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Practical Nozzle Temperature Control Method for Robot FDM Printing System

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Abstract

Fused Deposition Modeling (FDM) technology in 3D printing has beendeveloped for many years. In this paper, a robot FDM 3D printingsystem is proposed and the nozzle temperature control issue isfocused primarily. The temperature measurement adopts a data driven modeling method andthe parameters of the measurement model are trained by the particle swarm optimization algorithm. A practical temperature control method is presented in which thetemperature control of nozzle is divided into two periods. Duringthe temperature flying period, the heating voltage is givenaccording to the current temperature value and its varying trend. In thefalling time of nozzle temperature, the corresponding controlvoltage value is provided correspondingly. Based on this practical control strategy, a partdesigned with Solidworks software is printed using the robot FDM printing system which validates theeffectiveness of the practical temperature control method.

Keywords: Robot FDM printing, Nozzle temperature, Practical controllaw, Implementation

1. Introduction

Recently, 3D printing technology has become an advanced technology for the manufacturing of many parts. By incorporating 3D printing into the design life cycle, engineers could reduce both time and cost between product revisions. Until now, there are many 3D printing technologies (Tuan, Alireze, Gabriele, Kate, & David, 2018) such as the stereolithography (SLA), the Selective Laser Sintering (SLS), the Fused Deposition Modeling (FDM), Direct Metal Deposition (DMD), Direct Metal Laser Sintering (DMLS), Electron Beam Melting (EBM), Laser Consolidation (LC), Multi-Jet Modeling (MJM), and etc.

Among the above technologies, the FDM method is suit for the beginners of the 3D printing for its simple principle and cheap materials of ABS or PLA thermoplastic (Fuda, Weilong, Jingjing, Junhua & Shiren, 2015; Chacón, Caminero, García-Plaza & Núñez, 2017; Alafaghani, Qattawi, Buraaq & Arturo, 2017). But limited by the reachable arrange of the FDM printer, large part could not be printed by ordinary FDM printer. Therefore, the flexible industrial robot (Elisha, John & Adisa, 2017; Md. Hazrat, Aizat, Yerkhan, Zhandos & Anuar, 2018) could be selected as the 3D printing motion equipment which has been used in metal 3D manufacturing such laser cladding or arc welding printing. In our work, an industrial robot is taken as the motion equipment of the FDM printing system.

In FDM technology, the printing material is first changed into the liquid state and then solidified after being pushed out of the nozzle. So the nozzle temperature is the important factor for the successful printing of the FDM printer. In traditional FDM printer, the temperature control of nozzle is combined with the whole control system of the FDM printer (Kyong-Min, Hani, Jihun & Doo-Man, 2019; Hardikkumar, Darshan & Ankur, 2017). In this paper, a robot FDM printing system is provided. The nozzle temperature and the robot motion should be controlled separately. And through the communication of the two systems of robot and nozzle, the FDM printing task can be realized. The issue of nozzle temperature control is the focus of this paper.

The organization of this paper is as the follows. Section 2 introduces the hardware structure of the robot FDM printing system and some circuits for measurement and control of the nozzle temperature. The mathematical description the nozzle temperature control and the details of the practical control law design are given in section 3 and 4. The experiment is conducted in section 5. The conclusions are presented in section 6 at last.

2. Robot FDM Printing System Structure and Nozzle Temperature Control Hardware

2.1 Robot FDM System Structure

The robot FDM printing system used for experiments is constructed inour laboratory shown in figure 1. Its main components in figure 2 include the 6 degree freedom robot manipulator (motion system), the nozzle, wire-feed system and the printing bottom board.

