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Functional Design and Development of Smart Temperature Regulating Clothing Based on Artificial Intelligence

Dongli Wu[1,✉], Ruo Zhang[1], Lijing Zang[1]

[1] *Department of Fashion Engineering, Hebei Vocational University of Technology and Engineering, Xingtai, Hebei, 054035, China*

ABSTRACT

Intelligent thermoregulation clothing as a new type of functional clothing, the design and development of which is receiving more and more attention. PID algorithm, as a kind of classical control algorithm, realizes the precise control of the clothing temperature regulation system by adjusting the three parameters of proportionality, integration and differentiation. The control system is firstly constructed according to the principle of PID control. Then the PID controller parameters are optimized by BP neural network to improve the response speed and stability of the temperature control system. Finally, the intelligent thermoregulation garment with physical therapy and health care and portable storage is designed. Experimental verification of the parameter self-tuning PID control based on BP neural network, the BP neural network can make the temperature better maintained near the set value, the control effect is more satisfactory. The final design of the smart thermoregulation garment has a body surface temperature retention rate of 98.35% after 30 minutes at -10°C and with the heating function on. The thermal sensation evaluation of the intelligent thermoregulation garment by the subjects in different states is concentrated between "0-2", indicating that the garment can play a more ideal temperature control effect.

Keywords: PID algorithm, BP neural network, temperature control system, intelligent thermoregulation clothing

1. Introduction

Artificial intelligence has long been applied to the apparel industry, from fabric optimization [1], to apparel design [2], to the final production of the finished product [3] and so on. And smart apparel is the apparel that incorporates technology into the apparel so that it has smart functions. It includes sensors, processors and distributed networks, as well as other related components, so that people can obtain useful information and services through smart clothing [4-5]. Through the introduction of

✉ Corresponding author.
E-mail address: 13932980427@163.com (D. Wu).
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artificial intelligence technology, smart clothing can better meet the personalized needs of users. Artificial intelligence can provide appropriate fabrics and designs according to the user's body data, preferences and behavioral habits, so as to achieve a better wearing experience and comfort [6-8]. Artificial intelligence technology can make smart clothes have a higher level of intelligence. With the help of AI technology, smart clothes can automatically recognize the user's movement status, monitor health data, and obtain electrocardiograms and other functions, and provide timely health reminders, exercise guidance, and early warning prompts for the users [9-12]. Artificial intelligence technology can also give smart clothing more intelligent interactive functions. Intelligent clothing can be integrated with artificial intelligence technology to realize intelligent dialogue with the user, intelligent recommendation and other functions to further enhance the user experience, interactivity and emotional value [13-15]. The significance of the application of artificial intelligence technology in smart clothing is to enhance user experience, achieve personalized customization, increase the level of intelligence and enrich the intelligent interactive functions, which will bring broader development space and market prospects for the smart clothing industry. In addition, smart clothing can reduce dressing tangles, achieve fashion needs such as color change, and meet the protection needs such as military dusty weather [16-19].

Currently, the smart clothing market is an emerging market full of potential, and the demand for smart clothing will continue to grow as people pay more attention to health, sports and smart lifestyle [20]. The requirement of clothing temperature is an unchanging subject, and the ability to realize automatic adjustment of clothing temperature is the biggest feature and selling point of only clothing.

Research and design of PID-based intelligent control system is used for the research and development of intelligent thermoregulation clothing. The temperature controller is selected as the control object, and the PID controller parameters are optimized by BP neural network. The intelligent thermoregulation clothing designed and produced makes the intelligent thermal regulation system of the clothing can control the heat distribution in the spacing area of the clothing by reasonably setting the heating element and optimizing the heating position. And the electronic components such as carbon fiber heating pads, temperature sensors, and system controllers are attached and assembled in the inner layer of the garment, which can be disassembled before cleaning. In addition, the optimization effect of BP neural network on the parameters of PID controller is verified by designing the temperature control system experiment. And the use of intelligent thermoregulation clothing is verified by subjective and objective analysis.

