A Novel Smart Textiles To Reflect Emotion

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Research Article

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Abstract

The present study designs a wearable smart device regarding relationship between temperature and emotion. The device, amplifies, and sub-regionally transmits the current generated by the body temperature thermoelectric generator through a smart body temperature sensor. Different areas of clothing produce controllable and intelligent color, so that adult emotions can be understood through changes in clothing colors, which is conducive to judging their moods and promoting social interaction. Experimental results show that the device can accurately detect changes in human body temperature under hilarious, fearful, soothing, and angry emotions, so as to achieve changes in clothing colors, namely blue, red, green, and brown.

Introduction

Wearable devices mainly refer to electronic devices that can be directly worn on people. They are electronic products that can be integrated into clothes or similar clothes. With the development of electronic technology, a system that can monitor sign data in real time begin to appear. For example, smart home can adaptively adjust settings in accordance with human emotions [1]. Physiological recognition can be carried out by using smartphone camera [2]. MIT's laboratory research shows that emotional states can be identified based on physiological data, including temperature, heart rate, skin conductivity and muscle activity [3,4]. This research utilizes wearable technology to integrate multimedia, sensors and wireless communication technologies, and manufactured implants or accessories that can be integrated into individual users' clothes or bodies for data collection and transmission.

Emotion recognition has an important impact on improving product interaction. In the past, we recognized human emotions through body movement or language communication [5-7]. For example, six different emotion tags are set first, and then the accuracy of subjective emotion recognition reaches 60% through speech [8]. After actors show different emotions through facial expressions, the accuracy of subjective emotion discrimination is 70% - 98% [9]. The accuracy of emotion recognition by computer through facial expression is 80-98% [10,11]. Through cross validation, 38-51% accuracy can be obtained in four facial EMG signals, such as happiness, sadness, anger and fear[12]. However, this audio-visual technology only uses the external expression of emotion and can not accurately judge people's inner feelings and emotions [13]. Therefore, numerous researchers began to use wearable devices to investigate the relationship between physiological changes and emotions. For example, heart rate can be used as an indicator of tension. Words with emotional color can lead to skin electrical response. Happy and unpleasant emotional words can cause skin point response. Unpleasant word stimulation can generate skin electrical response more obviously [14]. The measurement circuit can monitor the change of shortness of breath, and the amplitude and width of R wave in ECG waveform will change accordingly with the change of emotional state. By analyzing the collected respiration and average heart rate, the emotion data can be obtained from the characteristics of machine training according to the interaction between emotion and physiological signals. It is very valuable to study the relationship between physiological signals and emotions [15]. The biggest advantage of using physiological signals for emotion recognition refers to that vital signs are more related to people's inner feelings, because it requires the interaction between the autonomic nervous system [16]. Most emotion recognition needs to be realized by wearing sensors based on physiological signals [17-19]. However, this identification method has some obvious limitations. It uses sensors that need to be worn additionally, interferes with users' normal life, and is also not suitable for long-term and extensive use. Although ZigBee and Wi Fi signals can also be used to obtain human information and physiological signals can achieve the purpose of emotional perception, these systems require users to be close to the line of sight path. The combination of sensor design and fashion clothing design presents the trend of wearable development, which is smaller, smarter, more fashionable and more suitable for life.

Traditional wearable devices such as lithium batteries confront security problems such as leakage. Clean energy, especially electrothermal energy, has become the first choice for researchers. Numerous researchers believe that body temperature, as an important physiological index of human body, is of great value in the population [20]. Body temperature is a necessary condition for metabolism and life activities of the body. Moreover, it is an important physiological parameter of the human body and is of great significance in patient monitoring and clinical diagnosis [21]. The use of body temperature for emotional discrimination and the use of body temperature for dedicated hot spot power generation satisfy the research needs of sustainable development.

