Design of Fuzzy PID Control System of Indoor Intelligent Temperature Based on PLC Technology

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Abstract. In order to meet the temperature requirements of residents and improve the accuracy of indoor temperature control, PLC technology is used to design an indoor intelligent temperature fuzzy PID control system. The hardware includes a sensor selection unit, a PLC hardware selection unit, a fuzzy PID controller unit and a power circuit design unit, and the software includes a PLC software module, a fuzzy PID control program module and a serial communication program module.Through the design of hardware unit and software module, the indoor intelligent temperature fuzzy PID control system is realized. The experimental data show that: compared with the existing system, the temperature control accuracy of the design system is higher, which fully proves the effectiveness and feasibility of the design system, and provides a more comfortable living environment for residents.

Keywords: PLC technology · Indoor · Temperature · Intelligence · Fuzziness · PID control

1 Introduction

With the rapid development of China's economy and the remarkable improvement of people's quality of life, the number and scale of Chinese buildings have achieved rapid development. Especially in recent decades, intelligent buildings have developed rapidly, and people have higher requirements for indoor comfort, especially temperature. In order to meet the needs of residents, a large number of new buildings adopt central air conditioning to provide a comfortable environment or meet the technological requirements in the room. But the high energy consumption of central air conditioning is also a problem which can not be ignored today, the situation of high energy consumption of central air conditioning and how to improve the utilization rate of energy is also an important topic of domestic and foreign scholars, which is directly related to the sustainable development of the country [1].

My country is a large resource-consuming country, and the energy consumption of output value is very high compared to developed countries. This requires us to save energy and reduce energy consumption in the use of energy. This is my country's

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basic national policy. The energy consumption of buildings in my country accounts for 30% of the total energy consumption. In buildings that use central air-conditioning, the energy consumption of central air-conditioning accounts for about 50% of the total building energy consumption, and this data is continuously increasing every year, so we can See the importance of energy saving in central air conditioning. According to the data of Guangzhou and Shenzhen, the power consumption of central air conditioning has accounted for 24% and 29% of the total power consumption of the city, which undoubtedly brings huge pressure to the city's power grid.

At present, in the domestic central air-conditioning chillers, the capacity of water pumps and fans is too large. The actual indoor load refers to the amount of cooling or heat required by the terminal equipment of the central air conditioner due to changes in indoor temperature. The indoor load will change with the seasons, environmental climate, equipment operation, and the size of the flow of people, this is a variable amount [2]. However, in order to meet the requirements of indoor load, central air conditioners generally operate under partial load conditions 90% of the time. In fact, the cooling or heat required by the equipment at the end of the air conditioner is often less than the set flow rate. It can be seen that if we adopt a constant flow operation mode, it will bring huge energy consumption problems.From the current situation, the energy saving research of central air conditioning, especially the water system, is the key task of energy saving of central air conditioning. In view of the defects of large energy consumption and long working time in partial load state, the control of water system is unreasonable. The lack of control and regulation device in water system will make the water system run at constant flow state. When the load changes and deviates from the design value, the cooling capacity of the system cannot change with the load, which will cause huge waste; The response capacity of the system is poor, and the water delivery speed is behind the load change speed, which will cause the parameter instability of the control system and affect the control effect.

In order to meet the temperature needs of today's residents, reduce energy consumption, and reduce the pressure on the power grid, how to control indoor temperature has become one of the national key research topics, so the indoor intelligent temperature fuzzy PID control system based on PLC technology is designed. Design system hardware through sensor selection unit, PLC hardware selection unit, fuzzy PID controller unit and power supply circuit design unit, design system software through PLC software module, fuzzy PID control program module and serial communication program module, according to system hardware and software The design realizes the design of the indoor intelligent temperature fuzzy PID control system, and the validity of the designed system in this paper is verified through simulation experiments.