2. Overview

Thermoregulation is the body’s own protection mechanism, which is related to the life and health of individuals. Literature [21] mentions cooling photonic membrane, one-way liquid transport membrane, waterproof and breathable membrane, thermoregulation membrane, heat-conducting membrane, and protective membrane in clothing system, which are all personalized to regulate the wearer’s temperature and humidity, but there are too many kinds of them and their functions are scattered. And the combination of intelligent technology and textile cloth realizes human body temperature monitoring [22]. Based on this, the garment realizes smart insulation [23], heating [24], smart cooling [25], and adaptive thermophysiological thermoregulation system [26]. Most of the smart thermo-physiological thermoregulation systems sense human physiology and environmental conditions with the help of temperature and humidity sensors, respond to temperature and humidity through actuators, and are equipped with regulating devices for cooling or heating [27]. This type of system is based on textile cloth not only to sense the human body temperature, but also to sense the temperature changes in the external environment. It can be seen that the most important component of smart clothes to sense temperature is the sensor, its material selection should not only fit the traditional clothing comfort, but also to achieve intelligent body temperature monitoring, literature [28] developed a composite ink printing sensors in the soft and lightweight basis to achieve continuous body temperature monitoring. And literature [29] used multi-scale disordered porous elastic fiber material to develop a sensor that can monitor body temperature based on strain temperature and self-cooling. In addition, personal thermal management is to regulate the exchange of heat between the human body and the environment in which it is located outside [30], and thermal comfort is the focus in the design of smart thermoregulation clothing and the main direction of sensor sensing. The human body's own thermal management is based on pore heat dissipation, and the intelligent realization of personal heat dissipation by radiation, conductance, convection, and promotion of sweat evaporation [31], and the clothing can realize intelligent temperature regulation from 15°C to 35°C in a few seconds [32]. And literature [33] designed a smart flap garment that simulates the work of pores based on the principle of human pore switch, and also involved a smart garment that can adjust the thickness of clothes to regulate the comfort of personal dressing. Such a design increases the visible technology of the clothes on top of the smart adjustment.

3. Research and development of intelligent thermoregulation clothing based on artificial intelligence

3.1. PID intelligent control system design

3.1.1. PID control principle. In analog control systems, PID control is the most commonly used control law for controllers. The block diagram of the analog PID control system is shown in Fig. 1. The system consists of an analog PID controller and the controlled object.

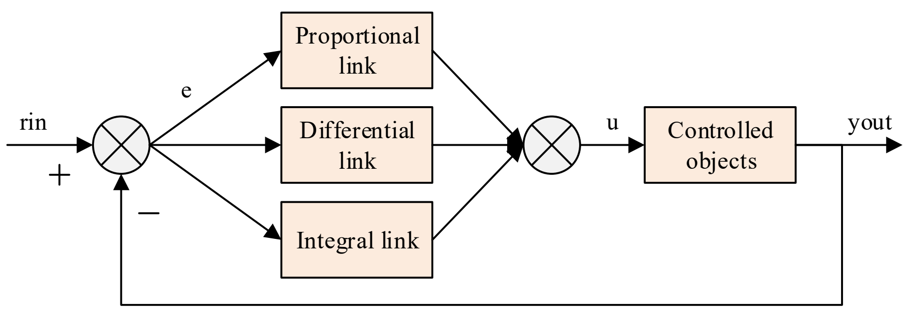

Fig. 1. Principle figure of PID control system

In Fig. 1 rin is the given input of the system. $yout$ is the output of the whole system. e is the deviation of the given value rin from the actual output value $yout$: $e = rin - yout$. The proportional, integral and differential links in the figure will e form the control quantity by linear combination and u is the output of the controller with the control rule:

$$u(t) = k_p \left(error(t) + \frac{1}{T_I} \int_0^t error(t)dt + \frac{T_D derror(t)}{dt} \right) \quad (1)$$

Or written in the form of a transfer function:

$$G(s) = \frac{U(s)}{E(s)} = k_p \left(1 + \frac{1}{T_I s} + T_D s \right) \quad (2)$$

Where k_p is the proportional amplification factor. T_I is the integral time constant. T_D is the differential time constant. In brief, the role of each correction link of the PID controller is as follows:
1) Proportional link (P) : It reflects the deviation signal $error(t)$ of the control system proportionally, and once the deviation is generated, the controller immediately produces control effect to reduce the deviation.

2) Integral link (I): It is mainly used to eliminate static deviation and improve the system's degree of freedom from deviation. The strength of the integrating effect depends on the integrating time constant T_I, the larger the T_I, the weaker the integrating effect, and vice versa, the stronger.
3) Differential link (D): Reflects the trend (rate of change) of the deviation signal and introduces an effective early correction signal into the system before the deviation signal becomes too large, thus speeding up the action of the system and reducing the regulation time.

3.1.2. PID modeling. There are many ways to build PID controllers, summarized in two categories: one is the theoretical calculation of the calibration method, and the other is the engineering calibration method. The engineering calibration method of the PID controller parameters, mainly has the critical ratio method, the reaction curve method and the attenuation method. These three methods have their own characteristics, their common point is through the test, and then in accordance with the engineering experience formula for the controller parameters to be adjusted.

