APPLICATION RESEARCH OF INTELLIGENT MONITORING SYSTEM OF LONGSHENG HOT SPRING WATER TEMPERATURE BASED ON INTERNET OF THINGS

by

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Original scientific paper
https://doi.org/10.2298/TSCI181127150L

Guangxi Guilin area, China, is rich in hot spring resources. In this paper, a hot spring water temperature monitoring system is developed for longsheng hot springs. Mainly using the hot water of eye of hot springs as the heat source, designing a set of multi-point temperature monitoring system with single-chip and multi-slave as the core of the single-chip microcomputer and wireless and bi-directional transmission for the main station and multiple slave stations to realize automatic temperature monitoring. The system slave station can exchange geothermal water with high temperature extracted from the eye of hot springs and cold water, and automatically control the temperature of the hot spring pool to reach a set value range by controlling the flow rate of the cold water. At the same time, the main station can complete the tasks of monitoring system by setting control commands such as temperature.

Key words: *IOT, hot springs, intelligent monitoring*

Introduction

Guilin is one of the most famous tourist cities in China, with rich hot spring resources and more than ten hot springs in Guilin area. The most spring is the Longsheng Hot Spring, which is gushed out of the rock strata at a depth of 1200 meters below the ground. The water temperature is between 45 °C and 58 °C. The red circle in fig. 1 shows the distribution of hot springs in Guilin and the hot spring in Longsheng in fig. 2.

Temperature is a very common and important physical parameter in production process and scientific experiment. Accurate measurement and efficient control of the temperature of the object in the production process are important conditions for achieving safe, efficient, and high quality production [1]. At present, there is no monitoring system for hot spring water temperature, which is essentially the application of temperature monitoring system in hot springs. With the continuous development of science and technology, temperature monitoring system in temperature control technology and the temperature measurement technology is generally moving towards intelligent and diversified development. With the development of intelligent control technology, the temperature control method has also made significant progress, and has changed from the direct control to the intelligent control methods such as PID control, neural network control, genetic algorithm, and fuzzy control.

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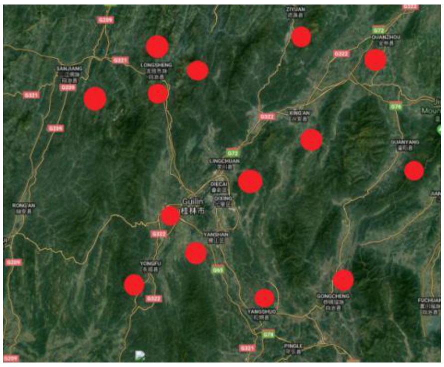

Figure 1. The distribution of hot springs in Guilin (*for color image see journal web site*)

Figure 2. Longsheng hot spring

The overall design of monitoring system in water temperature of hot springs

Controlling principle of water temperature

This system selects direct adjustment scheme of water temperature based on mixed mode, which is shown in two aspects:

– tested by water quality, system reference object contains lots of mineral elements needed by the human body; by using this mixing method, these mineral elements can be absorbed in the treatment pool by contacting with human skin, which can improve the health effect of spa treatment, attract more clients, and create higher benefits for the enterprise and

– the flow of geothermal water from eye of hot springs into the sanatorium is basically constant; only by adjusting the amount of cold water injected can adjust water temperature; the cold water injection rate is controlled by the frequency conversion speed regulation principle of the inverter so as to change the injection amount of cold water and realize intelligent control of temperature [2].

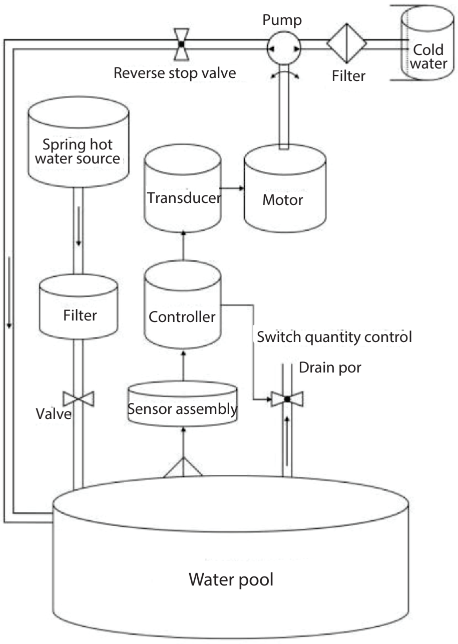

Figure 3. System structure of water temperature adjustment in spa pool of hot springs