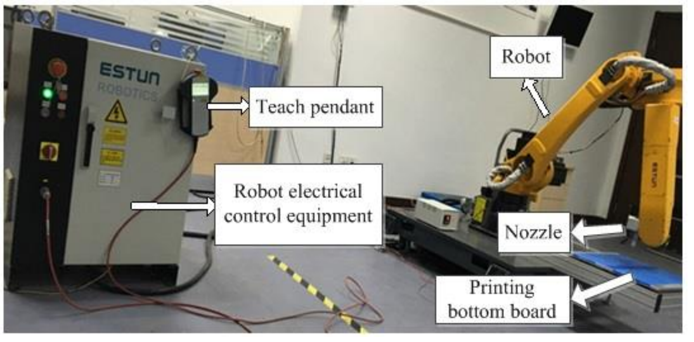


Figure 1. The robot FDM printing system

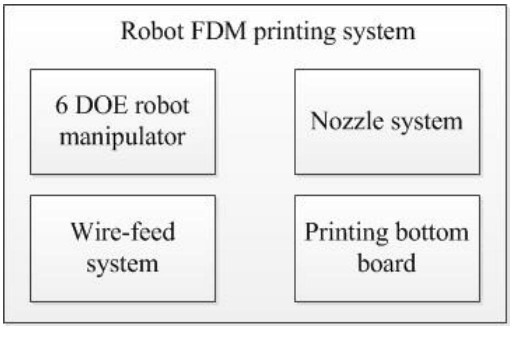


Figure 2. Illustration of the main components in robot FDM printing system

2.2 Nozzle System Hardware Components and Control Circuits

In FDM technology, the printing wire material is first changed fromsolid state to liquid phase over the melting point and thenconverted into solid sate after being pushed out of the nozzle.Among these procedure, the temperature plays an important role whichdetermines the state change and solidifying speed of the meltingwire material. In the presented robot FDM printing system, thenozzle hardware system and its every part are illustrated in figure 3.

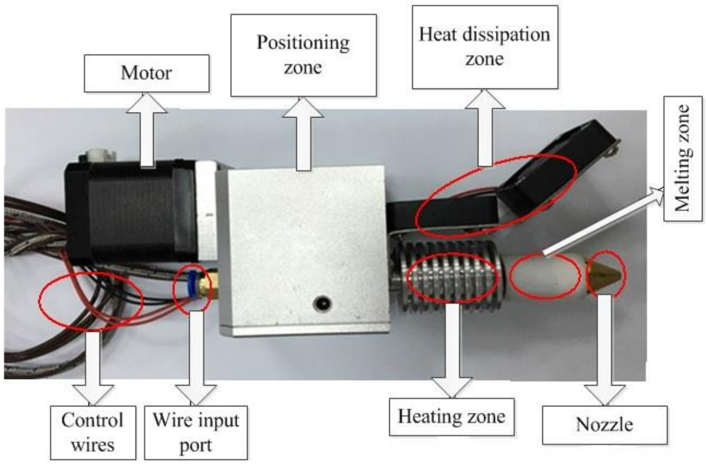
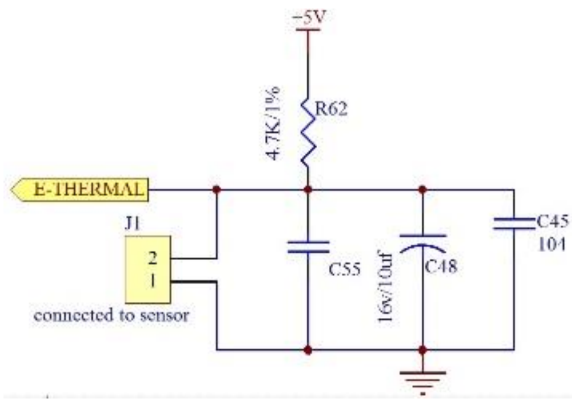


Figure 3. The nozzle hardware and its every part

We fucus on the temperature control issue of the nozzle in this paper. In order to realize the temperature control, the temperaturemeasuring and heating circuits are designed shown in figure 4 andfigure 5. The thermistor in nozzle is connected to the port of J1 infigure 4 and the port of J2 in figure 5 is connected to a heatingtube in nozzle. The controller adopts the MCU of Arduino Mega2560.The PWM port in Mega2560 is used as the heating control signalconnected to the heating circuit.



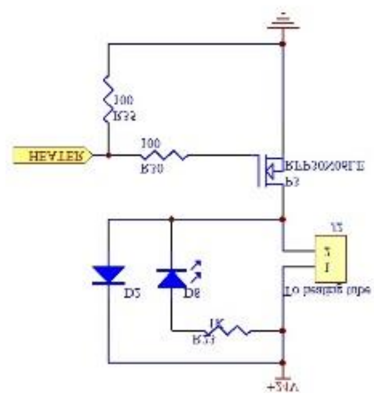


Figure 4. Nozzle temperature measurement circuit Figure 5. Nozzle heating circuit

3. Mathematical Description of the Nozzle Temperature Control Problem

The nozzle temperature control system is logically divided intothree procedures: temperature measurement, controller design andtemperature heating execution which is given in figure 6.