2 Hardware Design of Indoor Intelligent Temperature Fuzzy PID Control System

Hardware is the basis and premise of the stable operation of the design system. According to the requirements of indoor temperature control, the hardware of the system is divided into sensor selection unit, PLC hardware selection unit, fuzzy PID controller unit and power circuit design unit.

2.1 Sensor Selection Unit

The design system mainly selects four kinds of sensors: temperature sensor, humidity sensor, carbon dioxide concentration sensor and light intensity sensor, and controls the temperature through the sensor data [3]. We installed six temperature and humidity sensors, one light intensity sensor and one carbon dioxide concentration sensor in the room. Outdoor installation of a temperature and humidity sensor, as well as a light intensity sensor, the transmission mode of these sensors are analog transmission [4].

The sensor performance index is shown in Table 1.

Table 1. Sensor performance index table

Name	Model	Range
Indoor temperature sensor	LT/M	0–50 °C
Outdoor temperature sensor	LT/M	−40–60 °C
Humidity Sensor	LT/S	0–100% RH
Light intensity sensor	LT/G	0–200000 Lx
Carbon dioxide sensor	LT/CO_2	0–3000 ppm
Name	Output	Precision
Indoor temperature sensor	Rs485	±1 °C
Outdoor temperature sensor	Rs485	±1 °C
Humidity Sensor	Rs485	±7% RH
Light intensity sensor	Rs485	±5000 Lx
Carbon dioxide sensor	4–20 mA	±(20 + reading%) ppm

2.2 PLC Hardware Selection Unit

PLC is a high performance programmable logic controller. PLC takes microprocessor as the core, and integrates computer technology, automatic control technology and network communication technology [5]. It is a widely used industrial automation device with strong control ability, high reliability and flexible configuration.

Siemens S7-300 series PLC is a medium sized programmable logic controller, which is widely used in industrial automation and power industries. Modularization, easy implementation of distributed configuration, easy entry, fast processing speed, and strong communication capabilities make Siemens S7-300 series PLC the main control PLC for many complex control systems. Siemens S7-300 series PLC adopts modular structure design, and each individual module can be combined and expanded, mainly composed of rack, power module, CPU module, communication module, interface module, signal module and function module. The PLC structure module is shown in Fig. 1.

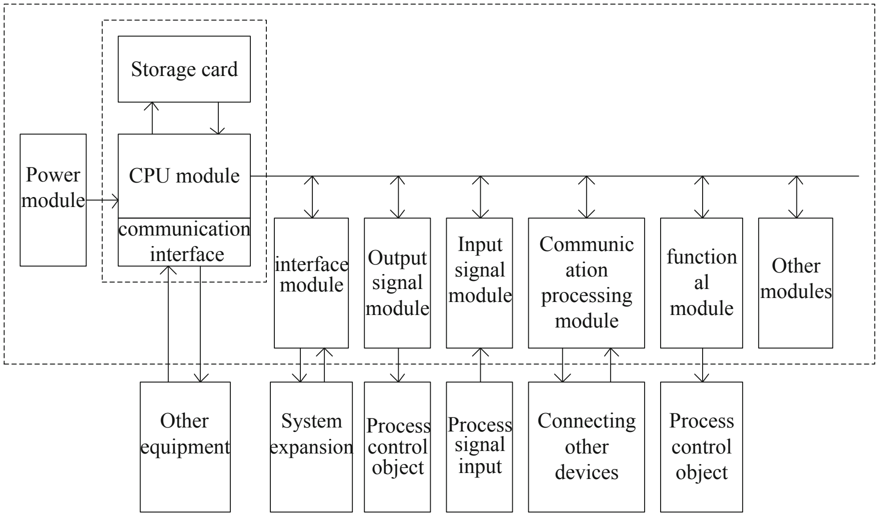

Fig. 1. Schematic diagram of PLC structure module

The purpose of each module of S7-300 series PLC is as follows:

Rack (RACK): a guide rail used to install and fix each PLC module.

Power supply module (PS): used to convert 120/240 V AC to 24 V or SV DC for use by PLC modules.