The water temperature of the spa pool is controlled. In accordance with fig. 3, in the dynamic situation, the water temperature of spa pool is directly related to the injected cold water-flow and the hot water-flow of hot springs eye. The water temperature of the system is mainly controlled by changing the cold water injection amount with rotational speed of the cold water pump to control the opening and closing of the solenoid valve of hot water for the eye of hot springs. When the actual temperature of certain spa pool is above the set temperature range, the execution agency must be adjusted to operate in order to lower the water temperature to the set range [3].

Block diagram of monitoring system of water temperature

The schematic diagram of the monitoring system studied in this subject is shown in fig. 4. The structure can be divided into two layers. The main station (host computer) constitutes the user monitoring layer, and slave station (lower computer) constitutes extension measurement and control layer. The master station and the slave station adopt a master-slave distribution structure to communicate by wireless communication. The slave station consists of the corresponding data acquisition module (temperature sensor), data processing module (micro-controller), control quantity output module, button display interface, and wireless communication module. It's structural block diagram is fig. 5, and the slave station can separately complete the temperature data acquisition, pre-processing and issuing control commands at each point, and can also receive the control parameters sent by the master station. The main station is mainly composed of data processing module (microcontroller unit – MCU), wireless transceiver module, liquid crystal display module, and button control module. Its structural block diagram is fig. 6, and the main station is responsible for the temperature data transmitted by each slave station through wireless. At the same time as the real-time display on the LCD, the control signals can be sent to the slaves by pressing the button [4].

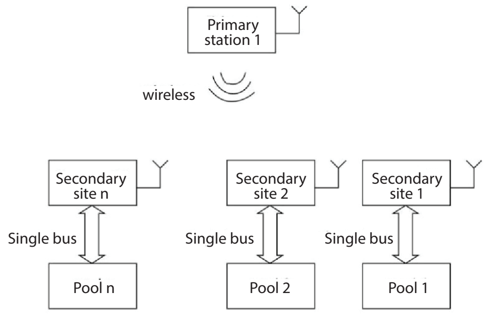

Figure 4. Schematic diagram of system composition

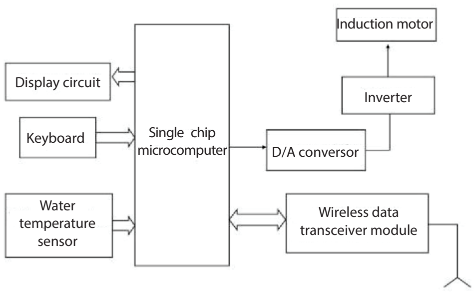

Figure 5. Block diagram of slave station in monitoring system

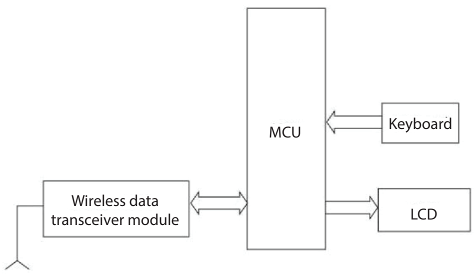

Figure 6. Block diagram of master station in monitoring system

From the overall structure of water temperature monitoring system of hot springs, it can be divided into three parts: temperature data acquisition, system control and data processing, bi-directional transmission of wireless data.

The system has the characteristics of actual and two communication modes. If the monitoring system of water temperature adopts wired communication modes, it is necessary to make the communication-line pass through the wet pool, so that the reliability of the signal cannot be guaranteed, and the wireless method can just solve this problem. For this reason, the communication between the master and slave stations of the monitoring system is wireless. The wireless transceiver mode not only makes the signal reliable, but also avoids a large number of complicated wiring problems in the wired transmission mode, which is both convenient and economical.

