A Fuzzy Self-tuning Temperature PID Control Algorithms for 3D Bio-printing Temperature Control System

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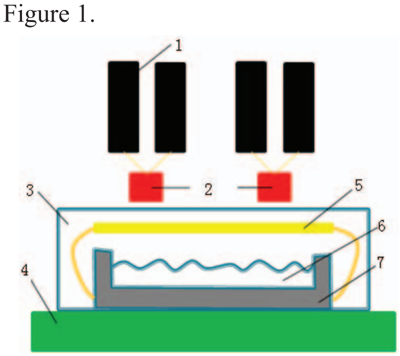
Abstract: The precision of temperature control in temperature control area of 3D bio-printing device is directly related to the continuity of printing material and the quality of rapid prototyping. In order to improve the accuracy of temperature control and reduce overshoot, the fuzzy self-tuning temperature PID control algorithm of temperature control area of 3D bio-printing device is studied. Experiments are carried out to verify the fuzzy self-tuning temperature PID control algorithm and BECKHOFF PID control algorithm respectively. The results show that the temperature self-tuning fuzzy PID control algorithm can greatly improve the robustness and static and dynamic performance of temperature control, reduce the steady-state time of actual temperature reaching steady state, greatly reduce the overshoot, enhance the anti-interference ability, and it can more effectively meet the requirement of temperature control accuracy for the quality and activity of rapid prototyping of biological tissue in 3D biological printing device.

Key Words: 3D Bio-printing, PID, Fuzzy self-tuning, Temperature control, Accuracy

1 INTRODUCTION

The temperature control area of the 3D biological printing device includes the cartridge area and the forming area, as shown in Figure 1.



1-Cartridge, 2-Nozzle, 3- Thermal insulation cover, 4-Base, 5-Rotating rod, 6-Nutrient solution, 7-Nutrient trough
Fig.1. Temperature Control System Diagram of the 3D bio-printing device

According to the research objective of temperature control system of 3D bio-printing device and the temperature requirement of vascular tissue printing and forming, the temperature of 3D bio-printing process should be controlled in the constant temperature range of 0～40℃ and the precision of temperature control should be ±0.5℃. In the process of 3D printing, hydrodynamic experiments and tissue rapid prototyping experiments require that the temperature of the printing area of double nozzles should be controlled above normal temperature, and the temperature of the angioplasty area should be controlled between 0 and 5 degrees Celsius. At the same time, according to the actual printing conditions such as ambient temperature, printing material characteristics and printing control process, the automatic adjustment of temperature control system of 3D bio-printing device is realized.

2 EXPERIMENTS OF BECKHOFF PID TEMPERATURE CONTROL ALGORITHMS

2.1 Experimental Process

The application of temperature control algorithm is related to the accuracy and stability of temperature control system of 3D biological printing device. The control algorithm of temperature control system should effectively reduce the temperature fluctuation and improve the robustness of the system [1]. Semiconductor direct temperature control system adopts BECKHOFF PID control algorithm. In order to verify the control quality of BECKHOFF PID control algorithm, the temperature of cartridge area is set at 30℃ and that of printing forming area is set at 5 ℃, respectively, at the experimental temperature of 20 ℃. Four probes of DS18B20 temperature sensor are fixed with thermal conductive glue at the surface feature points exposed in the air in the cartridge area.

The actual temperature of one end of the semiconductor silicon wafer is collected by PT-100 temperature sensor in

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real time, and fed back to the display screen of the constant temperature control box [2]. The temperature values corresponding to the two at 12 different times are taken, and the temperature values of the four characteristic points at each time are averaged. The thermal efficiency of semiconductor silicon wafer and the thermal conductivity of metal conductor are observed and analyzed as shown in Figure 2 and Figure 3.