Critical proportion method to adjust the PID parameters, also known as the Ziegler-Nichols engineering tuning method, in debugging the PID controller, the application of the Ziegler-Nichols method can be quickly and accurately calculate the value of the corresponding parameters [34], in the modeling circuit construction only needs to be fine-tuned to obtain the desired control effect. Parameter adjustment rules first through the unit step response curve, Liegler-Nichols method of the step response curve shown in Figure 2. In the output signal $u(t)$ unit step response curve, take the turning point for the tangent line, so that it is respectively intersected with the time axis and the tangent line, from the tangent line obtained by the two intersections to extract the output signal to get the time constant L and time delay constant T.

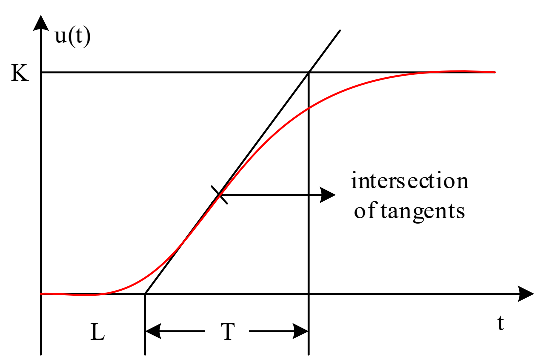

Fig. 2. The step response curve of Liegler-Nichols

The step response of the Ziegler-Nichols method is the trajectory of the system power output when a step input is added to the system. Subsequently, the parameter tuning rules of the Ziegler-Nichols first method are utilized to determine the parameter tuning values of each controller, and the parameter tuning rules are shown in Table 1, where L is the time constant, T is the time delay constant, Kp is the proportional gain, $Kp = T / L$, and $Ti = Kp / Ki$ is the integral time constant. $Td = Kd / Kp$ for the differential time constant, reference to the conversion formula in the table can be adjusted controller Kp, Ki, Kd parameter values.

Table 1. Ziegler-Nichols first method of the parameter of the first method

Controller	Kp	Ti	Td
P	T / L	∞	0
PI	$0.9T / L$	$L / 0.3$	0

PID	$1.2T / L$	$2L$	$0.5L$

If the system model cannot be derived directly from the physical model, experiments can be performed to extract the parameters of the approximate model. The temperature control belongs to the hysteresis control system, and the temperature control of the heater can be equated to a first-order pure time inertia delay input. In this paper, the system selects the temperature controller as the control object, and the approximate model transfer function $G(s)$ of the system is shown in Eq. (3), where the transfer function $e\hat{} - 2s$ represents the pure time delay of the system for 2 seconds:

$$G(s) = \frac{10}{80s+1} e^{-2s} \tag{3}$$

The final control effect of PID control depends largely on whether the selection of the three parameters Kp, Kd, Ki is appropriate. Therefore, the parameterization of the PID controller is the core of the PID control system.

3.2. Improvement of conventional PID by BP neural network

Artificial intelligence includes techniques such as machine learning and deep learning, and BP neural network is a basic algorithm in deep learning. This chapter uses BP neural networks to optimize the parameters of the traditional PID temperature control system.

In the traditional PID temperature control system, because the parameters cannot be adjusted online in real time, there is a great lag in the control process, the control time is long and the stability is not high, which does not achieve the desired effect in industrial production. Based on this, this control system uses BP neural network to self-tuning of PID parameters, in the temperature control process can be based on the size of the deviation value of the current temperature value and the set temperature value of the PID parameters for real-time adjustment, so as to achieve the fastest speed and stability to reach the set value.

The PID control method using BP neural network tuning is shown in Figure 3 below.

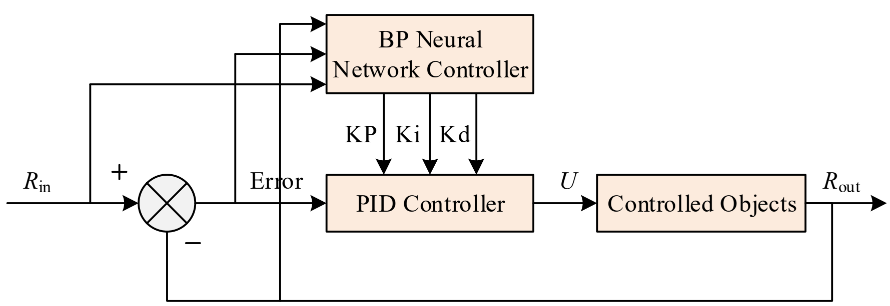

Fig. 3. Bp neural network control mode

This system uses the simplest 3-layer BP neural network, three-layer BP neural network structure network input layer node output is:

$$O_j^{(1)} = X(j)\left(j=1,2,3\right) \tag{4}$$

The inputs and outputs of the implicit layer of the network are:

$$net_i^{(2)}(k) = \sum_{j=0}^{M} w_{ij}^{(2)} o_j^{(1)} \tag{5}$$

$$O_i^{(2)}(k) = f\left(net_i^{(2)}(k)\right) \tag{6}$$

Where: $w_{ij}^{(2)}$ is the implicit layer weighting factor. $(j=1,2,3)$ represents the input, hidden and output layers, respectively.

