Advances in Computer, Signals and Systems (2023)
Clausius Scientific Press, Canada

DOI: 10.23977/acss.2023.070401
ISSN 2371-8838 Vol. 7 Num. 4

Construction of Intelligent Temperature Control System Based on STM32 Single-chip Microcomputer

Yao Ying*

School of Electrical and Automation Engineering, Liaoning Institute of Science and Technology, Benxi, Liaoning, 117004, China
9145188@qq.com
**corresponding author*

Keywords: STM32 Single-chip Microcomputer, Intelligent Temperature Control, System Construction, Fuzzy PID Control

Abstract: Temperature is a very common and important parameter in manufacturing processes and scientific research experiments. In order to conduct production efficiently and achieve the desired control effect, important parameters such as temperature, power, pressure, and speed must be effectively controlled during production or scientific experiments. The purpose of this article was to study the construction of an intelligent temperature control system based on the STM32 single-chip microcomputer. This article discussed the control of the surface temperature of the heating roller during the fixing operation of the copier. The main research content was the application of STM32 single-chip microcomputer in temperature control. Firstly, the advantages of STM32 single-chip microcomputer were described, and the fuzzy PID (Proportional Integral Derivative) control strategy was applied to temperature control, thus realizing the fuzzy PID control algorithm. Finally, the entire temperature control system was integrated into a complete copier, and the traditional PID control algorithm was compared with the fuzzy PID control algorithm. The results showed that the temperature control system using the fuzzy PID control algorithm had good stability, and its accuracy could be maintained within ±3 degrees Celsius.

1. Introduction

In many experiments, temperature is a very critical factor, and how to effectively control these factors would greatly affect the effectiveness of the experiment. In order to achieve a better temperature control effect, it is necessary to solve the two problems of temperature measurement and temperature control. Currently, the temperature measurement technology has been quite mature, with high temperature measurement accuracy. To achieve good temperature control, the prerequisite is to have high accuracy and stability. To achieve good temperature control effects, it is necessary to first have accurate measurements. Therefore, the quality of the temperature measurement circuit is crucial for the entire temperature control system [1-2]. Temperature control is the most critical and difficult link. Temperature control has been a problem for a long time. This is because temperature is a physical quantity with integral effects that has characteristics such as time lag and nonlinearity, and it is difficult to control it. However, in industrial production and scientific research experiments, the accuracy and stability of temperature are becoming increasingly important, which requires research on temperature control technology [3]. In today's society, photocopiers are a commonly used office equipment. For laser photocopiers, the fixing process is the most critical step in the electrostatic imaging process of photocopiers. The core role of the fixing component is to achieve temperature control of the entire heating system. Accurate fixing temperature is a key factor in determining the final replication effect [4-5].

In industrial production and scientific experiments, many devices need to heat them, and these devices need to ensure high temperature accuracy and stability of the controlled object. Therefore, the research on temperature control technology has become increasingly widespread. The control of furnace temperature has a great impact on the heating effect. In the process of reforming the tubular heat treatment furnace, Michiel A used STM32 as the foundation, STM32F103C8T6 microprocessor as the lower computer, and K-type thermocouple temperature sensor and Max31855 temperature conversion module as the upper computer. On this basis, an incremental control method based on PID was adopted to achieve real-time monitoring of furnace temperature. The test showed that under constant temperature (800±1), the system could accurately reflect the accuracy of the furnace temperature and the change rule of the furnace temperature. The overall control scheme met the temperature control requirements of the high-temperature tubular furnace [6]. Syed Usman Amin designed and implemented an intelligent home monitoring system based on the STM32 single-chip microcomputer. The hardware and software design of an embedded home monitoring system based on STM32 single-chip microcomputer was presented. The hardware architecture of the system included a remote user application terminal, a terminal control unit, and a plurality of terminals dispersed in various rooms. The system used ZigBee technology to achieve communication between terminals and field terminals. At the same time, using a combination of digital temperature and humidity sensors, real-time collection of temperature and humidity information for each room was achieved. Next, the dual band GSM (Global System for Mobile Communications)/GPRS (General Packet Radio Service) module SIM800A was selected to transmit sensing data and remote command information. The final test results showed that the remote terminal could control on-site intelligent household appliances, and remote users could also conveniently view the temperature and humidity in their homes [7]. Therefore, it was of practical significance to study the construction of intelligent temperature control system based on STM32 single-chip microcomputer.

