# Research on Intelligent Control System of Air Conditioning Based on Internet of Things

## Intelligent Control System of Air Conditioning

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***Abstract*—The current air conditioning intelligent control system cannot achieve the ideal energy-saving effect. The indoor temperature and humidity control is not good enough either. Therefore, an intelligent air-conditioning control system based on Internet of Things technology is designed. The hardware part of the system includes system control motherboard, sensor module, execution control structure, wireless communication module and access layer. The software includes the design of communication layer, the design of monitoring management, and the design of intelligent indoor air-conditioning temperature remote control algorithm. The experimental results show that the control effect of the intelligent air conditioner is more accurate and energy-saving, the opening degree of the air conditioning valve is larger, and the comfort is improved. The indoor temperature and humidity of the proposed system are both more ideal.**

***Keywords*—Internet of things technology; intelligent control of air conditioning; system design; double closed-loop load; virtual synchronizer of air conditioning**

## I. Introduction

In recent years, science and technology have developed rapidly, and smart home control has become the most important part of the development of the decoration field. The research and development of smart home can greatly reduce the energy consumption of electrical equipment, reduce the cost of manual operation and management, and provide customers with more comfort and humane environment [1-2]. In the intelligent building, the central air-conditioning system consumes a lot of electricity, and it is the most important part in building the automation control system. In modern buildings, warm air conditioning is the basic supporting equipment, which can adjust the overall temperature and humidity of the building. Heating air conditioning system accounts for more than half of the total electricity consumption of the whole building, so it is necessary to find a suitable technology to reduce its energy consumption. Relevant scholars have found that intelligent control is the core of the entire intelligent system. In order to achieve low power consumption and low cost, and to ensure the safe and stable operation of the air conditioning system, reliable algorithms and selection of hardware and software are required to ensure the function of the system. [3-4].

However, at present, most of the air-conditioning intelligent control systems of engineering projects are idle and resources are wasted. This is due to the design mistakes of relevant managers and the inability of air-conditioning intelligent systems to meet the needs of sustainable development and cost control. Researchers in this field have conducted relevant research on the above issues. For example, reference Yan Junwei et al. proposes an energy consumption prediction method based on machine learning divided operation modes. Firstly, the k-means algorithm is used to divide the system operation mode, and the main factors affecting the operation mode are selected by the random forest method. Then, the prediction model is established by BP neural network to predict the mode and energy consumption in turn [5]. Fu Huansen et al. designs a working algorithm of the air conditioning control system in different seasonal modes, analyzes the key points of PID control in Siemens s7-1200plc programming, and takes the combined air conditioning of an actual engineering project of a pharmaceutical group as an example to design the function of the touch screen configuration interface. The system ensures the priority control of humidity in the drug warehouse during the program design [6]. Li Xiaotong et al aiming at the characteristics of nonlinearity, large delay of central air conditioning system and the difficulty of establishing accurate model, proposes a temperature control method of central air conditioning system based on model free reinforcement learning. Aiming at the communication problem between Energy Pl us and MATLAB, MLE + tool is used to realize the joint simulation of them. Comparing reinforcement learning algorithm with benchmark start stop strategy and model predictive control strategy, the method can minimize the energy consumption of air conditioning system on the premise of ensuring comfort [7].

According to the above-mentioned current domestic and foreign researches, the existing air-conditioning control effects cannot take into account low power consumption and intelligent effects, and most of the air-conditioning valves have a low opening degree, which makes it difficult to bring users a more comfortable and humanized experience. In order to solve the above problems, the research designs dual closed-loop loads and perfect communication layer, monitoring management and remote-control functions of intelligent air conditioners on the basis of the Internet of Things with intelligent improvement strategies.

## II. Design of Air Conditioning Intelligent Control System based on Internet of Things Technology

From the composition point of view, the air-conditioning remote control system is mainly composed of wireless controller, mobile phone software, remote management and data analysis system. With the help of the sensor, the communication module of wireless controller can get the air conditioning running status information in time. Through the wireless network, the user can set the temperature in advance. Far away, users can use mobile phones or computer software to operate the system. According to the basic operation condition, the management system can send the corresponding control command. After receiving the command, the controller can control the air-conditioning system in real time by sending infrared coded signal.

### A. Application Principle of Internet of Things in Air Conditioning Control

The rapid development of Internet of Things has provided an important basis for the application of smart house. In the application of the Internet of Things, we should take full advantage of wireless technology, such as radio frequency, Bluetooth, infrared sensing, ZigBee and WIFI. ZigBee technology's energy consumption is low, and the cost is less than other technologies. It can be widely promoted in the future development. Wireless sensor networks are mainly deployed in the monitoring area, which is a self-organizing multi-hop form. There are a large number of sensor nodes, using the characteristics of sensor cheap [8-9]. After the application program and physical setup are completed, the user is authorized by the Web or application program, and then the command to be executed can be sent out in a graphical way. After the central controller receives the command, it requires the simulative starter to perform the corresponding operation. When the user doesn't give the operation instruction, the central controller can use the network technology and wireless sensor to receive the change of the outside environment, and then judge the safety factor effectively. When there is a danger, the central controller will find the corresponding security warning, and the central control will activate the scheduled function to notify or alarm the user [10]. When the external environment is relatively safe, the central controller will activate the corresponding control information when it exceeds the set range.

### B. System Hardware Design

#### 1) System Control Motherboard

The main control board of the system adopts the Arduino Mega2560 SCM development board with USB interface, with 54 digital input/output (16 of which can be used as PWM output), 16 analog input, 4 UART interfaces, 1 16MHz crystal oscillator, 1 USB port, 1 power socket, 1 ICSP header and 1 reset button. The motherboard is easy to use, can meet the requirements of air-conditioning control system, and has a more stable performance.