CPU module: used to execute user program and support plug-in memory card to expand memory. With RS485 and MPI communication interface, some models of CPU with PROFIBUS-DP communication interface.

Interface module (IM): used to extend the PLC rack, connecting the main rack and the extended rack, the distance is generally no more than 10 m.

Signal module (SM): used for input and output data. According to different data types, there are digital input/output modules and analog input and output modules.

Communication module (CP): used for point-to-point network connection between PLC and other devices with communication functions (PLC, computer, etc.).

Function module (FM): used to control positioning and high-speed counting operation in open-loop or closed-loop system.

CPU is a key component in PLC hardware, and its technical parameters are shown in Table 2.

Table 2. Technical parameters

Project	Parameter
Communication Interface	X1:MPI X2:DP/PN
Working memory capacity	256 kB

(*continued*)

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Project	Parameter
Carrying memory capacity	MMC max 8 MB
DB/FC/FB/OBSHUL Quantity/Capacity	1024/256 kB
Nonvolatile memory capacity	128 kB

2.3 Fuzzy PID Controller Unit

The design of fuzzy PID controller should first determine the basic structure of fuzzy PID controller according to the controlled object. According to the controlled object and the number of input and output variables, the fuzzy PID controller is divided into single input single output and multiple input multiple output from the structure [6].

Fuzzy PID controllers are divided into one-dimensional controllers, two-dimensional controllers and three-dimensional controllers according to the structure. The schematic diagrams are shown in Fig. 2, which correspond to Figures (a), (b), and (c) in Fig. 2.

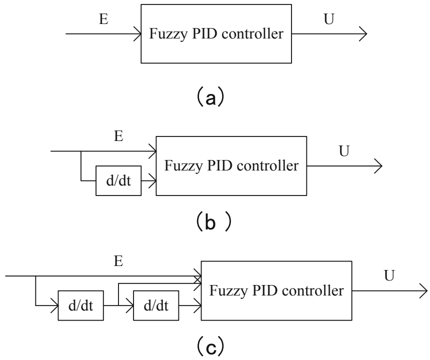

Fig. 2. Structure diagram of fuzzy PID controller

Theoretically speaking, the control effect of a fuzzy PID controller is related to its dimensionality, but as the dimensionality increases, the control law corresponding to the fuzzy PID controller's control object becomes more complicated, and the control algorithm has a higher level of achievement. The difficulty. However, the dimensionality is too low, and the deviation collection input points of the fuzzy PID controller are few, which makes it difficult to reflect the dynamic characteristics of the control system. Generally, a two-dimensional fuzzy PID controller is used, which can better reflect the dynamic quality of the control process, and is relatively not very complicated in the realization of the control algorithm. Therefore, the design system selects a two-dimensional fuzzy PID controller.

2.4 Power Circuit Design Unit

The design system adopts three-phase three wire power supply mode, M1 is the main circuit of water pump motor, M2 is fan motor, and the fan motor has 27 fan motors in total. The I/O distribution of the system slave is shown in Table 3.

Table 3. Input and output I/O allocation table

Output		Enter	
Q0.0	No. 1 fan unit 1	A1W0	PH 1
Q0.1	No. 1 fan unit 2	A1W2	No. 1 EC
Q0.2	No. 2 fan unit 1	A1W4	Pressure
Q0.3	No. 2 fan unit 2	A1W8	PH 2
Q0.4	No. 3 indoor fan	A1W10	EC 2
Q0.5	No. 4 fan unit 1		
Q0.6	No. 4 fan unit 2		
Q0.7	No. 1 indoor window		
Q0.8	No. 2 indoor window		
Q0.9	No. 3 indoor window		

The manual control circuit and the automatic control circuit share the relay and contactor. The toggle switch is used to directly control the relay KA, and the contactor is controlled by KA. The actions of the actuator are all controlled manually.

The hardware of the above design can not realize indoor temperature control, so based on hardware, the software module of the design system is designed.