The main work of this paper was to conduct in-depth research on precision temperature control technology, and design a temperature control system for instrument based on STM32 single-chip microcomputer. The system included a host computer system with good human-computer interaction, a powerful main control module, and temperature measurement and control modules. The system had the characteristics of high temperature control accuracy, strong versatility, could be used in the fixing temperature control system of photocopiers, strong portability, and good real-time performance. On this basis, it was possible to better conduct in-depth theoretical discussions on some commonly used precision temperature control technologies in the field of instrument applications, as well as better analyze some international cutting-edge technologies, thus laying a foundation for the development of practical new products.

2. Hardware Design of Intelligent Temperature Control System Based on STM32 Single-chip Microcomputer

2.1 Overall Design Principles of Temperature Control System

In the design of this temperature control system, there are mainly the following principles:

(1) System modular design principles

From top to bottom, the overall temperature control system is divided into several relatively independent and specific functional modules. Using the modular design concept, each relatively independent functional module is designed separately, and ultimately combined to form a complete system. This is the overall design principle [8-9].

(2) Scalability principle

When designing this system, sufficient attention must be paid to its scalability. If there are some changes in the application objects or functions of the system, it is only necessary to modify the software and hardware functions and implementation methods of the relevant parts of the system, without the need to rebuild the entire system.

(3) Reliability principle

Reliability refers to the ability to achieve predetermined operating performance under certain conditions and within a certain period of time. In this design, it is necessary to ensure that each functional module can achieve corresponding functions, and ensure the integrity of communication between the computer and peripheral hardware when the system is running [10].

(4) Economic principle

When selecting an implementation scheme, the performance price ratio of the system should be the main consideration. On the premise of ensuring the performance price ratio of the product, a feasible solution with short development cycle and low cost was selected.

(5) Ease of operation principle

An excellent temperature control system should not only have excellent temperature control performance, but also take into account the difficulty of system operation. Efforts should be made to develop a set of upper computer monitoring interfaces that are easy to operate and have good human-computer interaction, so as to reduce the professional requirements for operators [11].

2.2 Main Control Module STM32

Based on this, an embedded microprocessor with high speed, high control accuracy, rich configuration functions, and economic practicality is proposed. Compared with other embedded products, STM32 has many advantages, such as stronger performance, higher code density, better real-time performance, lower cost, and lower power consumption. It is a comprehensive and excellent development tool [12-13]. STM32 has eight series of up to 100 products in the M3 core alone, and can be packaged in multiple forms, with a high degree of integration [14]. The STM32 has 84 interrupts and 16 programmable priorities, making it extremely real-time. Many people choose STM32 because of its price advantage. Although it has 32 bit, it is much cheaper than 8 bit and 16 bit. Moreover, the cost of using STM32 to carry out projects is also very low, and there is no need to purchase expensive emulators. This only requires a serial port to meet the requirements of downloading programs and conducting simulation experiments. In view of the above advantages, this topic selects the STM32F103ZET6 development board as the core component of the system.

2.3 Design of Fuzzy Controller

(1) Structural design of fuzzy controller

When designing a fuzzy control system, the first step is to determine the structure of the system. According to the number of input and output variables, control systems can be divided into two categories: single valued, single valued, and multi valued. In control system theory, the number of input variables in a system is often designated as the dimension of a fuzzy controller. In ordinary control systems, the dimension is designed as one-dimensional or two-dimensional. In complex control systems, there are also cases where the controller is designed as three-dimensional [15-16].

The temperature control system uses a two-dimensional fuzzy controller with temperature error e and temperature error variation ec as the two input variables of the system, which can not only obtain good control results, but also facilitate the design of control laws.

(2) Fuzzy method for accurate quantities

The process of fuzzification is to convert an accurate numerical quantity into a fuzzy quantity described in fuzzy language [17]. The method includes three stages: First, the input is discretized within a specific domain; the fuzzy subset on a particular domain is determined; the degree of membership is determined [18].

According to the symmetry of the segments to be separated, quantization methods are divided into two categories:

Discrete interval symmetry: If the fuzzy variable x in the interval (a, b) is now converted to a symmetric discrete interval [-n, n], the calculation formula for the conversion is as follows:

$$y = \frac{2n[x - \frac{(a+b)}{2}]}{(b-a)} \tag{1}$$

Among them, y is rounded to the nearest integer, and n ≥ 2.