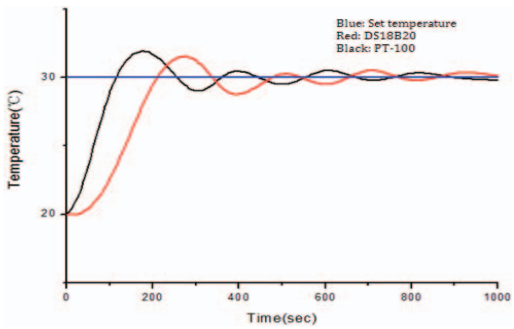

Fig. 2 The actual temperature curve and characteristic temperature curve of the cartridge area

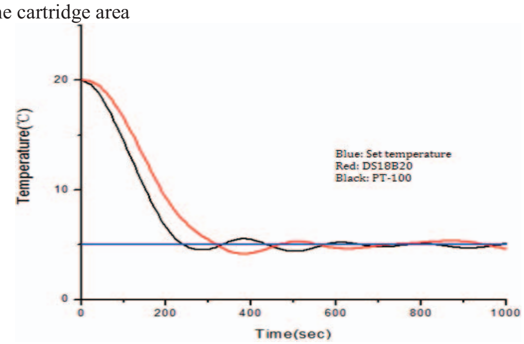

Fig. 3 The actual temperature curve and characteristic temperature curve of the print forming area

2.2 Analysis of experimental results

By comparing the experimental results of Fig. 2 and Fig. 3 horizontally and vertically, the following conclusions are drawn:

- The heat absorption and heat release of semiconductor are controlled by the PID algorithm of the controller. There are some overshoots and lags, which affect the stability and robustness of the temperature control region. It takes a period of time for the actual temperature and the characterization temperature to reach the set temperature.
- The short heat conduction time and high conduction efficiency of metal conductor verify the advantages of semiconductor direct cooling and heating.
- The cooling and heating efficiency of semiconductor silicon wafer is very high, and the time for temperature control region to reach the set temperature is very short. The characterization temperature always lags behind the actual temperature before the temperature control region reaches the set temperature.

3 RESEARCH ON FUZZY SELF-TUNING TEMPERATURE PID CONTROL ALGORITHMS

By analyzing the experimental results of the BECKHOFF PID temperature control algorithm, it can be concluded that the BECKHOFF controller has serious interference on the temperature control of the temperature control system, the lag of the temperature control process is large, and the temperature fluctuation is obvious. In order to effectively improve the accuracy and robustness of temperature control system and restrain temperature overshoot, a fuzzy self-tuning temperature PID control algorithm is proposed through repeated experiments [3].

3.1 Fuzzy Self-tuning Temperature PID Control Algorithms

According to the actual temperature situation of cartridge and forming area, fuzzy self-tuning temperature PID control algorithm can automatically adjust the proportional coefficient K_P, integral coefficient K_I and differential coefficient K_D, and adjust the temperature change in real time through self-tuning function module [4].

According to the requirement of biological tissue for temperature accuracy, the theoretical domain of temperature deviation E is [-0.5, 0.5], the theoretical domain of deviation rate EC is [-0.01, 0.01], the quantification factor K_E=6, K_{EC}=60, matching the fuzzy domain [-3, 3]. In order to improve the robustness and stability of the temperature control algorithm, seven fuzzy subsets are selected and their corresponding values are [-3, -2, -1, 0, 1, 2, 3]. The triangular membership function with membership degree of [0, 1] is selected and fuzzy processing is carried out. According to the real-time step response of the system, the exact values $\triangle K_P$, $\triangle K_I$ and $\triangle K_D$ of the fuzzified output need to be multiplied by their initial values to obtain the actual set PID parameters [5, 6]. The system block diagram of the fuzzy self-tuning temperature PID control algorithm is shown in Figure 4.