3 Software Design of Indoor Intelligent Temperature Fuzzy PID Control System

The design system software includes PLC software module, fuzzy PID control program module and serial communication program module. The specific design process is as follows:

3.1 PLC Software Module

STEP7-Micro/WIN programming software is an extremely powerful software specially developed by Siemens for its S7-200 series PLC. It is an indispensable R&D tool for 200PLC users. It has the characteristics of simple, easy to learn, practical and efficient, it can solve the complicated automation control requirements of the process, save the user's programming time, and make the operation of domestic users more convenient after the Chinese version is launched. STEP7-Micro/WIN is based on the WINDOWS platform, but its applicability to the system is relatively strong.It can write, compile, debug and configure the program in offline mode. In this process, the program and parameters are saved in the computer. After connecting with PLC, the communication of program and parameter data written by users is completed by uploading and downloading, and various operation functions of PLC are realized. In the process of programming, the software itself has a simple and effective syntax error detection function. With the help of this function, programmers can find syntax and data errors in advance. The software can also manage and encrypt the user program, which protects the programmer's intellectual property rights [7].

The software uses the WINDOWS program interface, which makes it easy for programmers to master. The programming window includes a browse bar, instruction tree, cross reference window, data block/data window, main menu bar, and tool bar. Switching between various windows is very convenient, enabling users to easily find the required data or symbols and their usage, which provides convenience for programming and debugging. Compared with the same type of Small PLC software, the main program, subroutine and interrupt program can be written in different windows, and the program written by the software can be edited into a library file. When the programmer writes the same type of program, he can directly call his own library file and edit it as his own recognizable name, so as to avoid the need of repeated work, At the same time, the design of sub window enables users to accurately find the subprogram where the problem is and make changes during on-site debugging, which is a function that many programming software do not have [8].

The design of this article uses the CPU226CN AC/DC/relay type with the highest CPU model among 200PLCs as the controller. Its performance advantages mainly include: first, more input and output points, strong expansion capability, 24 input points, 16 output points, and expansion The capacity is 7 I/O modules; second, the input voltage of the input power is 85–264 VAC, the digital input is 24 V DC, and the rated output voltage of the digital is 24 V DC or 250 V AC; third, it has two RS-485 Communication interface, PPI communication baud rate supports up to 187.5 kbaud, and free port communication baud rate is 1.2 KBaud to 115.2 KBaud.

3.2 Fuzzy PID Control Program Module

Through the method of fuzzy mathematics, the long-term experience of human beings is summed up as the rules of fuzzy reasoning, and then the fuzzy rules are input into the microcomputer. The deviation signal and deviation change rate signal produced by comparing the measured value with the known set value are sent to the fuzzy controller. After the completion of fuzzification, fuzzy reasoning and anti fuzzification, the corresponding three correction quantities ΔK_p, ΔK_i and ΔK_d are obtained, By inputting these three corrections into the PID controller, the PID parameters can be adjusted to the best state online, so as to realize the effective control of the controlled object.

This article uses a two-dimensional fuzzy controller. The two variables input to the fuzzy PID controller include the deviation of the return water temperature of the cold water system compared with the given value and the rate of change of the deviation. The output of the fuzzy controller is Parameters ΔK_p, ΔK_i and ΔK_d required by conventional PID controllers.

In practical application, the control effect depends on the selection of appropriate fuzzy rules, the quantization factor of input variables and the scale factor of output variables [9]. The given value of water temperature is set as 12oc. Considering the actual weather conditions, we set the range of deviation as [−14, 14] and the range of deviation change as [−18, 18]; According to the above expert experience and experimental trial and error method, the parameter variation range of controller ΔK_p, ΔK_i and ΔK_d is [−0.07, 0.07], [−0.001, 0.001] and [−0.02, 0.02] in turn. The fuzzy domain of each variable is set to {−6, −5, −4, −3, −2, −1, 0, 1, 2, 3, 4, 5, 6}; the input and output variables select 7 fuzzy subsets: $\{NB, NM, NS, Z, PS, PM, PB\}$, which correspond to negative large, negative medium, negative small, negative, positive small, positive medium, and positive large. The quantization factors $K_e = 0.5$ and $K_{ec} = 0.4$ of the deviation and deviation change, and the scale factor of the output variable are set to 0.015, 0.0002 and 0.065 respectively.