Discrete interval asymmetry: If the fuzzy variable x in the interval (a, b) is converted to an asymmetric discrete interval [-n, m], the calculation formula for the conversion is as follows:

$$y = \frac{(m+n)[x - \frac{(a+b)}{2}]}{(b-a) - \frac{(m-n)}{2}} \tag{2}$$

Among them, y is rounded to the nearest whole number.

(3) Defuzzification

The maximum membership method is also known as the direct method, which can directly output the value corresponding to the peak value of the membership function of a fuzzy subset in the output universe [19-20]. It is assumed that the fuzzy subset outputted by the fuzzy controller is U and the universe is U={-s, -s+1, -s+2……-1, 0, 1, 2, 3……s-1, s}, the corresponding fuzzy subset of U is as follows:

$$U = \frac{\mu(-s)}{-s} + \frac{\mu(-s+1)}{-s+1} + \dots + \frac{\mu(0)}{0} + \frac{\mu(1)}{1} + \dots + \frac{\mu(s)}{s} \tag{3}$$

According to the principle of maximum membership, the output of the element with the highest membership is taken as the maximum output, and the formula is as follows:

$$U_i = \max[\mu(-s), \mu(-s+1) \dots \mu(0), \mu(1) \dots \mu(s)] \tag{4}$$

Among them, Ui=i is the control quantity. If the membership function takes the maximum and i is not unique, the average value is taken and the integer is taken.

2.4 PID Parameter Tuning

In this paper, the critical oscillation method was used for PID parameter tuning. The proportional factor Kp in the proportional controller was gradually increased from 0 until the control loop generates a constant periodic vibration of equal amplitude. At this time, the gain was called the critical proportional gain, which was called Ku; at this point, the vibration period was a critical vibration period, which was called Tu. The parameters of PID controllers were adjusted based on the gain scaling factor Kp and the critical oscillation period Tu, and the tuning formulas for various controllers varied. The parameter adjustment formulas for each controller are listed in Table 1.

Table 1: PID parameter setting formula for critical oscillation method

ControlType	Kp	T ¡	Td
P	0.5Ku		
PI	0.45Ku	Tu/1.2	
PD	0.8Ku		Tu/8
Classic PID	0.6Ku	0.5Tu	Tu/8

3. Software Design of Intelligent Temperature Control System Based on STM32 Single-chip Microcomputer

The temperature control system used STM32F103ZET6 chip with Cortex-M3 as the core as the central processor. The software part was divided into two parts. The upper computer was written in VisualStudio using C++language, and the lower computer was written in KeiluVision5 environment. The software part of the temperature control system adopted a modular design approach, which modularized and divided the functions to be achieved. On the premise of ensuring the integrity of the control system, the correlation between various modules was minimized, thus allowing each module to assume its own responsibilities.

3.1 Upper Computer Software Design

The operation interface of the entire system is divided into three main areas: the working state setting area, the temperature time map area, and the real-time temperature indication area. At the bottom of the interface is the working state setting area, which includes two parts: the setting of the serial interface and the setting of the system state. Among them, the serial interface setting includes the selection of serial interfaces and the control of the status of serial interface switching, as well as the current status of the serial interface and the correctness of the setting status. The temperature time map area is mainly used to display dynamic images of temperature time, which presents dynamic images of temperature time in the most direct way. On the far right of the main control panel is the current temperature, which is displayed every 200 milliseconds.

3.2 Lower Computer Software Design

(1) Temperature detection module

The AD590 temperature sensor transmits a small amount of current proportional to the temperature change to the OP07 amplification circuit. After conversion and amplification, the resulting voltage is input to the STM32F103ZET6 chip. The analog quantity is converted into digital quantity through the built-in ADC (Analog-to-Digital Converter) of the chip to obtain corresponding temperature data. The specific design of the temperature detection sub module is shown in Figure 1:

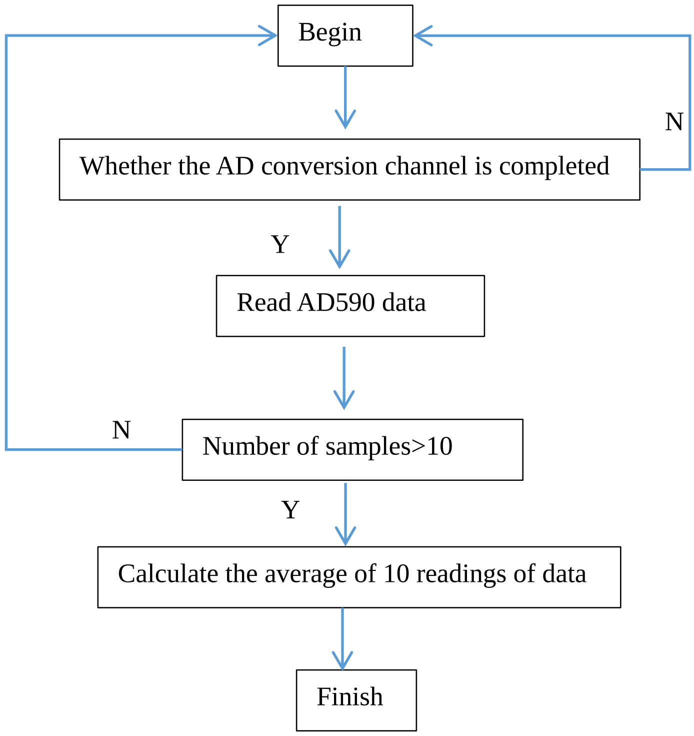

Figure 1: Flow chart of temperature acquisition module

During the temperature acquisition process, factors such as the system temperature variation range, the temperature variation rate determined by the power of the semiconductor refrigeration chip, the STM32 chip, the ADC sampling frequency, and the control effect are comprehensively considered. Under the condition that the system control accuracy and effect are satisfied, the system temperature acquisition frequency is determined to be 200 ms once. At the same time, the possible interference caused by external environmental disturbances on temperature measurement is taken into account, thereby affecting the accuracy of temperature measurement. The method of averaging multiple temperature measurement data is adopted to reduce the impact of random factors on temperature measurement results.

(2) Fuzzy control algorithm module

The design of fuzzy controller is the key of the entire system. First, the sampled value of the current temperature collected is compared with the set temperature, with e (k)= r (k)- y (k) indicating the error and ec (k)=[e (k)- e (k-1)]/T indicating the amount of change in the error. e and ec are blurred. By querying the membership function array tables of e and ec for Δ Kp, Δ Ki, and Δ Kd, the corresponding Δ Kp, Δ Ki, and Δ Kd are calculated, and Kp, Ki, and Kd are corrected to obtain the output of the fuzzy PID controller. The design process is shown in Figure 2:

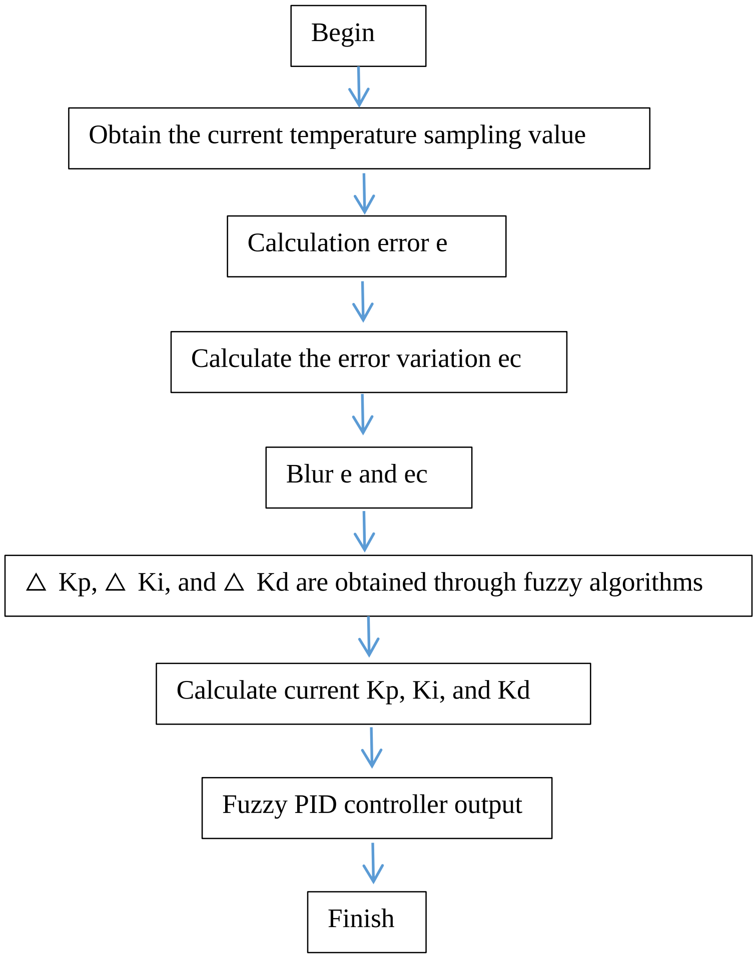

Figure 2: Flow chart of fuzzy control algorithm

4. Test of Temperature Control System

4.1 Test Plan

The mechanical structures and usage scenarios of different types of photocopiers vary greatly, so it is not possible to compare this system with the temperature control systems proposed in other relevant literature. In order to better verify the various characteristics of the temperature control system designed in this article, it was necessary to integrate the entire temperature control system into the overall control system of the copier, and control the conventional PID control algorithm and the fuzzy PID control algorithm used in this article, so as to achieve the testing of the system.

During fixing, whether the temperature of the heating roller surface of the printer is stable is an important indicator to determine the fixing effect of the printer. As can be seen from the previous text, the fixing component of a photocopier generally has preheating, standby, printing, and other working modes. After the preheating phase is completed, the photocopier would enter the standby phase, and the fixing component would immediately start printing after receiving a heating command in the standby phase. The requirements for the heating temperature of the heating roller in the standby phase and the heating phase of the photocopier are the same. In real life, due to the needs of companies or individuals, the working hours of photocopiers may be longer, and the fixing molds of photocopiers may also be in standby or printing mode for a long time. Therefore, in combination with the actual situation, it is necessary to test the change of the fixing temperature of the copier within 30 minutes to observe whether the surface temperature of the heating roller is stable under long-term operation. Here, the target temperature is set to 180 ℃, and the sampling period is set to 5 minutes.

4.2 Test Results

In specific experiments, the relevant parameters of the temperature control algorithm can be adjusted to achieve optimal results based on actual heating conditions. When applying a conventional PID control algorithm to the fixing module of a photocopier, the temperature change on the surface of the heating roller is shown in Figure 3. The experimental results of applying the fuzzy PID control algorithm to the fixing module of the copier are shown in Figure 4.

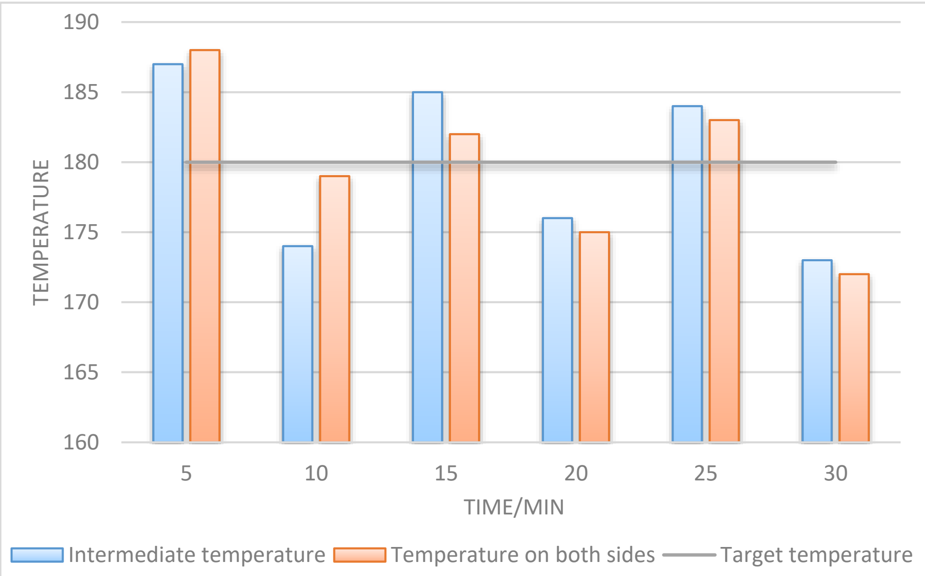

Figure 3: Temperature variation diagram of heating roller surface when applying traditional PID control algorithm

