Design and Implementation of Micro Temperature Control System Based on PWM

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Abstract. With the application of temperature control system in space remote sensors becoming more and more widespread, and with the increasing demand for high resolution of space remote sensors, the requirement of high precision and miniaturization of the temperature control system of remote sensors is constantly increasing. This paper mainly introduces the working principle of a self-closed micro temperature control system based on UC1825 high-speed pulse width modulation (PWM) controller. According to compare the target temperature with the acquisition temperature, it uses the controller for voltage modulation and outputs PWM pulse width with different duty cycles. And then it controls the on/off of the MOSFET to control the heating time of the controlled object. And finally a self-closed micro-temperature control system based on UC1825 is realized. Currently, the measurement and temperature control performance of the micro-temperature controller on orbit distributedly installed near the controlled object are good.

1. Introduction
Temperature is an important physical parameter affecting the working state of space remote sensor. With the continuous improvement of resolution of space remote sensor and the harshness of application environment, high-precision and miniaturized temperature measurement and control technology and engineering application have become a research hotspot, which is equally significance in the research of the field of space remote sensor. In the past, the temperature control system mostly had complex hardware resources and adopted the method of centralized temperature control. Because the driving power of heating sheet was transmitted from the long line to the heating sheet after centralized control by a single machine, which inevitably caused line loss, resulting in unnecessary waste of resources and power loss. However, some foreign defense satellite programs, optical systems, electronic frequency standards and other precise temperature control occasions have adopted a large number of distributed temperature control devices [1]. The distributed temperature control device installs the temperature control sensor, the heating sheet and the controller nearby to the controlled device, which not only can obtain high control precision, but also does not need to concentrate a large number of long lines on the temperature control device. It not only reduces measurement error and power loss because of the long-distance transmission, but also is beneficial to the thermal design topology layout and makes up for the shortcomings of the centralized temperature control system.

The use of distributed self-closed temperature control system to replace the traditional centralized temperature control system and realize the self-closed-loop high precision temperature control, which has become a development trend of space remote sensor temperature control design. This paper mainly introduces the working principle of a self-closed-loop temperature control system which uses the
UC1825 as the control core for voltage modulation, and drives MOSFET with dual-channel diodes based on pulse width modulation (PWM), finally, one a self-closed-loop temperature control system is to design successfully. This system, which can be applied to some temperature control systems of space remote sensor where the number of temperature control paths is small, has the characteristics of high control precision, small volume, simple structure and flexible installation.

2. The principles of temperature control system
The micro-temperature control system mainly includes a temperature setting module, a temperature gathered module, a PWM control module and a driving output module, as shown in 0. The temperature setting module mainly calculates one setting temperature with using the precision reference voltage source provided by UC1825 and provides the target voltage for subsequent module. The PWM control module and the driving output module are the core modules of the temperature control system. They are mainly composed of UC1825 high-speed PWM controller and MOSFET. The driving output module is directly connected to the controlled object to realize closed-loop management and control signal output functions. The temperature gathered module which mainly gathers the resistance value of the thermistor realizes the real-time temperature collection of the controlled object.

By collecting the real-time temperature of the controlled object, the temperature gathered module feeds back the sampling voltage $V_{ce}$ to the PWM control module which compares the sampling temperature voltage $V_{ce}$ with the setting temperature voltage $V_{set}$, and then the PWM control module drives through the difference between the two temperature voltages. Finally the driving output module controls the on-off time of the heating sheet to achieve temperature control of the controlled object. That is, the heating rate of the controlled object is controlled according to the difference between the sampling temperature $T_{ce}$ and the setting temperature $T_{set}$. When $T_{ce} > T_{set}$, the sampling temperature $T_{ce}$ is higher than the setting temperature $T_{set}$, the MOSFET is turned off to stop heating; when $T_{set} - T_{ce} > 0.2$ °C, the setting temperature $T_{set}$ is much higher than the sampling temperature $T_{ce}$, and the MOSFET is turned on at full power state; when $T_{set} - T_{ce} < 0.2$ °C, the MOSFET is turned on in the PWM pulse width modulation proportional heating state. Thus, when the temperature difference between the sampling temperature and the setting temperature is larger, the heating time is longer; the smaller the temperature difference is, the shorter the heating time is. After several times of fluctuation, the controlled object can be maintained at a relatively stable temperature, which not only ensures the temperature control accuracy but also ensures that the controlled object does not have temperature overshoot.