On the other hand, wearable technology needs the carrier of information presentation. Some researchers use Bluetooth transmission to monitor emotions through mobile phones. Some apply the monitor to detect the change of body temperature through radio communication. However, the utilization of multimedia equipment is not the best choice under the background of sustainable development. Researchers are looking for greener ways to present information. Houston discovered the temperature sensitive discoloration phenomena such as Cui in 1871. Then, it was developed by researchers. After that, a large number of temperature-sensitive discoloration materials, such as inorganic, organic, liquid crystal, and polymer ones, were widely used in industrial fields and people's daily life. Later, they began to be accepted by the fashion industry. For example, the Japanese Kanebo Company developed swimsuits made of temperature-sensitive and color-changing fibers, which could change colors on the shore, in the water, in the wild, indoors or even on the beach. It is due to the transfer of electrons in a certain temperature environment, resulting in different organic molecular structures and reinterpretation of colors [22]. In 2015, fashion designer Lauren Bowker used the high-tech psychedelic color clothing made of temperature sensitive and color changing fabric containing liquid crystal. As soon as the temperature changed, the color of the clothing surface changed, causing a sensation in the fashion industry.

Compared with the use of mobile phones to monitor body temperature or emotion, temperature change materials can be reflected in clothing patterns and colors, which is more intuitive and conducive to the benign development of social interaction. Traditional temperature-changing products are affected by the size of their thermal sensing areas. For most of them, the temperature of the external environment or the temperature change caused by artificial use of electric wind blowing should be considered. In fact, they have failed to make full use of the advantages and characteristics of temperature change products.

To sum up, this design studies a thermoelectric generator that absorbs people's body temperature, then identifies the current through the body temperature sensor, expands the current, disperses the power generation, and finally reflects the different body temperature on the clothing pattern coated with temperature change pigment. Based on the relationship between emotion and body temperature and the characteristics of temperature variable materials, fashion clothes can reflect people's immediate emotion under the concept of environmental protection and sustainability.

Materials

2.1. Thermoelectric generator

Wearable thermoelectric generators that use temperature difference to generate electricity can directly convert heat into electricity. There are two main types of wearable thermoelectric devices. One type is made of flexible thermoelectric materials such as polymers. Due to the low ZT value of polymer-based thermoelectric materials, the output power per unit area of such thermoelectric devices can be on the order of $0.1\mu W/cm^2$ or even lower. The other refers to flexible thermoelectric devices made of rigid inorganic thermoelectric materials connected with flexible fillers or flexible electrodes. Thermoelectric materials are printed on glass fiber to develop a power generation device that can generate electricity from body temperature [23]. The power generation device can use glass fiber and inorganic materials to reduce heat loss and add power output. The device is thinner (about 500μm thick) and lighter (about $0.13g/cm^2$ area density). On this basis, in order to collect human body heat, the researchers developed a flexible wearable thermoelectric generator based on flexible printed circuit board and 52 pairs of thermocouples. The generator has good output performance and can supply power for sensors [24].

In this study, a thermoelectric generator is applied, which contains a prototype of self-powered electronic system in the form of an arm ring tied to the arm. When the body temperature is above 35 degrees, the generator collects heat from the skin, which can be converted into electricity. Thermoelectric generators produce voltages from 2V to 5V. It has three special orders of voltage stabilizing input, temperature measuring bridge and amplifier circuit, which can satisfy the needs of charging devices such as mobile phones and will not cause harm to human body.

2.2 Organic reversible temperature-sensitive powder

Organic reversible temperature-sensitive powder, dominated by electron-transferred organic compounds, refers to an organic chromaticity. It consists of an electron donor, an electron acceptor, a regulator, a sensitizer and other solvents. Between the electron giver and the electron acceptor, the phenomenon of electron transfer occurs due to the change of temperature. In the process of electron transfer, the color change of certain wave is absorbed or radiated. Meanwhile, the long light composed of the hidden color dye, color developer and color-changing temperature control solvent appears to produce the reversible color-changing microcapsule (Table 1). The thermochromic capsule changes color by sensing heat, and the color-changing process is in a range, rather than at a point. The corresponding color-changing colors of different components of the thermochromic pigment are displayed in Table 1. There are many organic reversible thermochromic materials, which can be classified into triarylmethane phthalides, indoline phthalides, fluoranes, triphenylmethane, spiropyran, spiroring, dianthrone, α-naphthoquinone derivatives and so on. According to its composition, it is divided into two categories. One is a single-component temperature-sensitive color material. It's dominated by a single substance; Another is a kind of multi-component compound temperature discoloration material, the temperature change powder used in this study. It is a multi-component compound type temperature discoloration material. Its advantages include wide temperature discoloration range (20 ~ 200℃), obvious discoloration, bright color, high color sensitivity, and low production cost.