The activation function of the neurons in the hidden layer is taken as a positive and negative symmetric Sig-moid function:

$$f(x)=\tanh(x)=\frac{e^x-e^{-x}}{e^x+e^{-x}} \tag{7}$$

The inputs of the nodes in the output layer of the network, and the outputs are:

$$net_i^{(3)}(k)=\sum_{i=0}^{Q} W_{ij}^{(3)} O_i^{(2)}(k); O_i^{(3)}(k)=g\left(net_i^3(k)\right) \tag{8}$$

$$O_1^{(3)}(k)=K_p; O_2^{(3)}(k)=K_i; O_3^{(3)}(k)=K_d \tag{9}$$

The output of the BP network corresponds to the PID3 parameter K_P, K_I, K_D , and since K_P, K_I, K_D cannot be negative, the activation function of the neurons in the output layer can be expressed as:

$$g(x)=\frac{1}{2}(1+\tanh(x))=\frac{e^x}{e^x+e^{-x}} \tag{10}$$

The learning method of its neural network is taken:

$$\Delta w_{ij}^{(3)}(k)=-\eta\frac{\partial E(k)}{\partial w_{ij}^{(3)}}+\alpha\Delta w_{ij}^{(3)}(k-1) \tag{11}$$

Where: η is the learning rate, α is the inertia coefficient.

In this control system, the current temperature TEM, the user set temperature SET, and the deviation Error of the two as the input layer of the neural network, x_1, x_2, x_3. Then through the neural network self-tuning output control voltage U , U value as the duty cycle of the PWM wave to regulate the temperature, and finally constantly through the self-tuning to make the deviation of the current temperature and the user set temperature value is 0. Through the simulation, we can see that the PID control of BP neural network has fast response speed and high stability of temperature control [35], so methodologically the PID control of BP neural network has superior performance and good optimization of this control system, based on this, this system finally adopts the PID control of BP neural network as the control algorithm of this temperature control system.

3.3. Design and realization of temperature control system based on PID control algorithm

Based on the realization of the above PID temperature control algorithm, the development of the intelligent temperature control system is subsequently set up. The system collects temperature signals with temperature sensors and transmits them to the microcontroller for processing in the form of digital signals, so as to realize the temperature control of carbon fiber heating pads. The design and implementation of the temperature control system mainly contains the design of the hardware circuit and the implementation of the program system.

3.3.1. System Hardware Composition. Intelligent thermoregulation clothing is the power supply, temperature control device, circuit safety protection device through the wire connection to form a circuit, the use of power to control the clothing inside the electric heating element to generate heat of a class of clothing general term. In this study, a flexible heating material made of carbon fiber is selected as the heating element, and the selection of the heating element will directly affect the heating efficacy of the smart thermoregulation garment. Carbon fiber heating material is a breakthrough ultrathin material that generates heat uniformly and quickly, and is soft and washable. The carbon fiber heating element can also produce far infrared radiation with an emissivity of 0.95, which can provide physical therapy and health care benefits in long-term use.

3.3.2. System Software Composition and Realization. According to the functional requirements of the system design, the program of the intelligent temperature control system includes the temperature sensor reading temperature program, LCD1602 crystal display program, and relay heating program. When the intelligent temperature control module is connected to the power supply, the system starts to work and the data is initialized first. After initialization, the microcontroller measures the skin surface temperature in real time through the temperature sensor. When the temperature control module detects the signal input from the skin temperature sensor, the temperature controller converts these floating point signals into strings and transfers them to the display module. The system then compares the detected parameters with the predetermined time in the system and the control module decides whether to drive the heating program or not.

3.4. Functional design of intelligent temperature-regulating clothing

3.4.1. Heating design. In order to improve the comfort of intelligent temperature-regulating clothing and to exert its auxiliary physical therapy health care effect, the placement of each heating part needs to be designed based on the physiological characteristics of each part of the human body and thermal comfort. In addition, by reasonably setting the heating elements and optimizing the spacing of the heating areas, the heat distribution in the intervals between clothing areas can be controlled to avoid low-temperature burns caused by too high a temperature or concentrated heating. In this study, carbon fiber heating pads were installed to cover the cold-sensitive body parts of the human body to ensure the warmth of the body parts of the torso that are susceptible to freezing in a cold environment. As the thickness of the garment increases, the heat transfer from the garment to the interior of the body decreases. For this reason, the heating efficacy can be improved by decentralizing the heating area and increasing the heat transfer along the plane direction to enhance the thermal comfort of the smart thermoregulated heating garment.