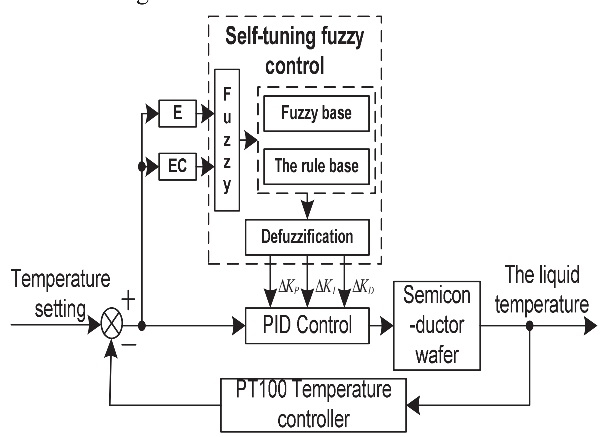

Fig.4 Self-tuning fuzzy PID control system diagram

3.2 Construction of Temperature Control System Experimental Platform for 3D Bio-printing Device

Semiconductor constant temperature control box is a high precision automatic PID bidirectional power independent control system, which supports automatic linear regulation of temperature rise and fall and output power. At the same time, the constant temperature control box can also be connected with EL6002 through RS-232 interface to realize the remote control of CX2030-0123 main controller [7, 8].

4 EXPERIMENTAL VERIFICATION OF FUZZY SELF-TUNING TEMPERATURE PID CONTROL ALGORITHMS

4.1 Experimental implementation scheme

The temperature control system of 3D biological printing device adopts the heat conduction mode of semiconductor direct cooling and heating. The cooling and heating efficiency of semiconductor is controlled by constant temperature control box and CX2030-0123 controller. In order to verify the ability of the fuzzy self-tuning temperature PID control algorithm in restraining temperature fluctuation and overshoot, this control algorithm is used in the experimental scheme to control the temperature rising process in the cartridge area and the temperature falling process in the forming area. PT-100 temperature sensor collects feedback temperature value every second in real time, compares with the actual output temperature value of the controller, fits the difference between them by SPLINE curve, depicts the temperature fluctuation spectrum in the process of temperature rising and falling, and then uses the temperature fluctuation spectrum to analyze the precision of temperature control under the fuzzy self-tuning temperature PID control algorithm.

4.2 Experimental implementation process

During the experiment, the constant temperature control box is monitored in real time by RS-232 and EtherCAT communication terminal module EL6002 and CX2030-0123 master controller. Under the function of fuzzy self-tuning temperature PID control algorithm, the steady-state temperature of cartridge area is set to 30℃, the steady-state temperature of forming area is set to 4℃, and the acquisition frequency of PT-100 temperature sensor is set to 1 s. After the beginning of the experiment, PT-100 temperature sensor collects the actual output temperature of semiconductor in real time. The collected signal is fed back to the constant temperature control box and the main controller. The acquisition period of the experiment is set to 1000s. At the end of one acquisition cycle, by comparing the actual output temperature of the semiconductor with the temperature output of the controller, the temperature output errors at every second are obtained. The 1000 temperature errors can be described as temperature rise fluctuation spectrum and temperature drop fluctuation spectrum, which can clearly reflect the temperature control accuracy of the temperature control system. Temperature rising spectrum of the ink box area is shown Figure. 5, Temperature drop fluctuation spectrum of the forming zone is shown Figure 6.

