

Fuzzy PID Controlled Temperature in Phototherapy Incubator for Infant Jaundice Treatment: A Simulation

Juhui He*, Xing Wen*, Jiapei Cai*,

Bing-Yuh Lu*, Hongjie Zheng*, Xiaokang Cheng*, Yiheng Chen*

*Guangdong University of Petrochemical Technology, Maoming City, Guangdong, China

1361721671@qq.com, 1606523313@qq.com, 2559156324@qq.com, franklinlu888@outlook.com, 1416764250@qq.com, 2577470296@qq.com, 918795199@qq.com

Abstract—PID controller is a popular method in many applications. However, the response of the PID controller can be improved by artificial intelligent algorithm. Therefore, this study employed the Fuzzy-PID controller to keep the constant temperature in phototherapy incubator for infant jaundice treatment. The Fuzzy interference rules were established by the error of feedback temperature and its 1st order difference. Compared with the PID controller, the Fuzzy-PID (FPID) controller presented the better performance of timing delay. The FPID controller performed much more reducing the timing delay than Fuzzy controller. In the simulation, the delay of FPID controller was around 2 seconds, and that of Fuzzy controller was around 25 second. Therefore, the results of simulation provide the design considerations of a modern phototherapy incubator for infant jaundice treatment.

Keywords—newborn infant, Fuzzy-PID controller, blue light optical therapy, neonatal jaundice, treatment, computer simulation.

I. INTRODUCTION

Neonatal jaundice is usually a normal physiological condition that occurs in the transitional period after birth. It is not a single disease, but a body finding associated with multiple possible aetiologies. Severe neonatal jaundice is considered pathophysiological. Jaundice reflects accumulation of the yellow-orange pigment bilirubin in the skin, sclera, and other tissues. [1]. The temperature control of phototherapy incubator influences some physiological parameters such as oxygen consumption, metabolic rate, water gain and so on [2]. Therefore, the temperature control is a significant work for the phototherapy incubator of the phototherapy incubator.

Classical proportional-integral-derivative (PID) controller, a very popular controller in industries, presents a good performance by the proportional, integrative, and differential operations of the error between setpoint value and feedback output value [3]. The characteristics of the PID controller are intuitively understandings, and easy to implement. The

operational amplifiers, resistors, capacitors, inductors can be configured to construct a PID controller. Therefore, many analogue systems such as motors, heaters, and tanks employ PID controller to operate the system normally.

However, the anti-disturbance ability of PID controller is a problem. The coefficients of gain (k_p), integration (k_i) and difference (k_d) are designed for the setpoint value. Therefore, the unexpected disturbances were changed the output and kept a duration of deviation. The phenomena also occur at many cases of the temperature controller. Consequently, we tried to concur the problem to enhance the anti-disturbance ability of the PID controller for the phototherapy incubator.

Fuzzy logic was firstly suggested by Lotfi Zadeh in 1965 [9]. He introduces the concept of “linguistic variables”, which was defined as the fuzzy set to be the interference rules of the controller [10-12]. Many research groups employed the artificial intelligence technologies to add into PID controllers and their family in 1990s. Mamdani has proposed the majority work of Fuzzy PID (FPID) controller and implemented some P-I and P-D cases [4-6]. Moreover, many researchers combined the two technologies to achieve the better behaviour of FPID controllers such as Wang and Kwok [7], Li and Gatland [8] and so on.

The traditional phototherapy incubator does not conclude the temperature control. The temperature in the phototherapy incubator is depended on the room temperature under control of air conditioner or heat radiator. However, some physiological parameters are sensitive in the change of temperatures, especially the newborn infant. Therefore, FPID controller was proposed in this study for a better performance of temperature control.

II. METHODS

The technical requirements of this phototherapy incubator were as follows:

- Temperature control
- Hotter and colder air conditioner
- Air flow control
- Control of Blue light source

For achieving the technical requirements, the system was designed by the following parts.