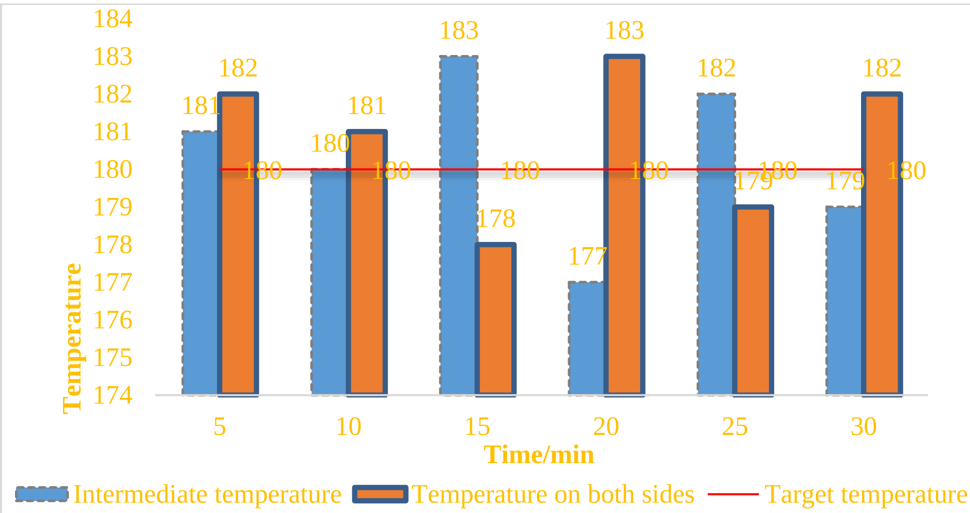

Figure 4: Temperature variation diagram of heating roller surface when applying fuzzy PID control algorithm

In practical testing, due to the low accuracy of temperature measurement using NTC (Negative Temperature Coefficient) thermistors, and in the process of converting resistance values to temperature values, the temperatures of both channels would vary to varying degrees, thus making it difficult to achieve simulation results. By simulating the printer, some subtle errors could be detected and corrected. In addition, due to the relatively complex structure of the printer fixing assembly, many physical and chemical changes could occur during the fixing process, and the temperature of the heating roller surface was extremely susceptible to complex heat transfer environments, thus resulting in deviations between simulation and actual measurement.

Through the analysis of the temperature fields of the two paths on the surface of the heating roller, it could be seen that the temperature control effect of the heating roller surface using the fuzzy PID control method was much better than the conventional PID control method, and the temperature control system using this method had better stability and little temperature fluctuation. After stabilizing the temperature at the middle and both ends of the heating roller, the accuracy of its change could be maintained within ±3 degrees Celsius, which fully met the design requirements of the system. At the same time, when the copier was printing or copying, due to the rapid flow of paper on the thermal roller surface without significant temperature changes, the overall temperature control system had good anti-interference performance. After being fixed by a photocopier, the surface of the paper was free of wrinkles, and the printed image was clearly visible. The imaging quality was good. The toner was stably printed on the paper without fading or falling off.

5. Conclusions

Accurate temperature control has important application value in industry, and would become a hot research topic for researchers in the long future. This article summarized the previous temperature control systems in terms of function and technology. On this basis, a creative design of a photocopier fixing temperature control system using a STM32 single-chip microcomputer as the core controller was developed, and it was combined with a laser photocopier. The implementation of this project would provide a new technical means for the development of high-precision temperature control technology, and would provide new ideas and theoretical basis for the development of high-precision temperature control technology in the future. Due to the relationship between time and effort, multiple functional circuit boards in the system were not integrated. Next, they could be integrated and reprocessed to further improve the performance of the system.

Acknowledgements

This work was supported by LJKMZ20221685.

References

[1] Blaise Ravelo, Mathieu Guerin, Wenceslas Rahajandraibe, Valentin Gies, Lala H. Rajaoarisoa, Sebastien Lallechere. (2022) Low-Pass NGD Numerical Function and STM32 MCU Emulation Test. IEEE Trans. Ind. Electron. 69(8): 8346-8355

[2] Cong Zhang, Zhisheng Wang, Dan Zhu, Haiwen Gao, Nianyu Zou. (2021) A lighting control system of art museum based on image recognition and STM32. Int. J. Sens. Networks 37(2): 112-124

[3] Patryk Chaber, Maciej Lawrynczuk. (2019) Fast Analytical Model Predictive Controllers and Their Implementation for STM32 ARM Microcontroller. IEEE Trans. Ind. Informatics 15(8): 4580-4590