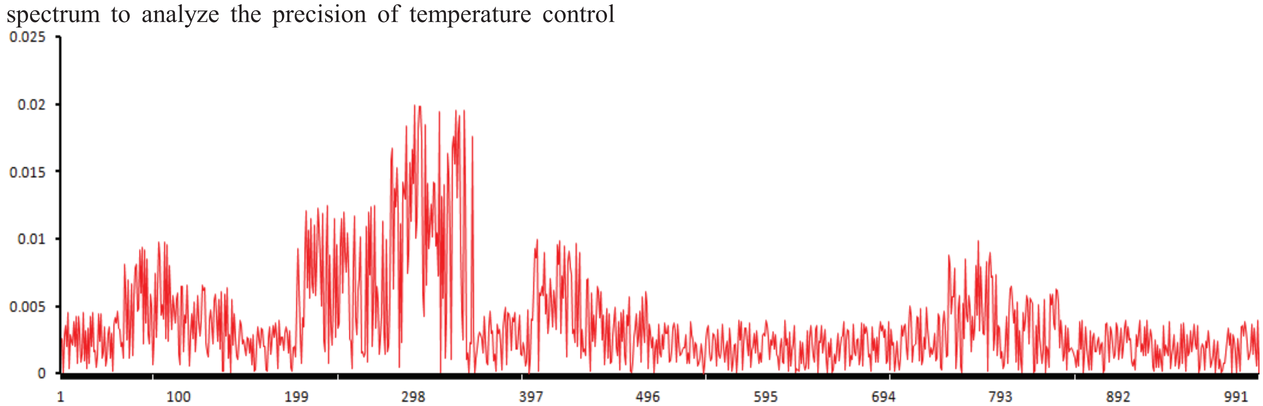

Fig.5 Temperature rising spectrum of the ink box area

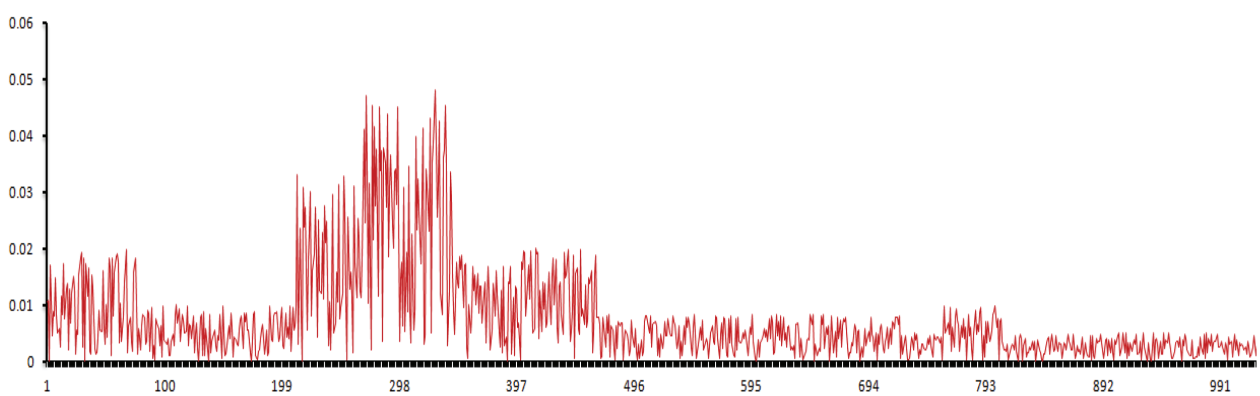

Fig.6 Temperature drop fluctuation spectrum of the forming zone

4.3 Analysis of experimental results

From the temperature fluctuation spectrum of the cartridge area, it can be seen that after using the fuzzy self-tuning temperature PID control algorithm, the temperature fluctuation occurs in the cartridge area near 300 s, and the maximum overshoot is less than 2%. After that, the cartridge area does not fluctuate significantly and the temperature output tends to be stable. This result also validates the simulation results of the control algorithm. At the same time, the temperature fluctuation occurs in the forming area near 290s, and the maximum overshoot does not exceed 5%. After that, the temperature output tends to be stable, and there is no large fluctuation. This result is also consistent with the simulation results.

Through the experimental verification of the fuzzy self-tuning temperature PID control algorithm, the temperature fluctuation spectrum of the actual operation of the control algorithm is obtained. From the above experimental results, it can be concluded that in the heat conduction process of semiconductor direct cooling and heating, the fuzzy self-tuning temperature PID control algorithm can indeed improve the temperature control accuracy of the high temperature control system, effectively suppress or weaken the temperature fluctuation and overshoot of the non-linear system, and is helpful to improve the temperature control quality of semiconductor direct cooling and heating.

5 CONCLUSIONS

In view of the temperature fluctuation and overshoot in the temperature control system test, a temperature self-tuning fuzzy PID control algorithm is proposed to improve the accuracy of temperature control and reduce overshoot. The experimental results show that in the heat conduction process of semiconductor direct cooling and heating, the fuzzy self-tuning temperature PID control algorithm can achieve the temperature control accuracy of the temperature control system in the range of (± 0.5℃), and it can effectively suppress or weaken the temperature fluctuation and overshoot in the non-linear system, and greatly improve the temperature control quality of semiconductor direct cooling and heating. For 3D bio-printing, it is helpful to meet the strict requirements of the quality and activity of rapid prototyping of biological tissue for temperature control system of 3D bio-printing device.

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