Fuzzy PID control method for water temperature of hot springs

Controlled object model

The control object of this system is the temperature in the spa pool. The water temperature of the spa pool is not only related to the heat dissipation caused by the flow, temperature and season of the hot water of the hot spring eye, but also related to the flow rate of the cold water fluid and the inlet temperature. However, as far as the water temperature control system is concerned, the heat-flow (hot water-flow rate of hot spring eye) and temperature, heat dissipation, and inlet temperature of cold water are uncontrollable. They are perturbations, the easiest to think of, and the most common control scheme is a control system that controls the motor speed to take the cold water-flow as a manipulated variable.

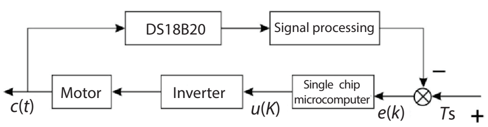

Figure 7. Block diagram of water temperature control system

In fig. 7, Ts [°C] is the water temperature value set, accurate to 0.1°C. The $E(k)$ [°C] is the difference between the water temperature sample value and the set value, accurate to 0.1°C. The $U(k)$ [V] is the control signal generated after the temperature difference is processed by the single-chip computer, and is the voltage value, accurate to 0.1 V. The $C(t)$ [rs^{-1}] is the motor speed. The Ts is the temperature value set by the user through the master station input or slave keyboard. The $e(k)$ is the difference between the K^{th} water temperature sample value and set value. After the micro-controller executes the algorithm program, output control signal $u(k)$ to the inverter. The inverter controls the motor speed, and the speed of the motor is obtained by software operation.This system is a constant temperature that reduces the temperature and maintains it at a set value by adding cold water to the spa pool. Theoretically, the water temperature regulation system of hot springs is a self-balancing ability, but the mixing and heat exchange of the cold water and the hot water of hot springs takes a certain amount of time. The temperature in the whole spa pool is not reduced at the moment of adding cold water, which leads to obvious hysteresis characteristics in the whole temperature measurement process. Through parameter identification, the water temperature measurement and control object can be described as an inertial element for hysteresis [5].

The transfer function of the fully delayed part is:

$$G(s) = \mathrm{e}^{-\tau s} \tag{1}$$

The transfer function of inertia part is:

$$G(s) = \frac{k}{T_1 S + 1} \tag{2}$$

The transfer function of the whole system is:

$$G(s) = \frac{k\mathrm{e}^{-\tau s}}{T_1 S + 1} \tag{3}$$

where k is a magnifying factor, T_1 – the an inertial time constant, and τ – the lag time.

The water temperature inertial element of the control object spa pool of the system is relatively large, and τ – the ratio of T_1 to naught is greater than 0.4, which has a large hysteresis characteristics. If the heat-flow (hot water-flow rate of hot spring eye) and temperature, heat dissipation, cold water inlet temperature and other uncontrollable disturbances are considered, the mathematical model of the system is difficult to establish. If the commonly used PID control is used, it is obviously difficult to achieve the control requirements of the system, which will cause long-term oscillation and large overshoot, and an intelligent control algorithm needs to be adopted for the system [6].

In the monitoring system, the fuzzy PID controlling water temperature principle of hot springs adopted by the slave station is shown in fig. 8. On the basis of the PID controller, the fuzzy control part takes the deviation and deviation change rate as input, Δk_p, Δk_i, and Δk_d, the increment of k_p, k_i, and k_d as the output, and three parameters of PID controller, k_p, k_i, and k_d are adjusted online by fuzzy logic reasoning and decision making to meet the requirements of different input conditions for the control parameters to make controlled object optimize dynamic and static performance. The parameter adjustment formula were:

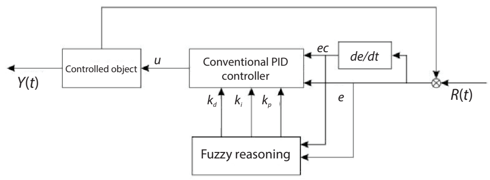

Figure 8. Block diagram of fuzzy PID control system principle

$$k_p = k_p' + \Delta k_p \tag{4}$$

$$k_i = k_i' + \Delta k_i \tag{5}$$

$$k_d = k_d' + \Delta k_d \tag{6}$$

where k_p', k_i', and k_d' are earlier set of PID parameters.