#### 2) Sensor Module

The system sensor module includes temperature and humidity sensor, HC-SR501 human body sensor and photoresistor. Two temperature sensors are respectively installed in the air outlet and the side of the air conditioner. The difference of temperature data is used to judge the on-off state and the refrigeration and heating state. HC-SR501 human body sensor is an automatic control module based on infrared technology. It adopts imported LHI778 probe from Germany, with high sensitivity and strong reliability. HC-SR 50 can be used to judge whether the user is near the air conditioner or not.

#### 3) Enforcement Control Structure

In the remote-control system, the infrared ray sends the instruction information. After receiving the infrared code, the remote management carries on the next instruction operation according to the information characteristic. Because there are many air-conditioning manufacturers, there are some differences in infrared protocol. During the test, the infrared information of different remote controllers should be collected and analyzed. Analyzing the infrared signals of different brands of air-conditioning and storing them according to the requirements, so as to improve the expansibility of the system and make it can be used in different air-conditioning models.

#### 4) Wireless Communication Module

As shown in Fig. 1, the system adopts ESP8266 serial port WIFI chip, which is a complete and self-contained WIFI network solution specially developed for wireless connection requirements. Temperature and humidity sensor can timely obtain indoor temperature and humidity information, through collecting and uploading information, so as to monitor indoor temperature and humidity in real time and achieve reasonable control of temperature and humidity.

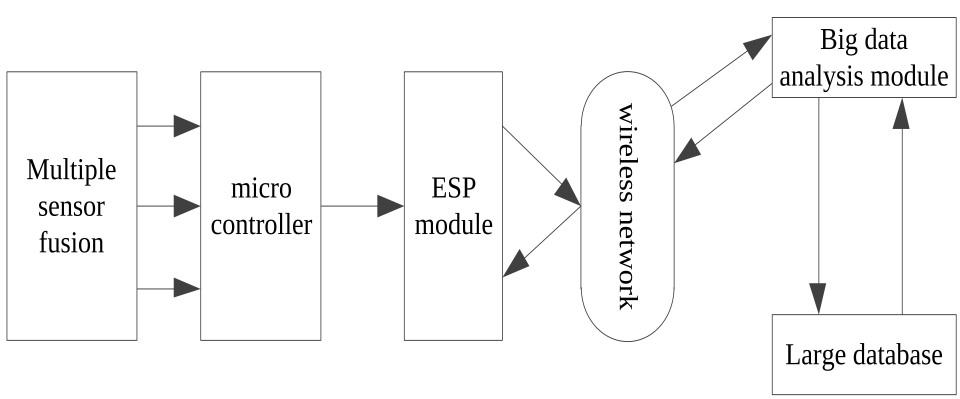


Fig. 1. System Framework

*5) Access Layer*

Wireless sensor network constitutes a perceptual control layer. It collects data information, uploads these data on the basis of network technology, and transfers them to the service management. Intelligent gateway plays the role of access layer, which can integrate multiple protocols, transfer the corresponding data by ZigBee protocol, and achieve the goal of Internet communication. The intelligent network also has the storage function. Through uploading the newest data, it helps the user to use the intelligent gateway to realize the information inquiry the function.

*a) Control Architecture Design*

As shown in Fig. 2, the basic control architecture of the intelligent control system for air conditioning. As a direct power supply device of air-conditioning virtual synchronizer, storage battery can provide AC electronic supply with voltage between 220-380V. AC suction nozzle is a standard AC device, which can provide AC current with frequency between 360-800HZ for air-conditioning virtual synchronizer. The main control architecture consists of a virtual cabinet and a synchronous load cabinet. Virtual cabinets contain air conditioning temperature display, temperature control chassis, virtual operators, TUR equipment and a part of the blank reserved area. Under the condition of long-term load operation, there will be a large number of control instructions in the system, which are stored in the blank reserved area until the transmission channel is idle. Synchronous load chassis includes 429 bus module, load frequency conversion module, air conditioning power analog output module, load voltage acquisition module. Each module has different physical execution function.

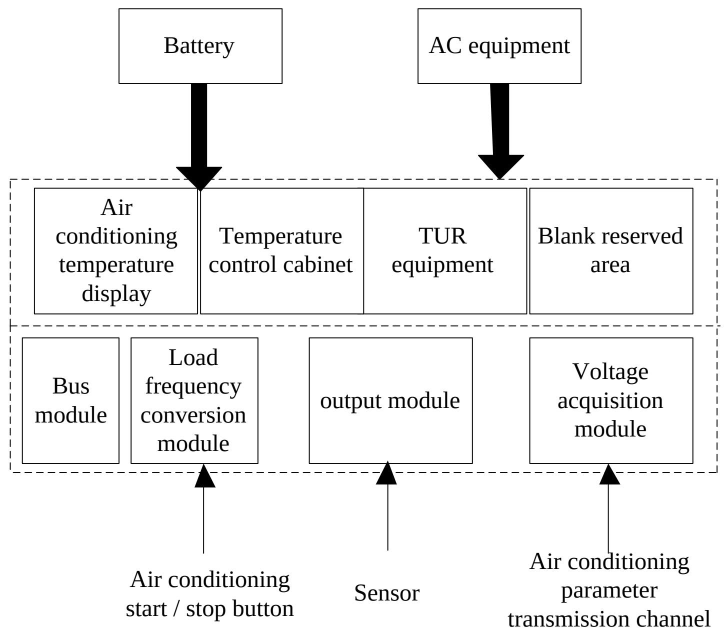


Fig. 2. System Hardware Control Architecture.