Table 1. Temperature change effect

Discoloration material	Discoloration change
$NiNH_4PO \cdot 6H_2O$	Bright green → Grey blue
$NH_4 \cdot VO_3$	White → Brown
$Cd(OH)_2$	White → yellow
$Fe_4[Fe(CN_6)]_2$	Blue → Brown
$Pb\ CO_3$	White → yellow
$Co\ C_2O_4$	Powder → black

2.3. Temperature sensor

The temperature sensor bases on the preparation of NTC thermistor to realize the body temperature recognition and analysis. The different voltage is transmitted to different areas of the garment through the 300D/3 conductive sewing thread. In order to control the discoloration of the material with temperature change, the electrothermal conversion is carried out by the conductive wire.

With NTC thermistor as body temperature sensor, energy conversion can be realized when temperature changes. NTC therminors can work stably for a long time and have a long life after being tested with high precision, high sensitivity, high reliability, super high temperature and high pressure. Featured with light weight, flexibility and low cost, they can be easily integrated on the surface of various flexible substrates or embedded in them. The operating temperature of NTC thermistor is -55°C-125°C, and the normal body temperature of human body is 36°C-37℃(measured in armpit). The highest and lowest body temperature of living human beings recorded are 46.5°C and 13.7°C, respectively. Obviously, the working temperature of NTC thermistor is suitable for human body temperature measurement. MT series medical NTC thermistor has a diameter of 5mm, and a dissipation coefficient of /2(mW·°C-1). Thermal time constant is 3.5s, which is relatively small. Rated power ≤20mW. B value is 3695-4262, which is cost-effective. The amplifier circuit in the temperature sensor uses THE OP07 chip of TI company, which sends the thermistor into the amplifier circuit through the output voltage of the bridge with the change of the human body temperature. The sensor needs to encode with the computer in advance and preset the voltage value corresponding to the temperature, aiming to prepare for the subsequent control of temperature change and color conversion. Body surface temperature of exposed parts such as wrist and forehead vary with environmental temperature [25]. The temperature sensor should be close to thearea of human body that strongly sweats, the heart position at the intersection of the connectinglines of the centers of forechests and underarms, so as to improve the accuracy of body temperature recognition.

SHN MARK grey 300D/3 sewing thread was used in this study, containing polyester and stainless steel fiber (Figure 1). It is antistatic and has conductive properties. Conductive sewing thread is used as a conductive connection to the sensor. It is an insulated thin wire, with heat prevention, durability, and extreme softness. Safety risks will not appear because of long-time work. In the sewing process, a z-shaped overlap mode (Figure 1) is adopted to sew between the two layers of fabric, and the sensor electrodes are connected at both ends.

Considering the fabric smoothness and physiological data monitoring sensor pin number, straight-line parallel connection is used as wiring connections (Figure 2). 4 silver conductive sewing threads are utilized. Sewing process parameters are set to the best spacing of 1 cm. They are parallelly sewn into the selected fabrics, respectively with a temperature sensor, the corresponding 4 pins and docking. Sensors are connected at one end, and the other end connects control module and power module. The flexible connection between garments and electronic components is realized by the detachable bolt interface.

2.4. Non-woven

Table 2 shows the anti-static performance results of non-woven fabrics. The anti-static performance is tested according to GB/ T12703.1-2008 "Evaluation of Electrostatic Properties of Textiles, Part 1: Static Voltage Half-Life", GB/ T12703.3-2009 "Evaluation of Electrostatic Properties of Textiles, Part 3: Charge Quantity", GB/ T12703.4-2010 "Evaluation of Electrostatic Properties of Textiles, Part 4: Resistivity".

Table 2. Fabric Composition

Fabric	Silver fiber	Polypropylene	Polyester fiber	Test result
Non woven fabric	9.4%	84.6%	6%	The fabric has been washed for many times, and the results meet the corresponding standards

2.5 Fashion design

The design of wearable clothing is often limited to the design rationality of clothing materials and wires, ignoring the unity of fashion and function. Based on 2021-2022 Autumn/Winter Fashion Trend Style Guide, this design adopts the deconstruction design style in the sweating areas of human body (breast center, alar the heart on the horizontal line intersection point), aiming to design a asymmetric pocket (removable and convenient for cleaning). Temperature sensors are also placed near the temperature thermoelectric generator (in the form of arm ring, tied to the arm). The length of the wire is shortened. The left and right versions of the clothing are asymmetrical, which is consistent with the overall style (Figure 3). The design of the temperature-changing pattern is inspired by the work of Dutch painter Mathijs Vissers, which is a complicated painting without any specific emotional tendency.