3.4.2. Storage design. Intelligent temperature-regulating heating clothing has two kinds of wearing state: one is the wearing state of normal life, and the electronic power supply attachment and carbon fiber heating piece can be dismantled on the clothing for cleaning. One is a functional wearing state with various functional electronic devices, all of its heating sheet devices, PCB circuit hidden in the seams of the clothes, making the hidden effect and simplicity of the clothing electronic circuit equipment better. First of all, the carbon fiber heating sheet and multiple temperature sensors are placed in the sandwich lining, in which the carbon fiber heating sheet is sewn together with Velcro on all four sides, which can be directly pasted or disassembled on the sandwich of the lining. The wires connecting the PCB to the carbon fiber heating pads are stored in long rectangular channel openings 2-3 cm wide or hidden in the seams of the garment so that the wires do not fall out in the lining. The temperature sensors are attached to the body by means of concealed buttons. The garment is equipped with front and back pockets, with concealed openings on the inside. The back pockets of the coat are used for lithium batteries, and the front pockets are used for the smart thermostat. The neckline and lapel of the upper garment's lining and face fabric have been fixed and sewn together, while the hemline is closed with a concealed button, which makes it easy to remove the built-in heating pads and wiring before washing the garment [36]. The storage design of the electric heating element of the lower garment is the same as that of the upper garment.

4. Results and discussion

4.1. Experimental analysis of temperature control system

The control performance and stability of the system should be completed through specific experimental tests, the temperature control system using the power supply 12V on the heating wire of the intelligent thermoregulation clothing heating, in order to observe the different control effects of different control modes, temperature control experiments were used in full-power heating, switching control combined with PID control and switching control combined with the PID control based on BP neural network parameter self-tuning in three ways The experiment was carried out.

The experiment was conducted in an indoor environment with a room temperature of 22℃ and slight air flow. The temperature measurement point of the sensor is the sandwich layer of the garment. The wearing state is static, i.e., no perturbation.

4.1.1. Full power heating experiment results and analysis. In order to observe the characteristics of intelligent temperature-regulating garments, full-power heating experiments are first conducted on intelligent temperature-regulating garments, i.e., the heating wire of intelligent temperature-regulating garments is always in the state of conduction for heating, so as to have a specific understanding of the heating characteristics of intelligent temperature-regulating garments. Another purpose is to ensure that when the heating is out of control, the full-power heating does not overheat and burn the skin of human limbs. The temperature control data obtained by recording the data every one minute in the full power heating state of the smart thermoregulation garment is shown in Fig. 4. The maximum temperature that can be reached by this temperature control system with full-power heating at 12V heating voltage is about 44.6°C. The temperature rises faster in the early stage of heating, and starts to slow down when it is about 40°C, and reaches the temperature equilibrium at about 43°C.