*b) Design of Governor for Virtual Synchronous Machine of Air Conditioner*

The traditional DC/AC inverter topology is used to adjust the output power of storage battery by collecting the modal information of load electronic power supply. From the functional point of view, the virtual synchrotron governor is the key subordinate structure of the control architecture, which can integrate the fixed virtual load electronics in the original motor, and provide a certain excitation effect for these electronics with the support of the generator. When the air-conditioned power analog output module sends out enough asynchronous sensing signals, the virtual power grid of the synchrotron changes from a closed state to an open state, absorbs all the load electronics, and temporarily stores them in the virtual control chip. In order to ensure the reasonable distribution of load electrons, two power-consuming components with the same resistance as the load voltage acquisition module must be installed around the generator, and the internal operating current of the governor must always be rated control current. The complete structure of the virtual synchronizer governor is shown in Fig. 3.

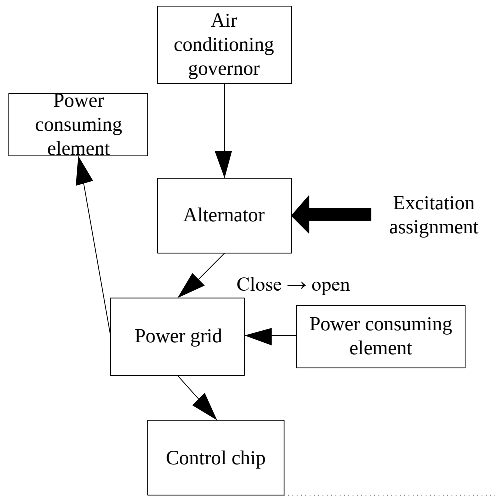


Fig. 3. Structure Diagram of Air Conditioner Virtual Synchronous Machine Governor.

*c) Load Double Closed Loop Design*

The load double closed-loop design includes two parts: synchronous controller and virtual load unit. According to the regulation rules and control requirements of air-conditioning equipment, the synchronous controller can control the power load signal unilaterally, and the virtual load unit can obtain more AC load signals by transmitting the power consumption signal to the central processor of air-conditioning. In the case of higher requirements for system control instructions, the load double closed-loop system can choose parallel or series operation mode according to the power output of the system to ensure that the air-conditioning virtual synchronizer governor always has sufficient AC electrons [11-12]. In parallel mode, the load double closed-loop, air-conditioning virtual synchronous governor can be selectively connected to the control circuit at the same time, effectively avoiding the arbitrary notice of the battery system. In series mode, the load double closed-loop, air-conditioning virtual synchronizer governor can also be connected to the control circuit at the same time, but in this case, the automatic load electrons can easily reach the maximum value. Fig. 4 shows the detailed load double closed loop structure.

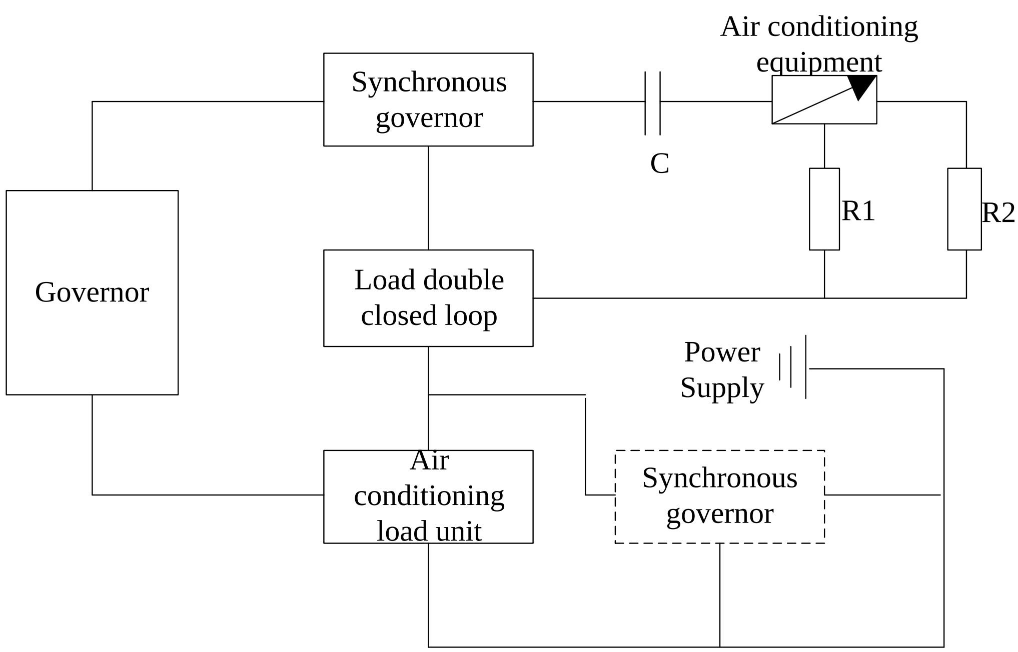


Fig. 4. Load Double Closed Loop Structure.

## C. System Software Design

### 1) Communication Layer Design

The Modbus communication protocol in the communication layer adopts RTU transmission mode to realize data reading. RTU transmission mode message frame format: function code is 8, CRC check code is 16 bits, data area is n * 8 bits, and slave bit address is 8. See Table I for common command codes and functions in the system of Modbus communication protocol.

TABLE I. COMMON COMMAND CODES AND FUNCTIONS IN THE SYSTEM OF MODBUS COMMUNICATION PROTOCOL

| Command code | Effect |
|---|---|
| **01** | Read controller value |
| **02** | Forced input of single switching value |
| **03** | Read switch status |
| **04** | Force input controller value |
| **05** | For exception response |
| **06** | Communication diagnosis |
| **07** | On off state |

*2) Design of Monitoring Management*

Through monitoring the management computer remote monitoring software with ModBus communication protocol and PLC communication, Real-time on-line monitoring of the operation of HVAC system is realized. The steps for remote online monitoring are shown in Fig. 5.