3. Design and analysis of Key circuit module

3.1. PWM control module
The PWM control module mainly consists of UC1825 high-speed PWM integrated control chip, which is widely used due to its simple peripheral circuit design and powerful functions. The micro temperature
control system mainly adopts the voltage control type of the UC1825 chip. By adjusting the duty ratio of the PWM output, the on-off time control of the MOSFET is realized. When the MOSFET is turned on, the controlled object is proportionally heated. When the MOSFET is turned off, the controlled object stops heating, thereby achieving the purpose of temperature control of the controlled object. Figure 2 is a circuit diagram of the PWM control module and the driving output module.

**Figure 2. PWM control module and driving output module circuit diagram**

The UC1825 integrates a high frequency oscillator, wide bandwidth error amplifier, PWM comparator, and PWM latch etc, and provides a very accurate reference voltage of VREF 5.1V with an accuracy of ±1%[2]. The UC1825 generates a sawtooth voltage as a carrier signal by the internal high frequency oscillator. The internal wide bandwidth error amplifier compares the setting voltage with the sampling voltage and then outputs a voltage difference which is used as a modulation signal. The superposition signal of carrier signal and modulation signal is used to determine the duty cycle of the pulse width modulated wave. The higher the sampling voltage is, the smaller the duty cycle of the output pulse width is, and vice versa [3].

The MOSFET is the primary device of the driving output module. If the PWM signal of the UC1825 is directly output to the controlled object, the heating power is limited. So The output of the PWM signal of UC1825 transmitted to the MOSFET in this way, it changes heating time of the controlled object by controlling the on/off of MOSFET, which not only expands heating power, but also can isolate the heating circuit and the PWM control circuit for protection.

**Figure 3. Schematic diagram of temperature gathered module**
3.2. Temperature gathered module
The accuracy of the temperature measurement technology is an important index parameter affecting the temperature control system. The temperature gathered module mainly collects the voltage value of the controlled object, and feeds back this voltage value to the PWM control module. After filtering, it is input as a sampling voltage. As shown in 0, the gathered temperature voltage \( V_{REF} \left( \frac{R_2 + R_8}{R_2 + R_8 + R_x} \right) \) through \( R_3 \) is input to the 1 pin of UC1825. The negative point and positive point of the UC1825 internal error amplifier are 1 pin and 2 pin respectively. And 3 pin is the output of the internal error amplifier. The resistor \( R_x \) and the capacitor \( C_4 \) between the 3 pin and the 1 pin form a proportional integral feedback compensation loop. The capacitor \( C_4 \) can effectively suppress high-frequency noise. This proportional-integral feedback compensation loop performs 10 times reverse amplification on the sampling signal to provide a control signal for the internal PWM comparator. At the same time, the integral action can eliminate the steady-state error for better temperature control precision.

The accuracy of the commonly used AD conversion technique is \( 2^n \), where \( n \) is the number of conversion bits of AD, and the larger the number of conversion bits \( n \), the higher the accuracy [4]. Only when \( n \) approaches infinity, the accuracy approaches 0, which is infinitely close to the analog quantity. Therefore, the analog temperature measurement can directly avoid the error caused by the AD bit limit [1]. This system uses analog quantity to measure temperature, which can avoid errors caused by AD conversion.