A. System structure

The system block diagram is presented in Fig. 1 which displayed the 2 modes of the controller. One is PID controller, the other is FPID. The modes can be alternated by the switch (S1). There were 2 air flow sources input the phototherapy incubator to adjust the temperature. The hot air flow source output higher temperature air ($h_t(t)$) with the flow speed of $h_f(t)$ where t denoted as time. The cold air flow source output lower temperature air ($c_t(t)$) with the flow speed of $c_f(t)$. The $h_t(t)$ and $c_t(t)$ input the temperature transfer block and output sensing temperature, i.e. $T(t)$ as well as $h_f(t)$ and $c_f(t)$ input the flow transfer block and output sensing flow, i.e. $F(t)$. The temperature and flow setpoints were $T_s(t)$ and $F_s(t)$, respectively. Therefore, in the fuzzy control mode, we have the errors of temperature ($e_t(t)$) and flow ($e_f(t)$), then the errors input the fuzzy inference system (FIS) to compute the next output flows of air sources, i.e. $h_f(t+\tau)$, and $c_f(t+\tau)$ where τ is the one step duration of time. If the S1 connected with PID controller, the control mode changed to FPID for computing the next flow $c_f(t+\tau)$.

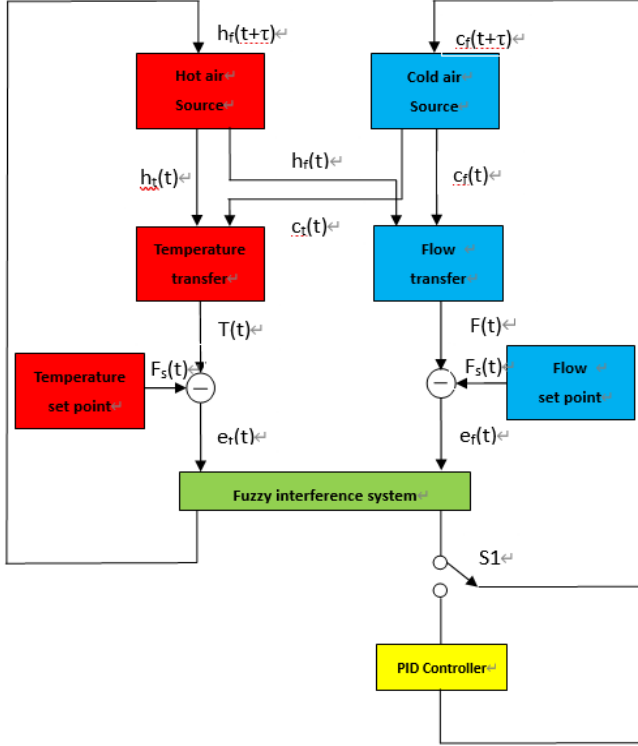


Figure 1. System structure

B. Transfer equations

The transfer equation of the temperature in the phototherapy incubator was written as:

$$T(t) = \frac{(h_t(t) \cdot h_f(t) + c_t(t) \cdot c_f(t))}{h_f(t) + c_f(t)} \quad (1)$$

In addition, air flow in the phototherapy incubator was written as:

$$F(t) = h_f(t) + c_f(t) \quad (2)$$

C. Fuzzy inference system

The membership functions (MFs) of the 2 inputs FIS were presented in Fig. 2. In (a), there were 3 states that were cold, good, and hot. They were defined by the error of the setpoint temperature between -20 and +20 degree C. The shapes of the MFs were all triangle. In (b), there were also 3 states that were low, middle, and high. They were defined by the error of the setpoint flow between -1 and +1. The shapes of the MFs were all triangle, too. All of the MFs are integrated in Fig. 4 [13-15].