In order to convert the remote intelligent control mode of the system, the control signal is transmitted to the PCL control layer through the command code of ModBus communication protocol in remote online monitoring software. If the automatic control mode is selected, the PCL selects the data in the controller, operates on the collected signal of HVAC according to the fuzzy self- adaptive PID controller. It judges the operation result, and automatically controls the stop or start of HVAC equipment. If you choose the manual control mode, in order to control the HVAC equipment, the input of single equipment switch is realized by ModBus communication protocol, the switch of relay in PLC is changed, and the manual remote control of HVAC equipment is stopped or started.

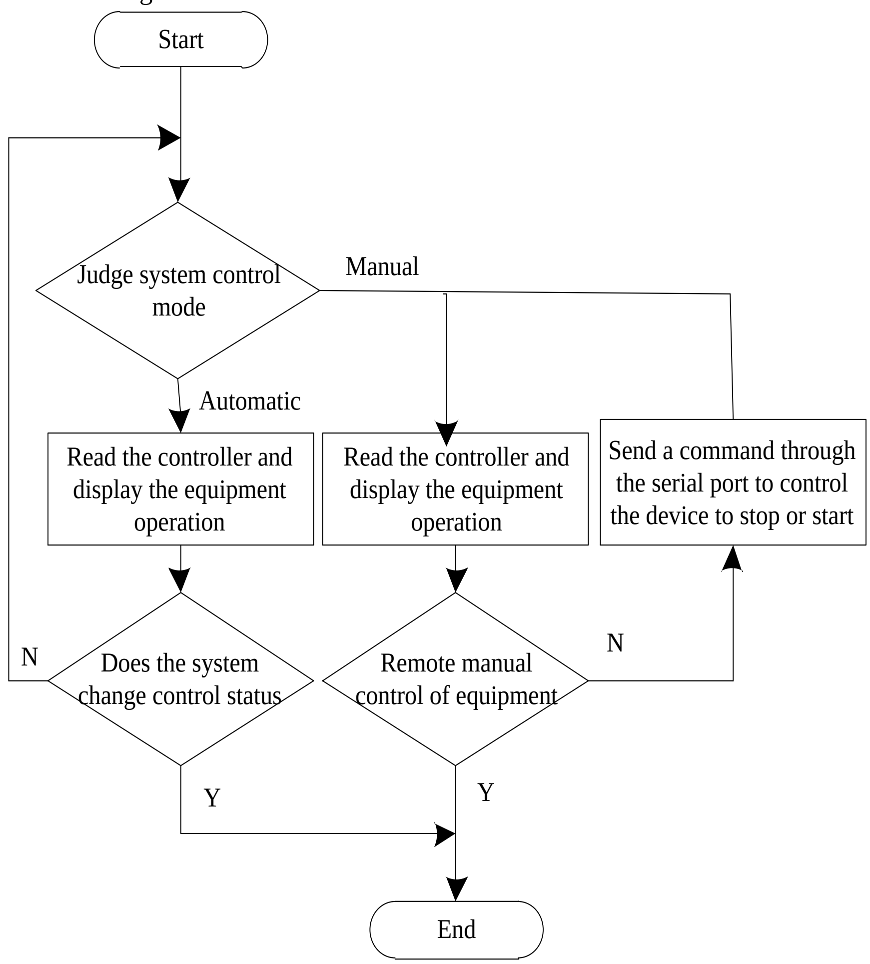


Fig. 5. Steps of Remote Online Monitoring.

*3) Implementation of Remote-Control Algorithm for Intelligent Indoor Air Conditioning Temperature*

The control structure of influencing factors of remote intelligent indoor air conditioning temperature control is shown in Fig. 6. The data actually measured by different sensors are sent to the PID controller after being adjusted, and the selection signal generated based on the parameters optimized by the PID controller, such as $k_p$, $k_i$ and $k_d$. They are used to keep the indoor air conditioner running and keep the room temperature, supply air temperature and supply air volume within the error control range [13-14].

The energy-saving principle of HVAC uses frequency conversion technology to realize frequency conversion control of temperature, but frequency conversion control is unable to build accurate mathematical model. So, the fuzzy adaptive PID controller is added into the PLC control layer. In order to improve the control quality and make the PID controller have the intelligent performance of fuzzy control, the fuzzy adaptive PID controller is generated by combining the conventional PID control and fuzzy control. Fuzzy adaptive PID control principle, see Fig. 7.

The parameters of each variable, fuzzy control rule, fuzzy subset and the membership function of input and output variables are designed by fuzzy adaptive PID controller. Initial setup of fuzzy adaptive PID controller, see Fig. 8.

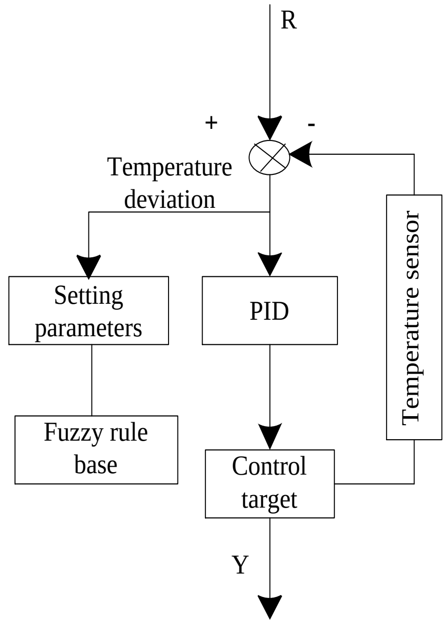


Fig. 6. Principle of Fuzzy Adaptive PID Control.