3.3. Driving output module
The driving output module mainly consists of a pulse output circuit of MOSFET and PWM control chip. When the PWM control chip outputs a modulation pulse width high level, the MOSFET is turned on, the controlled object is heated, and the output modulation pulse width is low, the MOSFET is turned off, the controlled object stops heating. The PWM control chip can output two modulation pulses with a phase difference of 180° [5]. The two pulse signals are combined or logically driven by a diode to drive the MOSFET. The schematic diagram of the driving output circuit is shown in 0. In order to provide a reliable turn-on voltage of the MOSFET and ensure reliable turn-off of the MOSFET during the period of the PWM signal, a reasonable selection of the \( R_7 \) resistor value is required.

Select the setting temperature to be 10.2 °C, and calculate the setting voltage to be 1.62V according to the resistance voltage relationship and the temperature value corresponding to the thermistor resistance value. Observe the duty cycle of the UC1825 single output and the MOSFET front end by the oscilloscope. It can be seen from the measured data that when the sampling signal is less than 1.593V, the single-channel output duty cycle of this circuit is close to 50% of the pulse, and the two channels work simultaneously to obtain the pulse with the duty cycle close to 100%. When the sampling signal is greater than 1.593V and continues increasing, the duty cycle of the output temperature of this circuit continues decreasing. When the sampling signal is greater than 1.616V, the control circuit stops outputting the pulse. The experimental data is shown in 0.

**Table 1. TabMicro temperature controller output data table**

| setting temperature | MF61Thermistor resistance value (Ω) | MF61Thermistor Corresponding Temperature (°C) | Corresponding acquisition voltage value (V) | UC1825 single output duty cycle | Duty cycle of pre-heated MOS |
|---------------------|------------------------------------|-----------------------------------------------|-------------------------------------------|-------------------------------|-----------------------------|
| 10.2 C              | 7111                               | 10.2                                          | 1.616                                     | 0                             | 0                           |
|                     | 7141                               | 10.1                                          | 1.612                                     | 6.95%                         | 13.76%                      |
|                     | 7172                               | 10.0                                          | 1.607                                     | 16.62%                        | 32.84%                      |
|                     | 7202                               | 9.9                                           | 1.603                                     | 29.91%                        | 59.83%                      |
|                     | 7234                               | 9.8                                           | 1.598                                     | 44.17%                        | 86.72%                      |
|                     | 7265                               | 9.7                                           | 1.593                                     | 49.87%                        | 99.91%                      |
4. Temperature control system test

The micro self-closed temperature controller has an operating voltage range of 8~35V, a size of 34mm*30mm*13mm, and a weight of about 33g. The engineering prototype is shown in 0. The red and black wires are connected to the positive and negative ends of the power supply, the pink and green wires are connected to both ends of the external thermistor; the yellow and blue wires are connected to the ends of the heating sheet on the controlled object.

![Figure 4. Engineering prototype physical map](image)

For the function and performance test of the micro temperature controller, in order to improve the accuracy of the test, replace the thermistor with the precision resistor box Rx. The positive and negative ends of the Rx are respectively connected with the pink and green leads of the micro-thermometer, and the Rx is adjusted. The resistance value simulates the temperature change of the controlled object. The yellow and blue lead connections are connected to simulate the controlled object. The test connection relationship is shown in 0:

![Figure 5. Connection Diagram for Accuracy Testing](image)

The simulated heat load was heated in the test chamber at an initial temperature of 22°C, and the estimated setting voltage value was 2.48 V, and the target temperature was set to 10.2°C. According to the resistance value of the thermistor, the real-time temperature was recorded with time. After about 20 minutes, the simulated load temperature was basically stable, and the thermistor feedback simulated load temperature varied from 10.0°C to 10.4°C. The surface simulation load reached the target temperature. With constant temperature, the micro temperature controller realized the independent temperature control function.

Acknowledgments

This paper mainly introduces the circuit design and working principle of a micro self-closed temperature control system based on the high PWM control chip UC1825. Through the research of the micro self-closed temperature control system, the micro temperature controller was successfully developed, which has high temperature control precision, small product size and easy installation. It has been proved by
experiments that it can meet the temperature control requirements of space remote sensors. At present, the temperature controller has been successfully applied in spacecraft, and the temperature control performance is good.

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