[4] Parvesh Saini, Padmanabh Thakur. (2022) H-Infinity Based Robust Temperature Controller Design for a Non-linear Systems. Wirel. Pers. Commun. 126(1): 305-333

[5] Vishal Vishnoi, Sheela Tiwari, Rajesh Kumar Singla. (2021) Controller Design for Temperature Control of MISO Water Tank System: Simulation Studies. Int. J. Cogn. Informatics Nat. Intell. 15(4): 1-13

[6] Michiel A. J. uit het Broek, Gerlach Van der Heide, Nicky D. van Foreest. (2020) Energy-saving policies for temperature-controlled production systems with state-dependent setup times and costs. Eur. J. Oper. Res. 287(3): 916-928

[7] Syed Usman Amin, Muhammad Aaquib Shahbaz, Syed Arsalan Jawed, Fahd Khan, Muhammad Junaid, Danish Kaleem, Musaddiq Siddiq, Zain Hussain Warsi, Naveed. (2022) Temperature and Humidity Controlled Test Bench for Temperature Sensor Characterization. J. Electron. Test. 38(4): 453-461

[8] Mihaela Popa, Daniel Alexuta, Valentina Emilia Balas. (2022) Fuzzy-interpolative control of temperatures for the intelligent rooftop greenhouse. J. Intell. Fuzzy Syst. 43(2): 1793-1797

[9] Vincent Taboga, Amine Bellahsen, Hanane Dagdougui. (2022) An Enhanced Adaptivity of Reinforcement Learning-Based Temperature Control in Buildings Using Generalized Training. IEEE Trans. Emerg. Top. Comput. Intell. 6(2): 255-266

[10] Ganapati Bhat, Suat Gumussoy, Umit Y. Ogras. (2021) Analysis and Control of Power-Temperature Dynamics in Heterogeneous Multiprocessors. IEEE Trans. Control. Syst. Technol. 29(1): 329-341

[11] Stefano Marelli, Matteo Corno. (2021) Model-Based Estimation of Lithium Concentrations and Temperature in Batteries Using Soft-Constrained Dual Unscented Kalman Filtering. IEEE Trans. Control. Syst. Technol. 29(2): 926-933

[12] Haocong Cai, Zhigang Wu, Min Chen. (2023) Design of STM32-based Quadrotor UAV Control System. KSII Trans. Internet Inf. Syst. 17(2): 353-368

[13] Xiaochun Guan, Sheng Lou, Han Li, Tinglong Tang. (2021) Intelligent control of quad-rotor aircrafts with a STM32 microcontroller using deep neural networks. Ind. Robot 48(5): 700-709

[14] Hung Guo, Evgeni Magid, Kuo-Hsien Hsia, Kuo-Lan Su. (2021) Development of IoT Module with AI Function Using STM32 Chip. J. Robotics Netw. Artif. Life 7(4): 253-257

[15] Qian Zhang, Tengjin Zhao, Zhiyue Zhang. (2020) Unfitted finite element for optimal control problem of the temperature in composite media with contact resistance. Numer. Algorithms 84(1): 165-180

[16] R. Vijay Aravind, P. Balasubramaniam. (2023) Membership-Function-Dependent Design of Quantized Fuzzy Sampled-Data Controller for Semi-Markovian Jump Systems With Actuator Faults. IEEE Trans. Fuzzy Syst. 31(1): 40-52

[17] Ankur Rai, Dushmanta Kumar Das. (2022) Ennoble class topper optimization algorithm based fuzzy PI-PD controller for micro-grid. Appl. Intell. 52(6): 6623-6645

[18] F. Vijay Amirtha Raj, V. Kamatchi Kannan. (2022) Particle Swarm Optimized Deep Convolutional Neural Sugeno-Takagi Fuzzy PID Controller in Permanent Magnet Synchronous Motor. Int. J. Fuzzy Syst. 24(1): 180-201

[19] Mohamed Barakat. (2022) Optimal design of fuzzy-PID controller for automatic generation control of multi-source interconnected power system. Neural Comput. Appl. 34(21): 18859-18880

[20] Ritu Raj, B. M. Mohan, Dong-Eun Lee, Jung-Min Yang. (2022) Derivation and structural analysis of a three-input interval type-2 TS fuzzy PID controller. Soft Comput. 26(2): 589-603