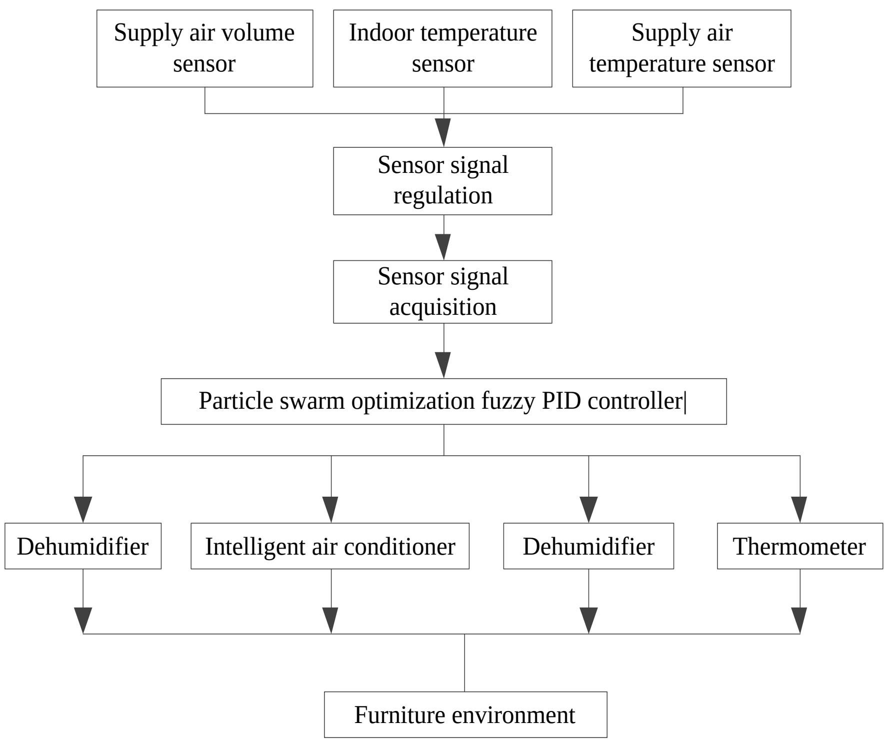


Fig. 7. Control Structure of Room Temperature, Air Supply Temperature and Air Supply Volume.

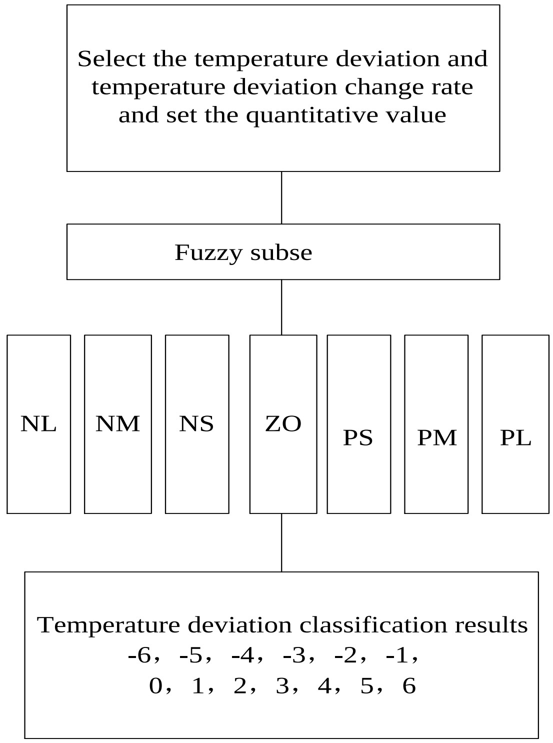


Fig. 8. Initial Setting of Fuzzy Adaptive PID Controller.

If $K_d$ and $K_p$ change in the predetermined range of $\left[K_{d,\min}, K_{d,\max}\right]$ and $\left[K_{p,\min}, K_{p,\max}\right]$, normalized $K_d$ and $K_p$ convert them to the parameters between 0 and 1. The newly converted parameters are described by $K_d'$ and $K_p'$ respectively, and their conversion process is described by formulas (1) and (2) respectively:

$$K_d' = \frac{K_d - K_{d,\min}}{K_{d,\max} - K_{d,\min}} \tag{1}$$

$$K_p' = \frac{K_p - K_{p,\min}}{K_{p,\max} - K_{p,\min}} \tag{2}$$

Formula (3) represents the relationship between integral and differential time constants:

$$T_i = \beta T_d \tag{3}$$

Where $T_d$ represents the differential time constant, $\beta$ represents the parameter, and $T_i$ represents the integral time constant.

The integral gain solution is described by formula (4):

$$K_i = \frac{K_p}{\beta T_d} = \frac{K^2{}_p}{\beta K_d} \tag{4}$$

The membership function of temperature deviation and temperature deviation change rate is a fuzzy subset language variable, which is described by $\{NL\ NM\ NS\ ZO\ PS\ PM\ PL\}$, and each value width is consistent and distributed in a triangle.

In order to judge the reasoning rules of parameters $K_d'$, $K_p'$ and $\beta$, the decision is made according to the temperature deviation, the knowledge base summarized by experts (fuzzy rule base) and the change rate of temperature deviation. The rules are as follows:

$if\ e(k)\ is\ A_i, \Delta e(k)\ is\ B_i\ then\ K_p'is\ C_i, K_d'\ is\ D_i, \beta = \beta_i$ ( $i = 1, 2, \cdots m$ ).

Among them, $A_i$, $B_i$, $C_i$, $D_i$ represent the language variable of $e(k)$, $\Delta e(k)$, $K_p'$, $K_d'$, $\beta$, a fuzzy relation has a rule, 7 fuzzy subsets have 49 fuzzy control rules [15]. Fuzzy control table is made up of 49 Fuzzy rules stored by computer. Fuzzy control table is made up of the relation between each input and output parameter according to expert's knowledge and experience, and then the Fuzzy control rules are made.