Fuzzy PID controller design of monitoring system

The input and output of the fuzzy controller are all accurate. Because the fuzzy logic reasoning is all about the fuzzy quantity, the controller first needs to blur the input quantity and output quantity, Δk_p, Δk_i, and Δk_d. In the fuzzy PID controller designed by this system, the input variables e and ec and the output quantity, linguistic variables are taken as seven values in total, such as *negative large (NB)*, *negative medium (NM)*, *negative small (NS)*, *zero (Z)*, *positive small (PS)*, *positive medium (PM*), and *positive large (PB)*, the domain {–6, –5, –4, –3, –2, –l, 0, 1, 2, 3, 4, 5, 6). The input quantity *e* and *ec* and the output quantity, degree of membership function of adopts the trigonometric function, and the degree of membership function can be obtained by running the plotmf function under MATLAB, as shown in fig. 9.

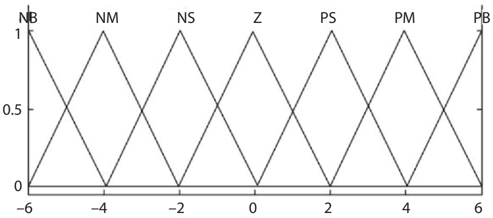

Figure 9. Membership function graph of input quantity and output quantity

The basic value range for variable:

$$e \in [-6,+6], ec \in [-6,+6], \Delta k_p \in [-0.3,+0.3], \Delta k_i \in [-0.06,+0.06], \Delta k_d \in [-0.5,+0.5]$$

The quantized factor for e and ec:

$$k_e = \frac{6}{6} = 1,\ \ k_{ec} = \frac{6}{6} = 1$$

and the quantized factor for Δk_p, Δk_i, and Δk_d were: 20/100/12. After quantization, the input quantities *e*, *ec* and output quantities Δk_p, Δk_i, and Δk_d , which is the values in the domain, can be obtained.

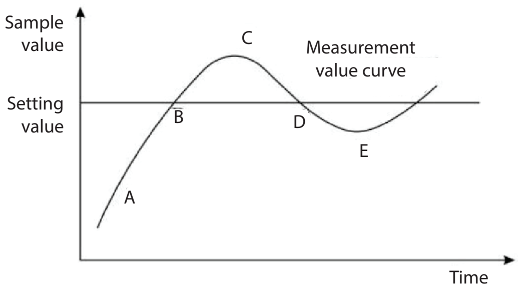

Figure 10. Dynamic response curve

In accordance with the basic idea of fuzzy control, and fuzzy rules, the fuzzy PID control adjusts the three parameters of the PID controller, k_p, k_i, and k_d . The controlling law is as shown in fig. 10. Combined with the control thoughts and control law, the fuzzy control table can be obtained the three parameters, such as k_p, k_i, and k_d, which is suitable for the system according to the long-term accumulated experience of the expert designers and operators.

The output dynamic response curve of the control system can be divided into several response segments according to several points of ABCDE. The main results are:

– when the AB was up parts, deviation $e > 0$, the deviation change rate $ec < 0$, and the deviation e is large, in order to make the water temperature sampling value close to the set value quickly and stabilize, it is necessary to eliminate the deviation,
– when it is close to B point, the deviation e becomes smaller,
– when it leaves B point and the deviation $e < 0$, the system changes to the direction of large deviation, and
– the dynamic curve converges along the direction ABCDE, which shows that the closer the sampling value of water temperature is to the set value, that is, the deviation e varies close to 0 along curve, and the deviation change rate is close to 0 after adjusting the speed of the motor to control the water injection.