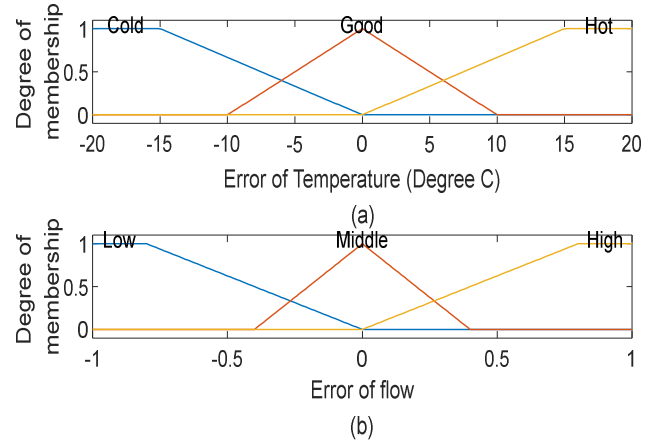


Figure 2. Membership functions of the 2 input FIS: (a) error of the temperature ($e_t(t)$); (b) error of flow ($e_f(t)$)

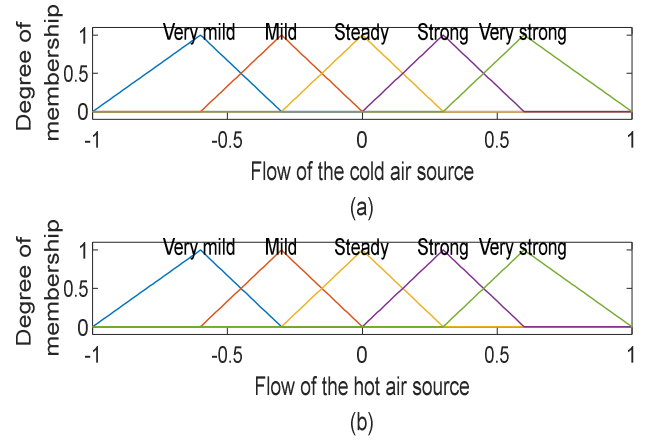


Figure 3. Membership functions of the 2 output FIS: (a) flow of the cold air source; (b) flow of the hot air source

D. PID controller

Actually, the PID controller was reduced to be PI controller. Therefore, the controller can be expressed as:

$$c_f(t + \tau) = k_p a_f(t) + k_i \int_0^{t+\tau} a_f(t) dt \quad (3)$$

E. Parameter settings

The parameter settings of this system are as follows:

- $ht(t) = 35$ degree C and $ct(t) = 15$ degree C
- $Ts(t) = 28 - 3\cos(2\pi * 0.001t)$ degree C and $Fs(t) = 0.8$ unit
- $k_p = k_i = 1$

In another word, the temperature control is intuitively implemented by 2 constant heat sources, but the flows of the 2 sources are variable. However, the summation of the 2 flows is a constant.

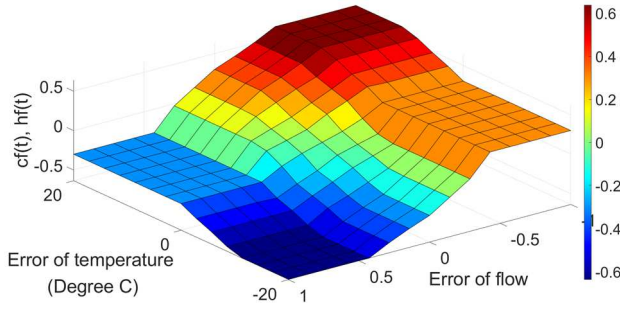


Figure 4. Integration of MFs in a 3-dimensional plot

F. Equipment

The simulation was computed in MATLAB R2016a (MathWorks, USA) development environment. The computer was a laptop PC (Lenovo DESKTOP-OSILGT4, China) with Intel CPU Core i5-8250U, and 12 GB DDR4 memory. The operating system was Microsoft Windows 10.1.

III. RESULTS

A. Fuzzy control

The controlled temperature of fuzzy controller was presented in Fig. 5. In (a), the inputs (errors) of FIS was displayed. The blue line was flow and the red line was temperature. The output of FIS was presented in (b) where the blue line was flow and the red line was temperature. In (c), the controlled temperature was displayed in (c). the response needed to improve because of 25 second delay.