## III. Experimental Design and Result Analysis

In order to verify the effectiveness of the intelligent control system based on Internet of Things, a simulation experiment is designed. The experimental comparison method is the composite air-conditioning control system and the central air-conditioning control system based on reinforcement learning proposed in reference [6] and [7] respectively. The PID parameters are set to $k_{p0} = 0.18$, $k_{i0} = 0.0012$ and

$k_{d0} = 0.5$, and the input quantization factors of the PID controller are set to $k_{up} = 0.005$, $k_{ui} = 0.02$ and $k_{ud} = 0.5$. After setting the relevant values of each characteristic parameter, the traditional PID algorithm and the PID control algorithm based on particle swarm optimization are analyzed, and the corresponding curve of the valve opening of each end of the PID controller is obtained as shown in Fig. 9.

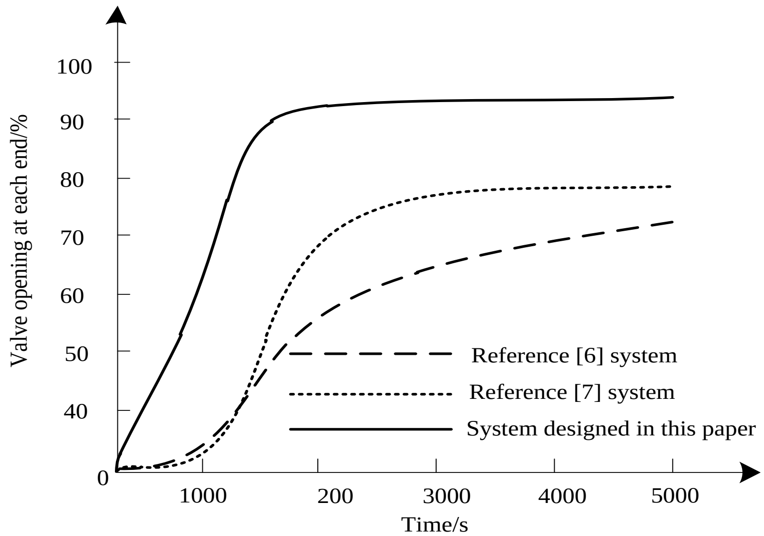


Fig. 9. Valve Opening at Each End of Household Intelligent Air Conditioning Structure.

As shown in Fig. 9, the operation time of the air-conditioning structure is expressed in abscissa (unit: s); the change in the opening of the air-conditioning valve at each end of the air-conditioning structure is expressed in ordinate. The results show that the opening trend curve is stable and the dynamic regulation performance is more stable than that of the traditional control method, and the opening trend fluctuates greatly and the period is longer. When the air-conditioning structure works normally, the opening degree of the traditional air-conditioning valve is about 78%, and the opening degree of the air-conditioning valve obtained by this method can be controlled at 95%, so the friction loss formed by the air-conditioning valve in the actual work of the air-conditioning structure can be reduced to the greatest extent. It is proved that the intelligent air-conditioning structure of modern home remote control realized by this method is more accurate and energy-saving. The larger the opening degree of the air-conditioning valve is, the lower the operating noise of the corresponding air-conditioning structure is, and the comfort degree of the operating environment of the air-conditioning structure for users is improved.

Set the output variable is the indoor temperature, the input variable is the frequency of HVAC compressor. Transfer function model of setting room temperature and frequency of HVAC compressor, described by formula (5):

$$H(s) = \frac{G'}{Ts+1} e^{-\varphi s} \tag{5}$$

Where, $s$ represents the complex variable, $T$ represents the system time constant, $G'$ represents the open-loop gain, which is set to 0.6℃ / Hz, and D represents the time constant of the delay link, which is set to 1000s.

In order to verify the effectiveness of the system in this paper, the system test is carried out with MATLAB. The comparison systems used in the experiment are the combined air conditioning control system proposed in reference [6] and the central air conditioning control system based on reinforcement learning proposed in reference [7]. The upper limit frequency of HVAC compressor is 240Hz, the indoor initial temperature is 0 ℃, the set temperature is 24 ℃, and the step input is applied to the three experimental systems. At the same time, the set temperature drops to 20 ℃ at 5000ms and rises to 24 ℃ at 9000s. After repeated tests, the indoor temperature response time curves of the three systems are recorded and described in Figure 10.

As can be seen from Fig. 10, the room temperature response speed and temperature control of this system are obviously higher than those of the other two systems. This system can quickly control the air conditioner and make the room temperature reach the set temperature. At 5000s, the room temperature drops to 22° C, and at 9000s, the room temperature rises to 24° C with a stable trend. Among them, the room temperature of document [7] system falls to 22° C only at 7000s, and the document [6] system is always in a fluctuating state, which does not meet the requirements of the set temperature, indicating that this system has a better temperature control effect.

In the cooling experiment, when the delay is 1000s, three kinds of system cooling-delay time curves are depicted in Fig. 11.