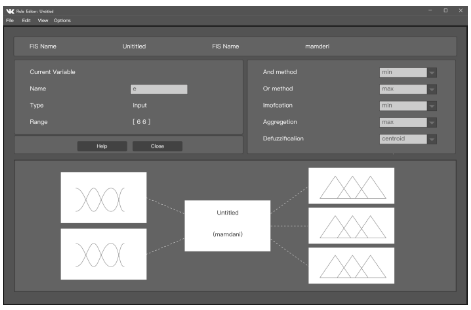

Figure 11. Fuzzy PID dynamic simulation environment

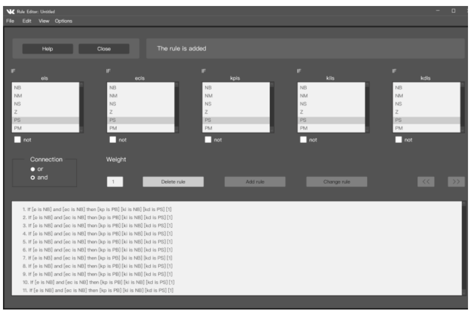

Figure 12. The MATLAB simulation implementation of fuzzy rules

Running fuzzy in the MATLAB can enter the dynamic simulation environment of MATLAB, as shown in fig. 11.

Through Rule editor, the fuzzy control table can be transformed into 49 items of fuzzy rules, as shown in fig. 12.

The result of fuzzy reasoning is fuzzy quantity, which cannot be directly functioned executing agency, and need to transform fuzzy quantity into accurate quantity through defuzzification. The fuzzy PID controller of this monitoring system uses weighted average method for fuzzy decision-making and its execution quantity $u_{\max}$:

$$u_{\max} = \frac{\sum k_i u_i}{\sum k_i}$$

Through weighted average methods, the variables of Δk_p, Δk_i, and Δk_d fuzzy control decision-making table of three parameters of PID controller can be obtained.

In order to illustrate the superiority of PID controller, we compare it with conventional PID controller, using Simulink tool box of MATLAB to model and simulate the two dynamic control system. Figure 13 is the simulation structure diagram of conventional PID controlling system, fig. 14 is the simulation structure diagram of fuzzy PID controlling system.

In fig. 14, the transfer function of the inertial element is realized by the function block. Transfer function, the expression:

$$G(s) = \frac{1}{60s+1}$$

and the transfer function of the pure time delay-element is realized with transport delay, set time delay element to 30 seconds. In the process of simulation, the three parameters of PID are continuously adjusted by empirical methods to get the best simulation curve, among which k_p = 0.0843, k_i = 0.0043, k_d = 0.4010.

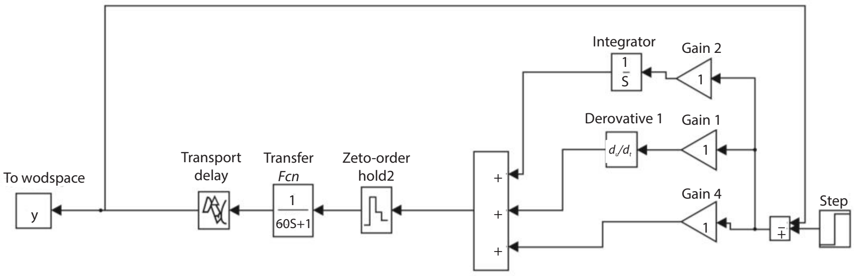

Figure 13. The simulation structure diagram of conventional PID controlling system