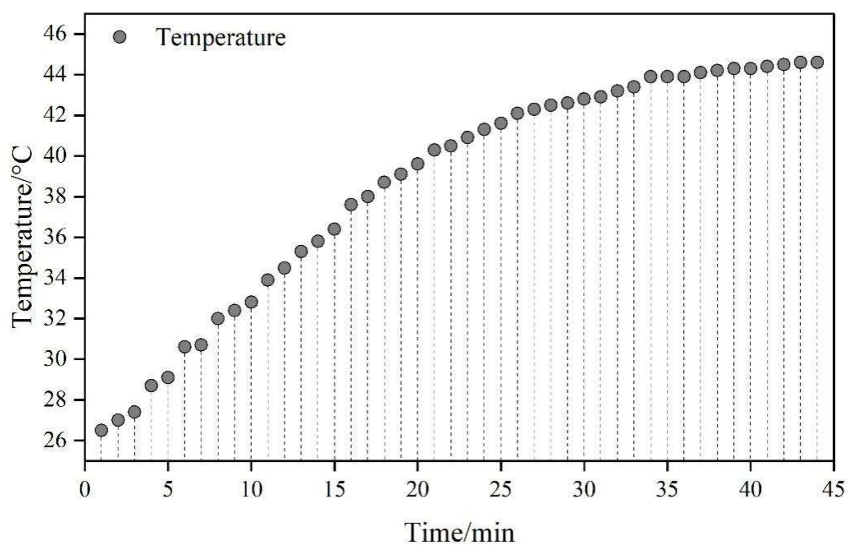

Fig 4. Full power heating temperature control

4.1.2. Experimental results and analysis of manual PID parameter adjustment control. Conventional PID control experiments were carried out on the temperature control system of the intelligent temperature-regulating garment, setting the temperature at the human body's comfortable temperature of 35°C and recording the temperature value every minute. According to the requirement of accuracy of ±2°C, full-power heating is carried out when the current temperature of the intelligent temperature-regulating garment is lower than the set temperature by 5°C. When the temperature difference with the set temperature is less than 5°C above and below, conventional PID control is run for heat preservation, and after repeated experiments, a set of fixed parameters selected from a number of groups of artificially calibrated PID parameters, the temperature control data obtained are shown in Figure 5. The manually parameter-tuned PID control can reach stability in about 14 minutes, but there are small fluctuations. The comfortable up and down range is 0.4°C up and 0.6°C down, and the temperature difference is 1°C. Although the accuracy meets the requirements, the temperature goes up and down faster. As the temperature difference always exists, the integral effect always exists, and the system is likely to enter the state of integral saturation.

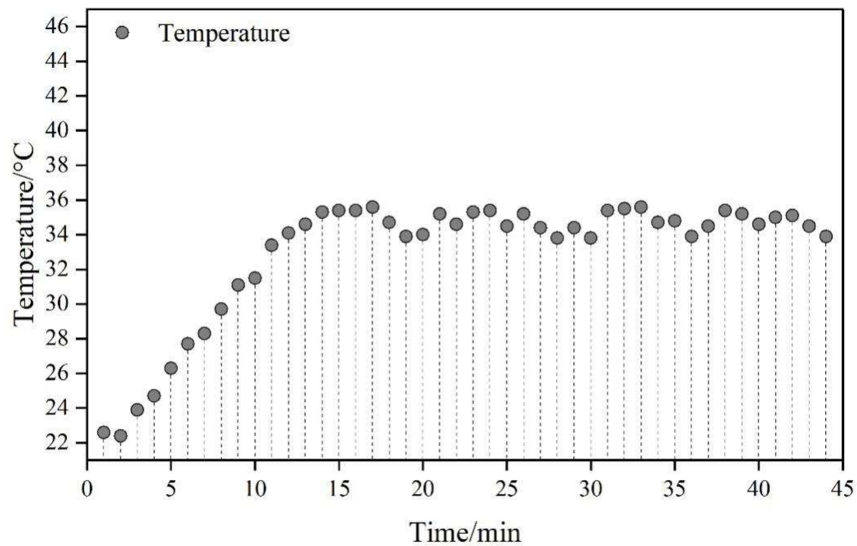

Fig. 5. The artificial PID parameter is controlled by the whole temperature control

4.1.3. Parameter self-tuning PID control experiment results and analysis. The parameter self-tuning PID control experiment based on BP neural network is carried out on the intelligent thermoregulation garment, and the experimental results are shown in Fig. 6. The stability of PID temperature control based on parameter self-tuning of BP neural network is obviously better than that of PID control with artificial parameter tuning, and it avoids repeated manual adjustment of PID parameters. This PID parameter self-tuning control algorithm makes the temperature control accuracy of the intelligent thermoregulation garment significantly improved, and the algorithm can make the temperature better maintained near 35°C. This PID parameter self-tuning algorithm is simple and convenient to implement, with small arithmetic, which is very suitable for the control field of microcontroller.