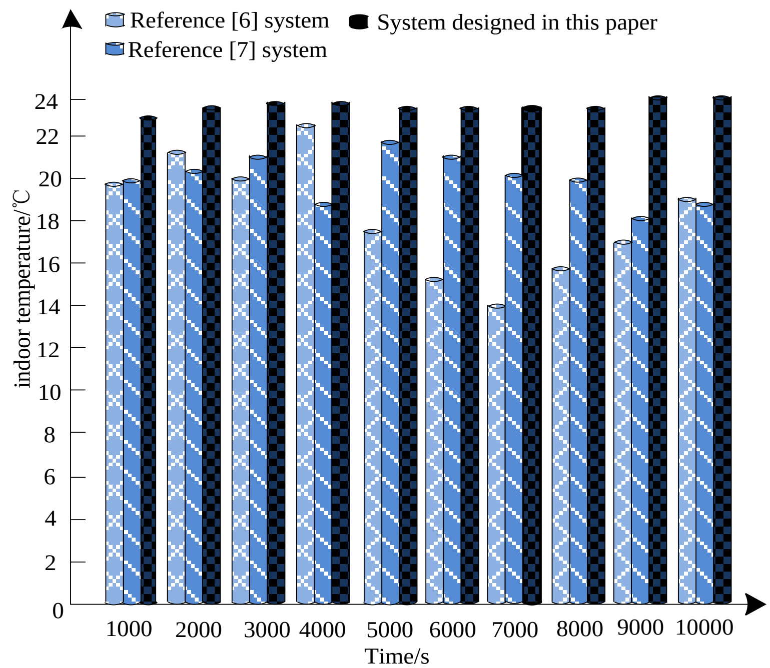


Fig. 10. Indoor Temperature Response Curve.

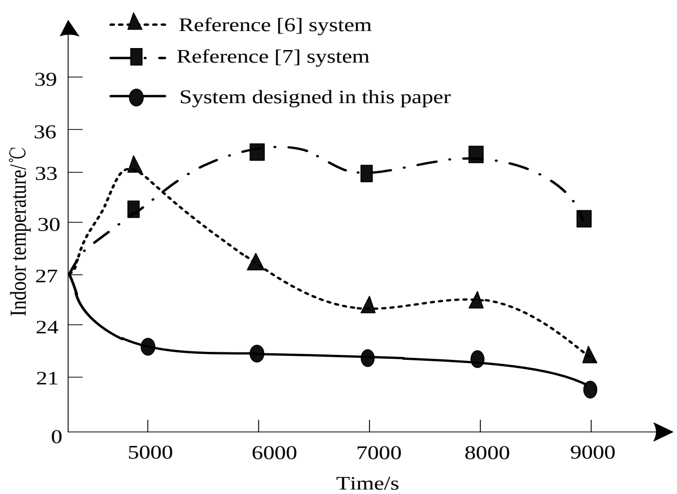


Fig. 11. Cooling Delay Time Curve.

It can be seen from Fig.11 that with the increase of the delay time, the cooling time curve of the system in this paper has little fluctuation and the cooling time is fast, while the cooling time curve of the other two systems has great fluctuation and the cooling time is slow, which shows that the cooling performance of the system in this paper is good.

In order to improve the energy-saving and emission reduction of HVAC, indoor relative humidity was set at 40% and $CO_2$ content was set at 70% in the experiment.

Fig. 12 shows that the effect of indoor relative humidity control of this system is superior to that of other two systems. The control effect of this system is less than 30%, the other two systems are not good, and the fluctuations of indoor relative humidity are large.

Fig. 13 shows that the control effect of $CO_2$ volume fraction of this system is obviously better than that of the other two systems. The indoor $CO_2$ content of this system reaches 3000 ppm at 1000s, after which the control is relatively stable. Although the control time of the system [7] is short and unstable at 4000s, the control time of the system [6] is short and unstable. The system [6] has not met the requirements of the indoor $CO_2$ content. Therefore, the control of the indoor $CO_2$ content of this system meets the requirements of energy saving and emission reduction.

Under the condition of 0.77 air conditioning load parameter, the change of load spike frequency is recorded in

60s as the experimental time, respectively, after the application of the control system of the experimental group and the control group (the combined air conditioning control system proposed in the reference document [6]). Experimental details are shown in Fig. 14.

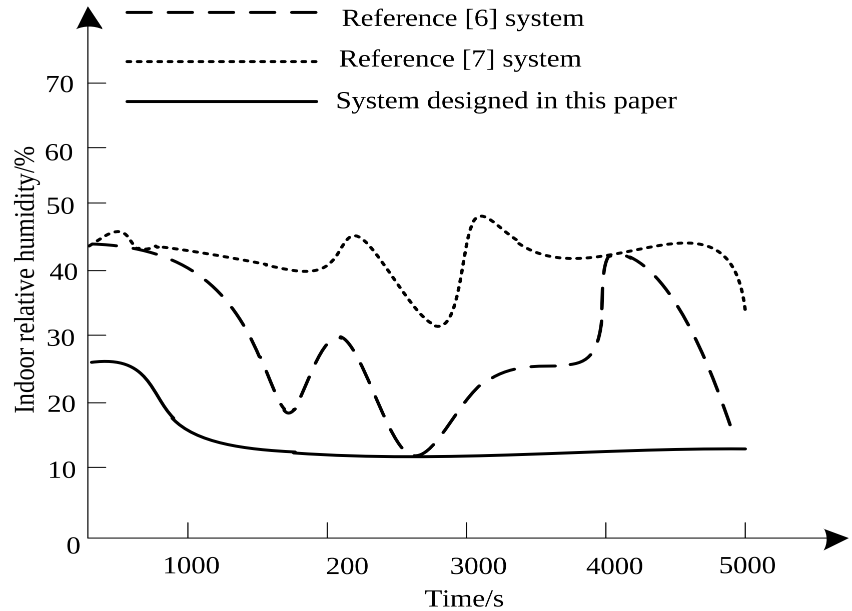


Fig. 12. Indoor Relative Humidity Control Curve.