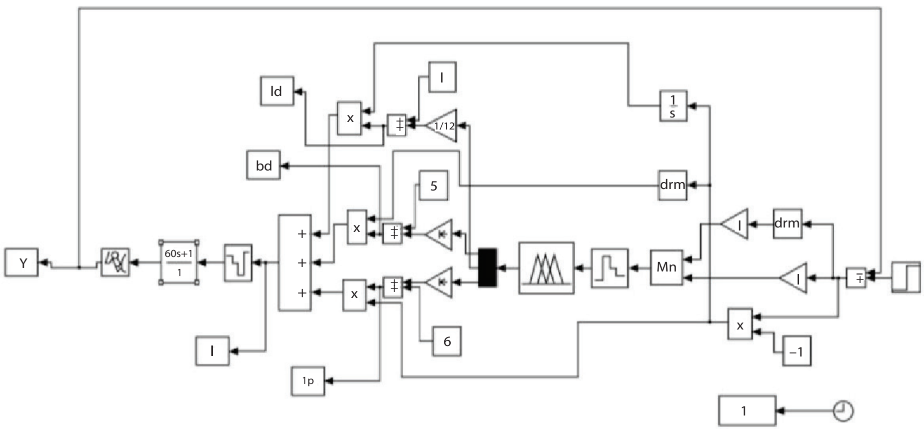

Figure 14. Simulation structure diagram of fuzzy PID control system

The mathematical model of control object of system simulation is the same as the simulation diagram of PID control system, the input signal and oscilloscope module are added into simulation system. The step response curves can be obtained PID control system and fuzzy PID control system from oscilloscope module, which is shown as fig. 15.

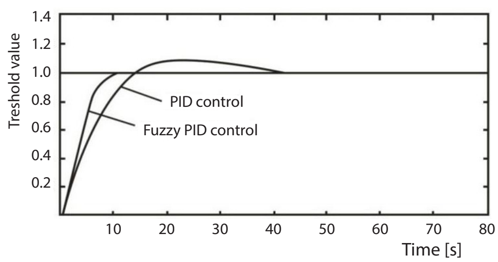

Figure 15. The step response curves of PID and fuzzy PID control system

As we can see from the simulation diagram: self-tuning PID controller of the fuzzy parameters is faster than the conventional PID controller in rising speed, short rising time, and small overshoot. When the mathematical model of controlling object is changed, the dynamic property of self-tuning PID controller for the fuzzy parameters will be obviously better than conventional PID due to robustness of fuzzy control.

Monitoring system design of hot spring water temperature

In according with the overall design analysis of the water temperature monitoring system, the overall framework of the hardware design of the system is shown in fig. 16. For the monitoring system of hot spring water temperature designed in this paper, a master-multi-slave distributed structure is adopted according to the actual situation of the system. The whole water temperature monitoring system consists of three parts: the multi-point acquisition control terminal of the slave station data, the wireless communication transceiver, and the monitoring terminal of the host computer main station. The slave station data multi-point acquisition control terminal is responsible for data collection, transmission and reception, and intelligent control of the control object through the execution agency is realized. The data transceiver terminal is responsible for data reception and processing, and the host computer master station is responsible for data display and temperature monitoring. At the same time, control commands can be sent to each slave station [7].

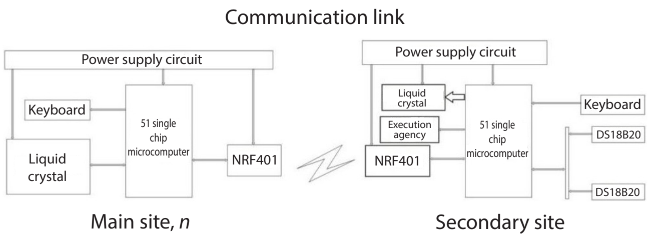

Figure 16. Overall design of the hardware

In order to improve the versatility, expansibility and readability of the system software, the monitoring system software adopts a modular structure, which includes a main program module, a temperature parameter setting module, a transmitting program module, a receiving program module, a temperature measuring program, and a fuzzy PID algorithm program modules*, etc.* The system program modules can be co-ordinated by interrupting handling subroutine.

System debugging results analysis

Temperature signal acquisition and debugging

Whether the temperature can be collected and the accuracy of the temperature data is the prerequisite for monitoring the water temperature. The temperature collected by the temperature sensor DS18B20 displayed on the liquid crystal display is compared with the standard temperature data of the cement thermometer taken at the same time. Run continuously for one hour to test the changing water temperature, read the cement thermometer once every five minutes, and observe the LCD display results. The results are shown in tab. 1.