B. FPID control

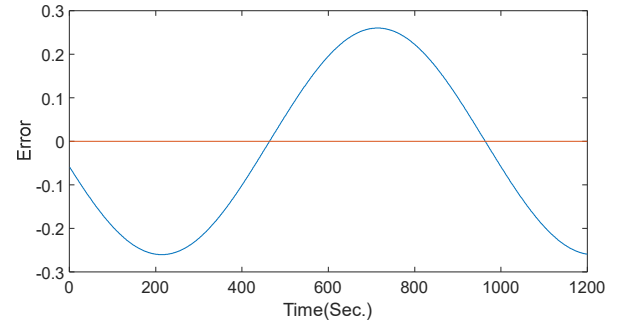
Moreover, the controlled temperature of FPID controller was presented in Fig. 6. In (a), the inputs (errors) of FIS was displayed. The blue line was flow and the red line was temperature. The output of FIS was presented in (b) where the blue line was flow and the red line was temperature. In (c), the controlled temperature was displayed in (c), The response was better because the delay time was less than 2 seconds.

IV. DISCUSSION

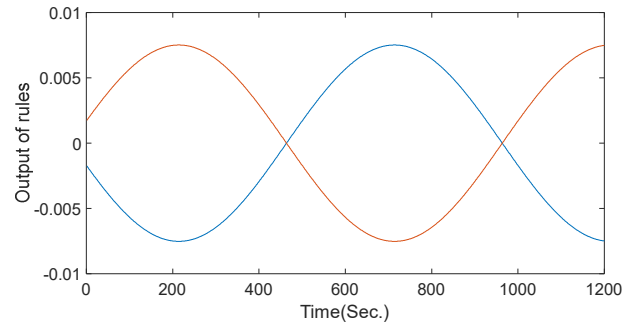
The performance of FPID was better than that of FIS-only because the response of delay time was much shorter. However, the FPID controller was not traditionally input by errors. It input the output of FIS. The PID controller was actually served as a integrator of the output of FIS. Because of

the flow response is slow. The integrator works. Therefore, it can improve the delay.

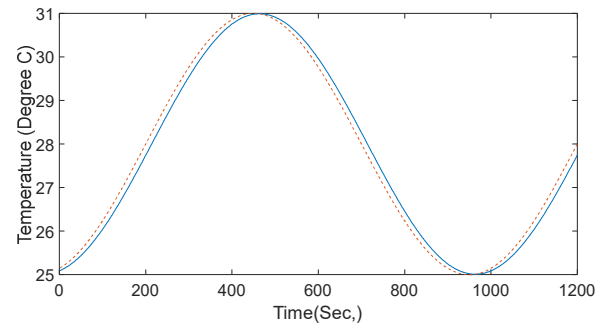
The setpoint of the temperature was designed to be a sine wave, because of the necessity of the phototherapy. The blue light is an energy. Therefore, the radiation of the blue light produced the heat. However, the higher temperature enhanced the effect of the blue light phototherapy. Therefore, the average temperature was set at 28-degree C. The phototherapy was working in the lower half-cycles and taking rests in the upper half-cycles for the thermal safety. The FPID supported a precise timing for therapy.



(a)



(b)



(c)

Figure 5. Fuzzy controller: (a) input of FIS (blue line: flow, red line: temperature); (b) output of FIS (blue line: flow, red line: temperature); (c) temperature control (blue line setpoint, red dashed line: output temperature)

V. CONCLUSION

This study supported the mode of controller for phototherapy incubator. In the viewpoint of precise timing control, the FPID controller is one of the solutions for the infant's phototherapy. Adding the rules of FIS can improve the accuracy of timing. However, the FPID method we

proposed just inserted a simple PID equation for integration. Therefore, the computing processes are more precise and efficient.

The phase control of upper and lower half-cycles enhances the safety of the infant's treatment. Therefore, based on the simulation of this study, we are going to design and implement the real therapy system for the further study.