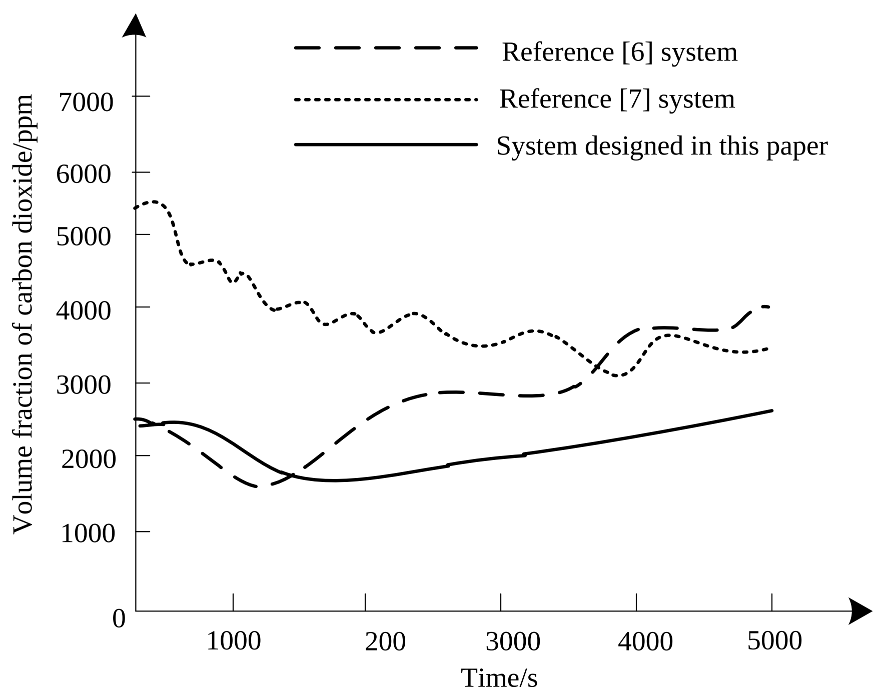


Fig. 13. Indoor Carbon Dioxide Content Control Curve.

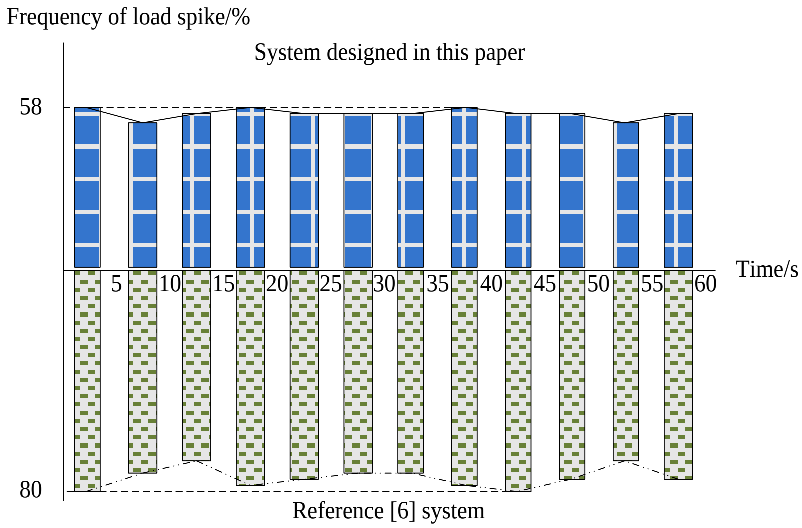


Fig. 14. Frequency Comparison of Load Spikes.

Fig.14 shows that with the increase of experimental time, the frequency of load spike of experimental group presents a more stable trend, the frequency of load spike reaches 58% of the maximum value. The peak frequency of load in the control group also showed a more stable trend, but compared with the experimental group, this trend was significantly worse. The peak frequency of load in the control group reached 80%, much higher than the experimental group. There was no significant change in the peak frequency of load in the control group in the early and late experiment. In conclusion, under the condition of air conditioning load parameter of 0.77, the frequency of load spike can be greatly reduced by using the designed control system.

## IV. Conclusion

In order to solve the current air conditioning, intelligent control system indoor temperature and humidity control effect is not enough ideal problem. Therefore, an intelligent air-conditioning control system based on Internet of Things technology is designed. The application principle of Internet of things in air conditioning control is analyzed. Based on this, the hardware and software of the system are designed. The hardware part of the system includes system control motherboard, sensor module, execution control structure, wireless communication module and access layer. The control architecture of the system and the governor of the virtual synchronizer are designed. In order to realize the energy-saving control of air conditioning, double closed-loop load is designed. The load double closed-loop design includes two parts: synchronous controller and virtual load unit. The software of the system includes the design of communication layer, the design of monitoring management, and the design of intelligent indoor air-conditioning temperature remote control algorithm. The experimental results show that when the air-conditioning structure is working normally, the opening of the traditional air-conditioning valve is about 78%, and the opening of the intelligent control system proposed by the study can be controlled at about 95%. In the research system, the room temperature decreased from 5000s to 22° C, and the room temperature increased to 24° C in 9 000s. The trend was stable at this stage, but the room temperature of the system in [7] only dropped to 22°C at 7000s, and the system in [6] was always in a state of fluctuation. The control effect of this system is stable at 30%, while the indoor relative humidity of the other two systems fluctuates greatly. The indoor $CO_2$ content of the system reaches 3000ppm in 1000s, and then the control is in a stable state. The control of indoor $CO_2$ content can meet the policy requirements of energy conservation and emission reduction. Under the condition that the air-conditioning load parameter is 0.77, the load peak frequency can be greatly reduced by using the designed control system. In summary, the air-conditioning intelligent control system proposed in the study can effectively reduce energy consumption and carbon emissions, and provide users with a more intelligent and comfortable indoor environment. However, there are still shortcomings in the research. With the development of information technology, the application of low-power wide-area network technology in air-conditioning intelligent control systems can be further explored in the future.

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