 2 Block diagram of a hardware module

The core control module of the STM32c8t6 microcontroller mainly includes the writing of the temperature acquisition code and related filter code of the DS18B20 temperature sensor and the PWM module code of the STM32c8t6 microcontroller. After the temperature is collected by the DS18B20 temperature sensor, the duty cycle of PWM is calculated and output by the PID algorithm using the collected temperature value.

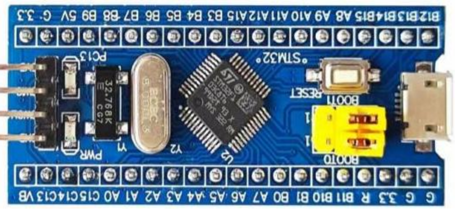

Figure 3 STM32 c8t6 microcontroller *Figure 4 DS18B20 temperature sensor*

The temperature acquisition module is a DS18B20 temperature sensor. DS18B20 is a commonly used high-precision single-bus digital temperature measurement chip. It has the characteristics of small size, low hardware overhead, strong anti-interference ability and high precision. The temperature range is -55°C to 125°C, and the error is ±0.5°C from -10°C to 85°C. Because of the use of single-bus digital transmission mode, the anti-interference of the system is greatly improved. It is suitable for high-temperature ambient temperature measurement, which can accurately measure the temperature of hot water and return the temperature value to the microcontroller.

The analog conversion module includes a PWM-to-voltage module, a solid-state voltage regulator, and a 24V DC voltage source. The working voltage of the PWM to voltage module is 12V-30V, the receiving frequency of the PWM signal is 1KHZ-3KHZ, the conversion range is 0%-100%, and the PWM is converted to 0-10V voltage, and the allowable range is 5%. Solid-state regulators achieve voltage regulation by changing the trigger phase angle (i.e., conduction angle) of the thyristor. When the input signal changes, the control circuit adjusts the on-time of the thyristor during each AC cycle. The larger the conduction angle, the higher the output voltage; The lower it is. In this experiment, the control terminal voltage of the solid-state voltage regulator is 0V-10V, and the output terminal voltage is 0V-380V. A 24V DC voltage source supplies power to the PWM to voltage module. Firstly, the PWM to voltage module is calibrated for PWM, and then the 0%-100% PWM signal output by the single-chip microcomputer is converted into 0-10V voltage, and then the 0-10V voltage is output to the solid-state voltage regulator to realize the continuous control of the output voltage of the solid-state voltage regulator. This enables continuous control of analog quantities.

Figure 5 PWM to voltage module *Figure 6 Solid-state voltage regulators*

The heating module is a heating rod with a power of 1800W. The live wire of the heating rod is connected to a solid-state voltage regulator and then to a 220V alternating current, so that the voltage is continuously adjustable and heated.

Figure 7 Heating rods

4. Positional PID control algorithm

PID control is a commonly used feedback control method, and each PID controller consists of three parts: proportional control, integral control, and derivative control. The PID controller calculates the difference between the given value and the actual value to reach the control deviation e(t), and then acts on the control deviation in the three links of P, I, and D, and then generates and outputs the control quantity through linear combination, and then controls the controlled object, which is PID control [1]. The basic schematic diagram [2] is shown in Figure 8, where R(t) is the output value of the PID and C(t) is the output of the controlled object.

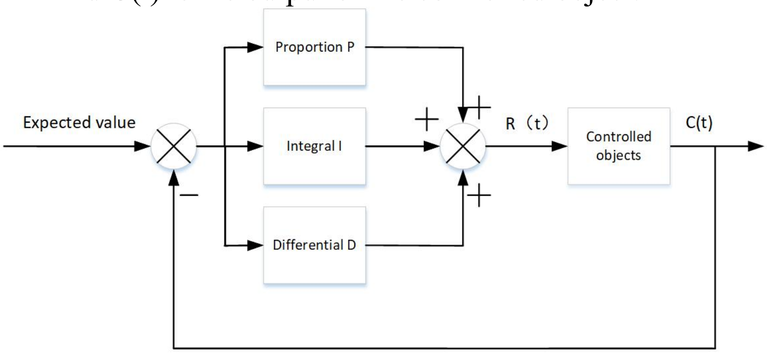

Figure 8 PID basic schematic

The expression of the algorithm is:

$$u(t) = K_p[e(t) + 1/T_i \int_0^t e(t)\,dt + 1/T_d \times de(t)/dt] \quad (1)$$

where: K_p is the proportional factor; T_i is the integration time constant; T_d is a differential time constant.

The expression of the positional PID control algorithm is:

$$u(k) = K_p e(k) + K_i \sum_{j=0}^{k} e(j) + K_d[e(k) - e(k-1) \quad (2)$$

where: j is the number of samples, j=0,1,⋯ k; The K_p、K_i，K_d are proportional coefficients, integral coefficients, and differential coefficients.