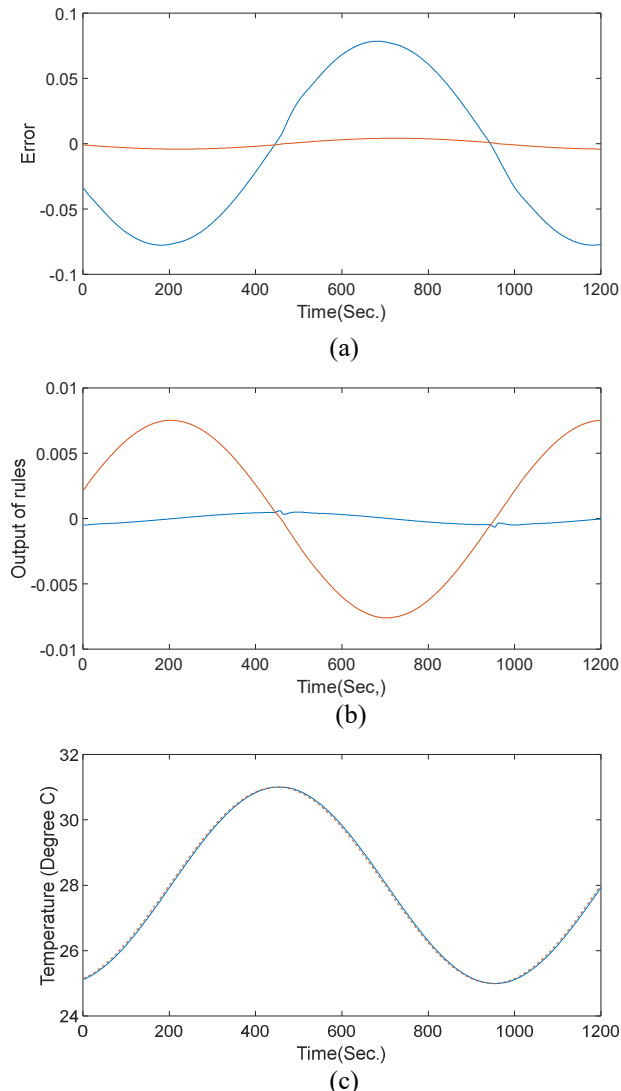


Figure 6. FPID controller: (a) input of FIS (blue line: flow, red line: temperature); (b) output of FIS (blue line: flow, red line: temperature); (c) temperature control (blue line setpoint, red dashed line: output temperature)

ACKNOWLEDGMENTS

The authors thank for the support from Guangdong University of Petrochemical Technology, Guangdong, China (Project number: 702/72100003142) and the funding from Maoming Green Chemical Industry Research Institute (Project number: MMGCIRI-2022YFJH-Y-042), Guangdong, China.

REFERENCES

- [1] Cohen, R. S., Wong, R. J., & Stevenson, D. K., "Understanding neonatal jaundice: a perspective on causation," *Pediatrics & Neonatology*, vol. 51, no. 3, pp. 143-148, 2010.