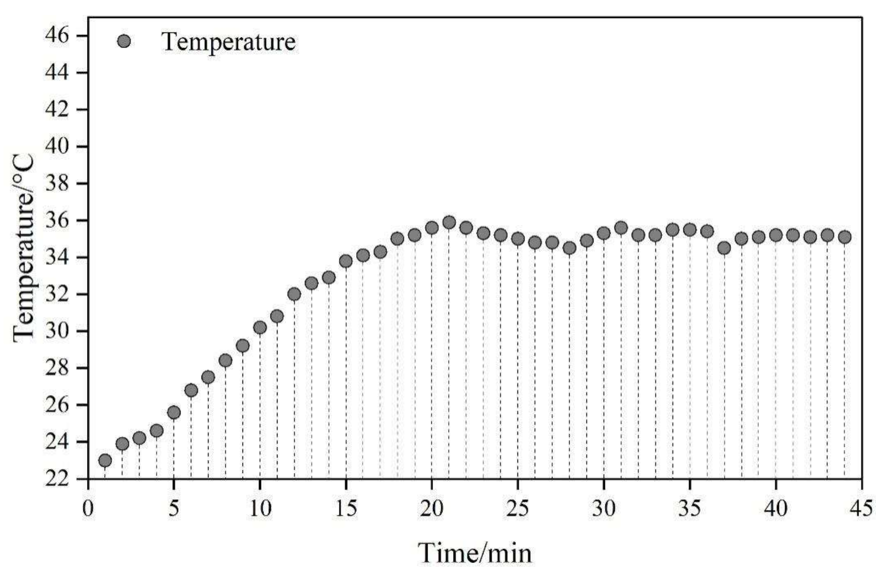

Fig. 6. PID parameter self-setting temperature control

4.2. Warmth Evaluation of Intelligent Thermoregulation Clothing

4.2.1. Experimental design. The warmth evaluation experiment was conducted in an artificial climate chamber at a clothing college, and the subjects were asked to sit outside the chamber for about 30 minutes to stabilize their body temperature before the experiment. Temperature sensor probes were attached to the skin surface of eight parts of the subjects: forehead, left anterior chest, right upper arm, left lower arm, back of the left hand, right scapula, front side of the right thigh and back side of the left calf using medical tape. The subjects wore the same undershirt and air layer internally, and successively wore the electric smart thermoregulation garment and the normal cold-proof clothing. After the start of the experiment, the subjects entered the artificial climate chamber. The subjects were allowed to remain stationary for ten minutes to acclimatize to the cryogenic environment of the climate chamber and to allow the subjects to stabilize to a state of thermal equilibrium. The temperature of the chamber was set to -10°C, the humidity of the air was 50%, and the wind size was 3. The subjects were placed on a treadmill. Subjects walked on a treadmill for 30 min at a speed of 4 km/h. During the experiment, objective temperature data were recorded every 1 min, and subjects evaluated their subjective thermal sensation every 5 min.

4.2.2. Objective skin temperature analysis. Wearing the intelligent thermoregulation clothing designed for this experiment to turn on the heating function and not turn on the heating function and the average skin temperature of the commercially available cold-proof jacket is shown in Figure 7. Within ten minutes of the preparation stage of the experiment, all three states of the garment possessed a relatively stable warmth-keeping ability, and none of the skin temperatures dropped significantly, and were in the temperature range of 33℃-34℃, which was in the comfortable range according to the measurement and evaluation criteria. With the continuous application of cold air to the subjects, the subjects began to move, the air flow rate increased, convective heat dissipation increased, as well as the evaporation of sweat multiple factors, the average skin temperature decreased significantly, the three states of the garment body surface temperature there are large differences. In the heated suit with the heating function turned on, the change in body surface temperature was only a slight decrease, the magnitude was small, and the skin temperature was always more comfortable. In the state with the heating function turned off, the temperature dropped significantly, about 1.6℃ lower body surface temperature. In contrast, the skin temperature of commercially available warm clothing decreased by about 2.4°C. According to the data, this design of intelligent thermoregulation clothing has a good warming effect, and if the heating function is turned on, its warming effect is even better. It can be seen wearing intelligent thermoregulation clothing without heating function under the conditions of -10 ℃ after 30 minutes body surface temperature retention rate of 95.22%, under the same conditions of the commercially available cold weather clothing body surface temperature retention rate of 92.79%, both have a better thermal insulation ability can be used as a comparison of the experiments, the intelligent thermoregulation clothing to open the conditions of the heating function in the next 30 minutes body surface temperature retention rate of 98.35%, it can be assumed that the intelligent thermoregulation clothing to open the heating function in the next 30 minutes body surface temperature retention rate is 98.35%, it can be considered that the intelligent thermoregulation clothing compared to the commercially available cold-proof clothing has a better cold-proof effect.