Table 1. Temperature measurement results of system operation record (interval five minutes)

Number of observations	1	2	3	4	5	6
LCD display	42.5	41.7	42.9	43.7	40.7	36.8
Thermometer reading	42.4	41.8	42.7	43.8	40.6	36.7
Number of observations	7	8	9	10	11	12
LCD display	34.2	35.6	37.1	32.8	33.9	30.1
Thermometer reading	34.1	35.5	37.3	33.0	34.0	30.2

Comparing the recorded temperature data, the LCD display temperature value in the monitoring system is basically the same as the standard cement thermometer reading, within the error tolerance range (±0.3°). That is, during the continuous change of temperature, the temperature value collected by the monitoring system is basically consistent with the actual value, which can meet the requirements of control accuracy.

Wireless communication module debugging

Whether the data of the master and slave stations can be transmitted in both directions, whether the slave station can relay and the actual wireless communication distance between the two nodes, the debugging is performed separately:

– the master station sets the temperature of slave station 1-28 °C through the keyboard, and after starting the transmission delay for a short time, slave station 1 obtains the temperature setting 28°C of the master station, indicating that the master station can wirelessly transmit data to the slave station; the master station displays the actual temperature of the slave station at 40°, indicating that the slave station can send the measured temperature value to the master station, so the monitoring system can implement the wireless two-way data transmission of master-slave station,
– put the master and slave stations of the control system in an open environment, and pull the distance between the master and slave stations from near to far until the data cannot be accepted; record the actual communication distance with a tape measure, as shown in tab. 2, and

Table 2. Wireless communication distance test

Distance	10	15	20	25	30	35	40	45	50
Send data	01H	02H	01H	02H	01H	02H	02H	02H	02H
Receive data	01H	02H	01H	02H	01H	01H	01H	01H	02H

– the slave station 1 is placed within the transmission radius of the master station, and the slave station 2 is placed outside the transmission radius of the master station; first, the slave station 1 is turned off, the master station transmits data 02H to the slave station 2, and the slave station 2 maintains the data 01H without change, open slave station 1, the master station sends data 02H to slave station 2 again; after 2 to 3 seconds delay, slave station 2 receives data 02H, indicating that the slave function of this system is realized, but the delay is longer, such as multi-level relay, which will reduce the real-time performance of the system.

Simulation test of system control algorithm

The system uses the analog indirect method to verify the control algorithm. Combined with the principle of water temperature regulation, it can be seen from tab. 3 that when the temperature is higher than the set value, the duty ratio of the PWM wave is larger, the motor runs faster, and the injection amount of cold water is increased. The duty ratio of the PWM wave is reduced, the running speed of the motor is slowed down, and the injection amount of cold water is reduced. When the temperature is set to a value, the duty ratio of the PWM wave is also relatively stable, and with the duty ratio of the PWM wave following the temperature deviation, the size is also different accordingly. The results are in good agreement with the principle of the control algorithm, so it can be considered that the control algorithm of the system can achieve the established control process.

Table 3. Temperature and duty ratio of the corresponding motor PWM wave

Number	1	2	3	4	5	6	7
Temperature	7.1	26.8	26.5	26.4	25.9	25.4	25.2
PWM ratio	70.1	68.9	67.8	65.8	64.8	62.5	61.7
Number	8	9	10	11	12	13	14
Temperature	25.6	24.8	24.6	24.5	25.1	28.3	27.8
PWM ratio	59.8	60.2	60.3	58.9	59.4	73.9	72.3

Conclusion

This paper puts forward the overall hardware structure of the hot spring water temperature monitoring system. The sub-module designs the power supply circuit of the control system, the controller reset circuit, the temperature acquisition circuit, the liquid crystal display circuit, the wireless communication circuit, the motor control circuit and the button part circuit. The system is divided into modules for debugging analysis, including temperature acquisition test, wireless communication module test and system control algorithm simulation test. The system can be used not only for multi-point temperature control, but also for other fields, and has broad application prospects.

Acknowledgment

2017 Guangxi Education Science Ten-Three-Five' Planning Project: Based on Zte's ICT Education Platform of Fusion, Work-Integrated Learning Education Training Mode Research (No. 2017B107).

2018 Guangxi Young and Middle-aged Teachers'Achievement Project: Design and Implementation of Picking Robot Based on Internet of Things (No. 2018KY0556).

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Paper submitted: November 27, 2018
Paper revised: January 25, 2019
Paper accepted: February 5, 2019