When establishing the fuzzy rule table, the setting requirements of K_p, K_i and K_d of PID controller are different when the value of deviation $|e|$ and deviation rate $|ec|$ changes.

(1) When the value of $|e|$ is relatively large, if the control system is required to have good tracking performance and speed up the system response, then a relatively large K_p and a relatively small K_d should be selected. In this process, in order to prevent the system from overshooting Excessive adjustment will cause integral saturation, and the effect of integral should be limited. Generally, $K_i = 0$ is selected;
(2) When the values of $|e|$ and $|ec|$ are medium, if the system is required to have a small overshoot and a certain response speed, then a smaller K_p and an appropriate K_i should be selected. In this process, K_d has a greater impact on the system, and an appropriate K_d value should be selected;
(3) When the value of $|e|$ is relatively small, it means that the output value is close to the set value. If the system is required to have better stability, the values of K_p and T should be increased at this time. In order to avoid shocks during this process, If $|ec|$ is relatively large, K_d should have a medium value; if $|ec|$ is relatively small, the value of K_d should be relatively large to make the system's anti-interference ability stronger.

For any input e and ec of the measured variable, its output u is required, and the fuzzy reasoning relation set R is needed first. The fuzzy inference relation set R of the system temperature is expressed as follows:

$$R = \underset{i,j}{U}\left(E_j \times EC_j \times U_{ij}\right) \tag{1}$$

In formula (1), E_j, EC_j and U_{ij} represent deviation, deviation change and the fuzzy state of output u; the value range of i and j is.

According to the above, the fuzzy relation corresponding to rule R_i can be obtained

$$\underset{\sim}{R_1} = NB_e \times (NB_{ec} \cup NS_{ec} \cup Z_{ec}) \times PB_u \tag{2}$$

According to formula (2), the fuzzy relationship matrix $\underset{\sim}{R}$ is inferred, and each element of the universe E and EC is used as input, and the corresponding fuzzy amount of the control variable is obtained through the fuzzy inference synthesis operation:

$$\underset{\sim}{u}(k) = \left(\underset{\sim}{E}(k) \times \underset{\sim}{EC}(k)\right) \circ \underset{\sim}{R} = (NBe \times PSec) \circ R \quad (3)$$

In formula (3), $(NBe \times PSec)$ represents the input fuzzy state, and its membership function vector must be combined with the subsequent $\underset{\sim}{R}$. Therefore, the operation result of $(NBe \times PSec)$ is expanded into a row vector, and then combined with it.

In the design system, the minimum rule is used in the fuzzy operation, and the maximum rule is used in the fuzzy synthesis rule; In the process of anti fuzziness, we use the maximum membership method. By synthesizing the assignment table of different membership degrees of known fuzzy subsets and the fuzzy control model with different parameters, we can get the accurate values of ΔK_p, ΔK_i D and ΔK_d to adjust the PID parameters.

3.3 Serial Communication Program Module

The communication port of S7-200 CPU is the standard RS-485 half duplex serial communication port. The format of serial character communication can include: a start bit, 7 or 8 characters (data bytes), a parity bit, or no parity bit, and a stop bit. The baud rate of communication can be set to 9600 bit/s, 19200 bit/s, 115200 bit/s. All serial communication devices that conform to these formats can communicate with S7–200 CPU. With the help of free port communication mode, S7-200 CPU can communicate with other devices and controllers disclosed by many communication protocols.