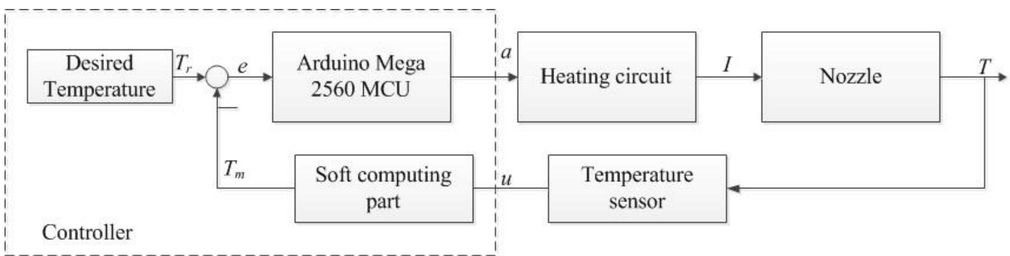


Figure 6. Nozzle temperature control system structure

3.1 Data-driven Temperature Model and Measurement Computing Method

The temperature sensor is thermistor with the negative temperatureco efficient. Assume the mathematical relationship between the actualtemperature and output voltage u is $f(.)$ and unknown. But themeasured data of $T(i),u(i),i=1,...,N$ could be obtained. If we canknow the inverse relationship $\Psi(.)=f^{-1}(.)$ between u and T. Then the measured temperature T_m could be obtained the sameas the actual temperature.

$$T_m=f(.)\ \Psi(.)=T(1)$$

Table 1. Samples for the training of temperature measured model

Temperature.T/℃	25	28	31	34	37	40	43
V oltage.u/V	4.7755	4.7455	4.7124	4.6760	4.6362	4.5928	4.5458
Temperature.T/℃	47	50	53	56	59	61	63
V oltage.u/V	4.4949	4.4401	4.3813	4.3185	4.2518	4.1810	4.1064
Temperature.T/℃	67	70	73	76	79	82	85
V oltage.u/V	4.0281	3.9461	3.8607	3.7722	3.6808	3.5867	3.4904

Firstly, the experiment data is list in the table 1. From thesamples the following two order polynomial equation is given in thefollowing equation with three coefficients parameters ofa_2, $a_1$and a_0.

$$T'=a_2u^2+a_1u+a_0 \tag{2}$$

$$f_{itness}=\sqrt{\frac{\sum_{k=1}^{N}[T'(k)-T(k)]^2}{N-1}} \tag{3}$$

T' denotes the output of the temperature measured model. Using the particle swarm optimization algorithm (PSO), the parameters inthe above model can be optimized as a_2=-19.3535, a_1=114.7015, a_0=-79.9385. Under these parameters, the performanceevaluation index defined in equation 3 is 0.6948. So in the actualFDM printing, the two order polynomial model T' is adopted as themeasured temperature T_m.

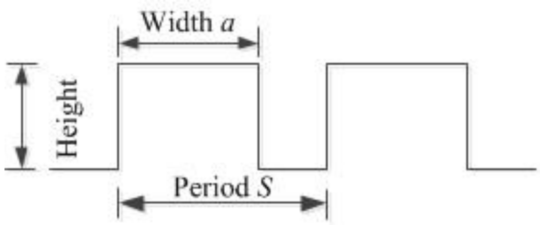


Figure 7. PWM heating method

3.2 Electrical Heating Part Model

The heating part is based on the PWM method shown in figure 7. During the period of S, the heating time maintains the width a. The current of the nozzle heating circuit in figure 5 will changed through the turning of the width of a. Therefore the model of electrical heating part model can be described as.

$$I=\Phi(a,t) \tag{4}$$

Where Φ denotes the heating relationship between the width a and the nozzle heating current I. t is given as the heating time.

4. Practical Design Method for Nozzle Temperature Control

For the viewpoint of control, the nozzle temperature is determined by the input heating current I. Therefore, the controller will give the control law to present the desired current based on the measured temperature T_m and the desired temperature T_r.

In our work, a practical control method is proposed in which the temperature control is divided into two procedures. The first procedure is the temperature flying period and the second procedure is the temperature falling period. In theses periods, the temperature is divided different ranges according to the difference T_e

between the desired and actual temperature. Considering the temperature inertia and varying speed, the details of the control law is described in table 2.