- [2] Maisels, M. J., & McDonagh, A. F., "Phototherapy for neonatal jaundice," *New England Journal of Medicine*, vol. 358, no. 9, pp. 920-928, 2008.
- [3] Kumar, V., Nakra, B. C., & Mittal, A. P., "A review on classical and fuzzy PID controllers," *International Journal of Intelligent Control and Systems*, vol. 16, no. 3, pp. 170-181, 2011.
- [4] Mamdani, E. H. & Assilian, S., "An Experiment in Linguistic Synthesis with a Fuzzy Logic Controller," *International Journal of Human-Computer Studies*, vol. 51, no. 2, pp. 135-147, August 1999.
- [5] Mamdani, E. H. "Application of fuzzy algorithms for control of simple dynamic plant," in *Proceedings of IEE (Control and Science)*, vol. 121, no. 12, 1974, pp. 1585-1588.
- [6] Mamdani, E.H. & Assilian, S., "An experiment in linguistic synthesis with a fuzzy logic controller," *International Journal of Man-Machine Studies*, vol. 7, no. 1, pp. 1-13, January 1975.
- [7] Wang P. & Kwok, D. P., "Analysis and synthesis of an intelligent control system based on fuzzy logic and the PID principle," *Intelligent System Engineering*, vol. 1, no. 2, pp. 157-171, 1992
- [8] Li, H. X. & Gatland, H. B. "Enhance methods of fuzzy logic control," in *proceedings of International Joint Conference of the 4th IEEE International Conference on Fuzzy Systems and The 2nd International Fuzzy Engineering Symposium.*, vol. 1, Yokohama, Japan, March 1995, pp. 331-336.
- [9] Zadeh, L. A., "Fuzzy sets," *Information and Control*, vol. 8, no.3, pp. 338-353, June 1965.
- [10] Zadeh, L. A., "Similarity relations and fuzzy orderings," *Information Sciences*, vol. 3, no. 2, pp. 177-200, April 1971.
- [11] Zadeh, L. A., "The concept of a linguistic variable and its application to approximate reasoning, part I," *Information Sciences*, vol. 8, no. 3, pp. 199-249, July 1975.
- [12] L. A. Zadeh, "The concept of a linguistic variable and its application to approximate reasoning, part II," *Information Sciences*, vol. 8, no. 4, pp. 301-357, October 1975
- [13] Eltag, K., Aslamx, M. S., & Ullah, R., "Dynamic stability enhancement using fuzzy PID control technology for power system," *International Journal of Control, Automation and Systems*, vol. 17, no. 1, pp. 234-242, 2019.
- [14] Somwanshi, D., Bunde, M., Kumar, G., & Parashar, G., "Comparison of fuzzy-PID and PID controller for speed control of DC motor using LabVIEW," *Procedia Computer Science*, vol. 152, pp. 252-260, 2019.
- [15] Lee, K., Im, D. Y., Kwak, B., & Ryoo, Y. J., "Design of fuzzy-PID controller for path tracking of mobile robot with differential drive," *International Journal of Fuzzy Logic and Intelligent Systems*, vol. 18, no. 3, pp. 220-228, 2018.



Juhui He is a student with Faculty of Automation, Guangdong University of Petrochemical Technology, Guangdong, China. His major is intelligent science and technology. He is the member and winner of the student competition of innovation and creation proposal in Faculty of Automation, Guangdong University of Petrochemical Technology.



Xing Wen is now a student at Faculty of Automation, Guangdong University of Petrochemical Technology, Guangdong, China. He won the third prize of the 7th National Undergraduate Biomedical Engineering Innovation Design Competition in 2022 and the second prize of the 2022 Guangdong Undergraduate Electronic Design Competition in China.



Jiapei Cai is a student at the School of Automation, Guangdong University of Petrochemical Technology. He won the third prize of the 7th National College Students Biomedical Engineering Innovation Design Competition in 2022 and the second prize of Guangdong College Students Electronic Design Competition in 2022.



Bing-Yuh Lu received his BS in electrical engineering from National Central University in 1988, MS in electrical engineering from National Taiwan University in 1993, and PhD in electrical engineering from National Taiwan University in 2000. He is currently a professor with Faculty of Automation, Guangdong University of Petrochemical Technology, Maoming City, Guangdong, China. His academic interests focus on acoustics and medical engineering.



Hongjie Zheng is a student with Faculty of Automation, Guangdong University of Petrochemical Technology, Guangdong, China. He won the third prize of the Seventh National College Students Biomedical Engineering Innovation Design Competition in 2022, the second prize of Guangdong College Students' Electronic Design Competition in 2022, and the third prize of Guangdong Engineering College Students' Comprehensive Experimental Skills Competition in 2022.



Xiaokang Cheng is a student with Guangdong University of Petrochemical Technology, Guangdong, China. A sophomore majoring in Guangdong University of Petrochemical Technology. His current major is industrial design.



Yiheng Chen is a student with Faculty: of Automation, Guangdong University of Petrochemical Technology, Guangdong, China. He won the third prize of 2022 "Cossberg Cup" Engineering College Students' Comprehensive Experimental Skills Competition of Guangdong University of Petrochemical Technology, and participated in the 2022 "Application Innovation" project of "Sail Plan" of Maoming Green Chemical Research Institute.