When sending XMT and receiving RCV commands as the core command of Freeport communication, note that multiple commands cannot be valid at the same time. The sending and receiving of data needs to pass through the data buffer. The sending command is to send the data in the buffer through the communication port and accept the command. The data is received from the communication port into the buffer. When calling and sending XMT and receiving RCV commands, only the starting byte address of the communication port and the data buffer is required.Sending XMT and receiving RCV instructions have nothing to do with the address of the communication object on the network, but only operate on the local communication port. If there are multiple devices on the network, the message must contain address information, which is the processing object of sending XMT and receiving RCV instructions [10].

Through the design of the above hardware unit and software module, the operation of the indoor intelligent temperature fuzzy PID control system is realized, which provides effective system support for indoor temperature control and provides a good living environment for residents.

4 Experiment and Result Analysis

4.1 Selection of Experimental Software

With the development of computer technology, simulation technology has been paid more and more attention, which makes people get better design reliability and research prospect in scientific research and production application, and saves the cost of scientific research and production. System simulation has a wide range of applications, it is not only widely used in the field of natural science, but also in the management and other fields has been successfully applied. There are many kinds of software used for simulation. Here, the simulation of PMV value control is MATLAB software. Therefore, it is necessary to introduce the application of this typical system simulation software in the control field.

The MATLAB software was launched by Math Works in the United States. The software provides a wealth of functions such as numerical analysis, matrix calculations, graphics rendering, data processing, image processing, etc. In addition, MATLAB has also launched more than 30 functions for different application disciplines. Application toolboxes, such as control system toolbox, fuzzy control toolbox, neural network toolbox, optimization toolbox, statistics toolbox and symbolic mathematics toolbox, etc. At present, it has become one of the most widely popular languages in the international control community, and is known as the "universal" tool for engineers, scientists, educators, and professionals from all walks of life all over the world.

SIMIJLINK toolbox is an extension of MATLAB software. It is mainly used for modeling, analysis and simulation of dynamic systems. It provides graphical user interfaces with most of the dynamic system structure modules required to establish system models. After entering the MATLAB environment, just type the SIMULINK command to open the module library. The user can select the required module according to his own system, drag it to his own system model with the mouse, and then use the mouse to draw a line to connect it. It constitutes the SIMULINK description of the system. After the model of the system is built, the user can set or change the parameters of the module according to the different needs of the system, then open the simulation menu, set the simulation parameters, and start the simulation process. After the simulation, the user can observe the simulation output of the system through the output oscilloscope or plot function。

4.2 Analysis of Experimental Results

According to the above selected experimental software, the simulation experiment is carried out for Indoor Intelligent Temperature Fuzzy PID control, and the application performance of the system is displayed by the control accuracy. The analysis process of the specific experimental results is as follows.

The control precision obtained by experiment is shown in Table 4.

Table 4. Control accuracy data sheet

Number of experiments	Design system	Existing system
20	78.56%	56.45%
40	70.12%	45.12%

(*continued*)

Table 4. (*continued*)

Number of experiments	Design system	Existing system
60	71.23%	48.79%
80	80.11%	41.20%
100	75.45%	45.18%
120	76.69%	49.51%
140	78.52%	40.00%
160	81.32%	58.49%

As shown in Table 4, the design system temperature control accuracy range is 70.12%–81.32%, and the existing system temperature control accuracy range is 40.00%–58.49%. The comparison of the above data shows that the temperature control accuracy of the design system is higher, which fully proves the effectiveness and feasibility of the design system.

5 Conclusion

This research uses PLC technology to design a new indoor intelligent temperature fuzzy PID control system, through the sensor selection unit, PLC hardware selection unit, fuzzy PID controller unit and power supply circuit design unit design system hardware, based on the hardware design through PLC Software module, fuzzy PID control program module and serial communication program module design system software, so as to realize the design of indoor intelligent temperature fuzzy PID control system. The design system in this paper greatly improves the temperature control accuracy and can better control the indoor temperature for residents. Provide a more comfortable environment.

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