Table 2. Practical control law of *a*

a	*Period*	*T*	T_e
255	*flying*	$0 \sim (T_r - 20)$ ℃	$T_e >= 20$ ℃
240		$(T_r - 20) \sim (T_r - 10)$ ℃	$10^\circ <= T_e < 20$ ℃
200		$(T_r - 10) \sim (T_r - 7)$ ℃	$7^\circ <= T_e < 10$ ℃
160		$(T_r - 7) \sim (T_r - 5)$ ℃	$5^\circ <= T_e < 7$ ℃
80		$(T_r - 5) \sim (T_r - 3)$ ℃	$3^\circ <= T_e < 5$ ℃
0		$> (T_r - 3)$ ℃	$T_e < 3$ ℃
225	*falling*	$< (T_r - 5)$ ℃	5 ℃ $<= T_e$
210		$(T_r - 5) \sim (T_r - 2)$ ℃	$2^\circ C <= T_e < 5$ ℃
220		$> (T_r - 2)$ ℃	$T_e < 2$ ℃

5. Implementation Experiment and Results

The nozzle temperature experiment is conducted and the type of the printing material is PLA with the desired melting temperature 230 ℃. The control result is shown in figure 8 and it can be seen that the temperature control law can meet the requirement of the robot FDM printing. The control accuracy of the temperature control can maintain the range of 3 ℃

To validate the control effectiveness of the nozzle temperature, a cubic model with holes is designed illustrated in figure 9. Under the temperature control law shown in table 2, the printed object is presented in figure 10. With the help of the nozzle temperature control, the robot FDM system can print the designed model successfully.

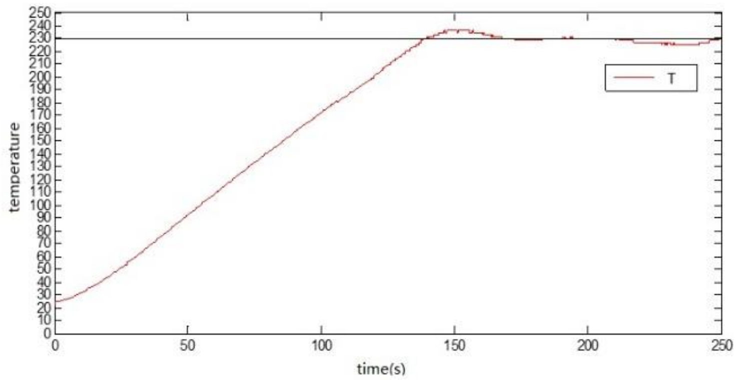


Figure 8. Off-line nozzle temperature control with PLA printing material

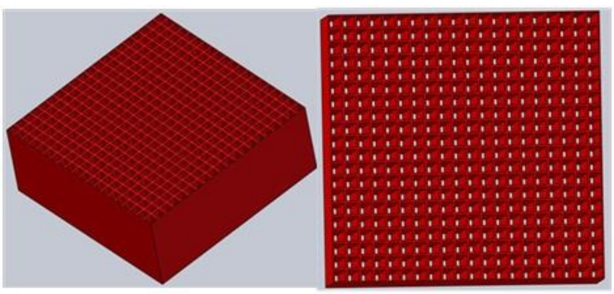


Figure 9. Designed cubic model with holes

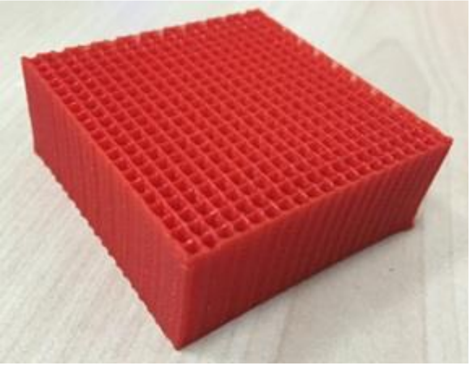


Figure 10. Printed object using the robot FDM printing system and temperature control law

6. Conclusion

A robot FDM printing system is presented and the nozzle temperature control issue is given in this paper. After introducing the hardware components and mathematical model of the nozzle temperature control system, the details of the temperature measurement and practical control law is proposed. The temperature control and printing experiments results show that practical control law is effective and can meet the need of the robot FDM printing system.

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