The positional PID control algorithm is a branch of the PID control algorithm, the position of the actuator corresponds to the input signal one-to-one, and the controller calculates the value of the control variable output after the nth sampling according to the deviation e between the nth sampling result and the given value. In this experiment, when the sensor measures the water temperature, it is calculated by the positional PID algorithm, and then the duty cycle of the output PWM is adjusted according to the results, and the output voltage of the PWM to voltage module is controlled by inputting PWM with different duty cycles. Then, the output voltage of the PWM to voltage module is input to the solid-state voltage regulator, so as to realize the continuous control of the voltage of the heating system.

5. Experimental results

In the process of experiment, the serial port module on the microcontroller, the VOFA serial port debugging assistant and the drawing of the MATLAB temperature curve are added, so that the real-time water temperature can be intuitively observed and the change curve of water temperature can be clearly displayed. After initializing the STM32 c8t6 serial port module, modify the temperature value uploaded by the DS18B20 temperature sensor to the data format of the VOFA serial port debugging assistant, and upload the temperature data in real time, and the data can be observed in real time in the data receiving area of the VOFA serial port debugging assistant. After completing a test, save all the temperature data of an experiment in the VOFA serial port debugging assistant, and save it in an Excel table, and then import the temperature data in Excel into MATLAB for temperature curve drawing, and use the stackedplot() function to plot the imported data, and the relevant temperature curve is shown in Figure 9.

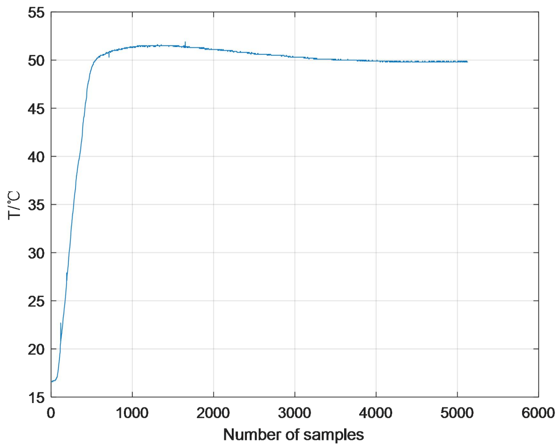

Figure 9 PID temperature curve

To verify the integrity of the system, we made a step change in the set temperature value, and the temperature curve is shown in Figure 10. The system generates an analog control voltage based on the PID algorithm and drives the actuator to adjust the temperature. The experimental results show that under the closed-loop control, the system can reach a new steady state in a period of time, in which the proportional link accelerates the response process, the integral link eliminates the static difference, and the differential link inhibits overshoot.

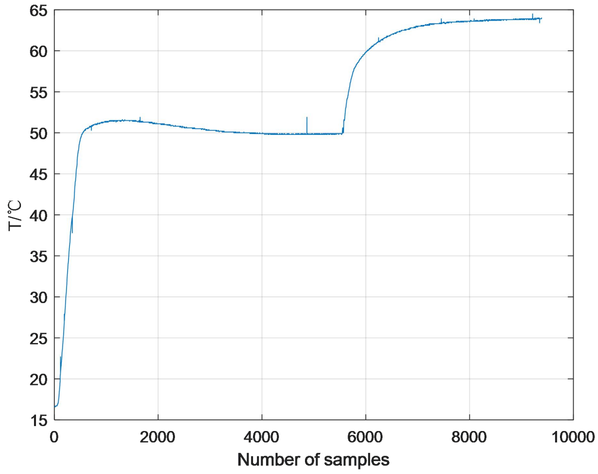

Figure 10 Twice PID adjusts the temperature curve

From the above experimental data, it can be seen that when the analog voltage and PID control are used, the temperature system is relatively stable and the steady-state error is small, and the steady-state error of the system is less than 0.6% after many experiments, which can meet the requirements of the systematic error design. The results show that the temperature value is more accurate than that of the Bang-Bang control [3], which can meet the temperature control requirements. Therefore, it can be proved that the scheme of using the PID algorithm of temperature value to control the duty cycle of 0%-100% PWM of the output, and then controlling the output voltage of 0-10V voltage by the duty cycle of 0%-100% PWM of the input, and finally controlling the analog control of the heating rod voltage by the input voltage of 0-10V is feasible, which can meet the needs of temperature control experiments. At the same time, the hardware design of this analog temperature control system is reasonable and can meet the temperature requirements and space requirements, which can save space well.

6. Conclusion

The analog-based temperature control system realizes the continuous controllability of the heating rod voltage through the analog conversion modules such as PID algorithm, PWM to voltage module and solid-state voltage regulator, which effectively solves the problem that the Bang-Bang control method may cause the oscillation and instability of the system and has a large steady-state error. The control process of the temperature system is more stable, the temperature is more accurate, and it can better meet the heating conditions. At the same time, the hardware circuit of the temperature system has low requirements for space conditions, which can better save space than traditional process control instruments. Bang-Bang control requires a large number of switches, and the consumption of hardware circuits is also relatively serious, and the consumption and wear of hardware by using this analog hardware circuit are also relatively low. Has a longer lifespan.

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