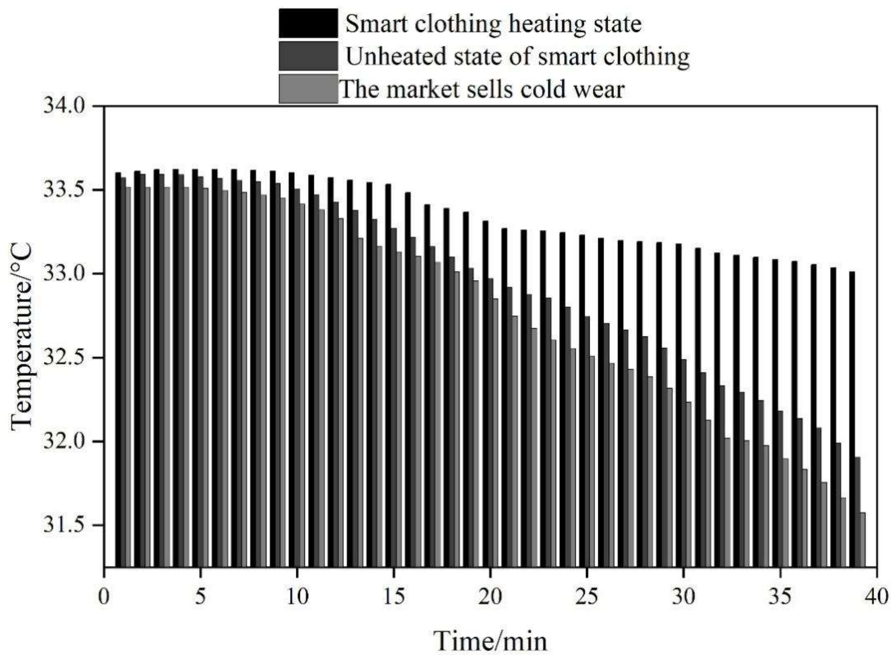

Fig. 7. Experimental comparison

IBM SPSS Statistics 26 software was used to analyze the data, and paired samples t-test was used to determine whether there was a significant difference between the test variables at each time point under the 2 kinds of garments, and the level of difference was set at $p<0.05$.

The experimental data were analyzed by SPSS, and the paired samples statistics of the ordinary garments and the intelligent thermoregulation garments are shown in Table 2, and the paired samples T-test is shown in Table 3. From 10min-39min, the correlation coefficient is 0.953, and the significance level is 0.000, which can be recognized as the interval can be confident, and it can be concluded that there is an obvious linear relationship between the temperature of these two garments.

Table 2. Paired sample statistics

		M	N	SD	Standard error of mean	Correlation coefficient	Sig.
Pair 1	Ordinary	32.76	30	0.5336	0.1362	0.953	0.000
	Smart clothing	33.36	30	0.1163	0.0362		

Table 3. Pair sample T test

	M	SD	Standard error of mean	95% confidence interval of the difference		t	df	Sig.
				Lower limit	Upper limit			
Ordinary- Smart clothing	-0.6	0.4236	0.0741	-0.9325	-0.6233	-10.365	36	0.000

4.2.3. Subjective evaluation. The subjective heat sensation rating scale categorizes heat sensation into eight levels: -2 is cool, -1 is slightly cool, 0 is comfortable, 1 is slightly warm, 2 is warm, 3 is slightly hot, 4 is hot, and 5 is very hot. Prior to the start of the test, the tester would explain the thermal sensation level criteria to the subjects. During the subjective evaluation test of the warmth of the smart thermoregulation garment designed in this paper, the subjective evaluation of thermal sensation was asked to the subjects at regular intervals and the relevant forms were filled in.

The statistical results of the data on subjective thermal sensation are shown in Table 4, with * representing a significant difference at the $p=0.05$ level of significance. The results of one-way ANOVA showed that activity status ($p<0.001$), heating method ($p<0.001$), body part ($p<0.001$), and heating time ($p=0.032$) had a significant effect on subjective thermal sensation of the body. As the heating method went from unheated to heated, the subjective thermal sensation of skin temperature increased from 0.54 to 1.96. Within-group comparisons showed that there was a significant difference in subjective thermal sensation between the heated and unheated states. When the activity state was walking, the subjective thermal sensation score was 1.51, which was higher than that of 0.96 in the standing state.The smart thermoregulation garment had a smaller effect on the skin temperature of the chest and abdomen, and a higher effect on the skin temperature of the back and waist. The longer the heating time, the higher the subjective thermal sensation score.

Table 4. Statistical results of subjective heat perception

Influencing factor		M	SD	Sig.
Active state	Standing	0.96	0.66	<0.001*
	Walk	1.51	0.73	
Heating mode	Non heating	0.54	0.52	<0.001*
	Heating	1.94	0.88	
Body part	Back	1.83	0.8	<0.001*
	Chest	0.77	0.73	
	Waist	1.06	0.42	
	Abdomen	0.79	0.36	
Heating time	5min	0.95	0.67	0.032*
	10min	1.15	0.67	
	15min	1.39	0.64	

5. Conclusion

The study uses BP neural network to optimize the PID controller parameters, and the designed temperature control system is used for intelligent thermoregulation clothing.
1) The self-tuning control algorithm of PID parameters based on BP neural network has a small amount of arithmetic and can stabilize the temperature near the set value in a short time.
2) Intelligent temperature-regulating garments have a better warming effect after turning on the heating function. Under the condition of -10℃, the temperature retention rate of the body surface is 98.35% after 30 minutes, which is 5.56% higher than that of ordinary commercially available cold-proof clothing, and it has a better effect of cold-proof.
3) Activity state, heating mode, body part and heating time have significant effects on the subjective thermal sensation of the human body. The subjective thermal sensation score is concentrated in the range of “0-2”, which indicates that the subjects are more satisfied with the temperature control effect of intelligent thermoregulation clothing.

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