□-□ for the pattern drawn with warm pigment, the four areas correspond to four different emotions, namely relief, fear, laughter and anger (Figure 4).

□This study informed consent was obtained from the picture model.□

2.76Circuit Design

The material components involved in the temperature change area include thermoelectric generator, temperature sensor, some alligator clips, some jumper wires, bread board, diode, transistor, organic reversible temperature change powder, conductive sewing thread and hot melt film.

The specific experimental steps include:

Step 1: After the design drawing of clothing effect drawing is completed, the garment CAD plate making is carried out according to the effect drawing.

Step 2: Print the DXL file of garment CAD plate making, create the plane plate making and cut into slices.

Step 3: The organic reversible temperature-sensitive powder is first added with water to turn into temperature-sensitive pigment, and the pattern is drawn on the surface of the non-woven fabric after being cut.

Step 4: Complete the stitching of the entire garment, including pockets and other parts, and put the temperature sensor in a strap bag on the chest.

Step 5: Finish stitching the arm ring and connect the conducting wires.

Step 6: Calculate the length range of the conductive sewing thread at each position; Sew the conductive sewing thread on the painted back, and the interlayer between the face cloth and the lining cloth. If the sewing thread is exposed from the front because of the thin fabric, sew the sewing thread on another suitable fabric, and then glue the two fabrics together with hot melt film.The connection sequence of conductive wires is shown in Figure 5: port 1 of conductive sewing thread – thermoelectric generator – Port 1 of temperature sensor, port 9 of temperature sensor – breadboard, port 1 of temperature sensor – breadboard – port 2 of conductive sewing thread, and temperature sensor – diode and transistor are connected to the breadboard.

Step 7: The temperature change region is programmed into the temperature sensor program, and the voltage is obtained according to the following algorithm.

Experimental / Methods

In the context of sustainable development, this study designs a fashion garment that can detect adult emotions based on the development of intelligent wearable, as well as the principle of the relationship between emotion and body temperature. The garment uses thermoelectric generators to convert heat from the skin into electricity, which drives the temperature sensor to generate electricity. The temperature sensor detects the change in the temperature of human body, and controls the currents of different magnitudes to flow into different regions as temperature changes. Additionally, the electric current of different sizes will show different colors through the pattern of the temperature change pigment, thus reflecting the change of people's mood. The experiment was divided into several different stages (Figure 6):

The first stage: The thermoelectric generator collects the body temperature and converts it into a voltage of 2V-5V according to the different body temperature.

The second stage: The body temperature signal is collected through the body temperature sensor, and the voltage of different 2V-5V is transmitted to the conductive sewing threads in different areas □ and □ on the clothing (Figure 6).

The third stage: The conductive sewing threads of different voltages present different temperatures, and the graphs drawn by the temperature sensitive pigments feel the temperature, aiming to carry out different color rendering in different areas of the clothing.

After conducting the basic experiment, the test experiment was carried out. In the test stage, 50 college students watched short videos with different emotional themes in groups to stimulate the subjects to obtain the data of emotional changes and temperature changes with the aim to test the effectiveness of the product.

All the methods mentioned above were carrried out in accordance with Sanda University relevant guidelines and regulations. The steps and specifications of this experiment were approved by the Sanda University ethics committee. Informed consent was obtained from all the subjects for participation in the study as well as for publishing their identifying information in an online open-access publication

3.1. Temperature and emotion classifier

When the emotional state changes, it will cause changes in the body temperature. Emotion is closely associated with body temperature. In different emotional states, there is an asymmetry in the changes of body temperature, which can affect the base level of skin resistance. Both finger and head temperatures are lower in fear than in anger, and skin resistance levels are higher in fear than in anger. Body temperature is a physiological signal that changes extremely slowly. It is of necessity to design a classifier before emotion discrimination, that is, to distinguish the physiological characteristics of several emotions to be studied. Based on the existing literature, a classifier of body temperature and emotion was designed in the present study. In the pre-test stage, a relatively introverted and inexpressive college student was found, and his daily activities were tracked and recorded. In addition, the changes of his physiological parameters were collected in real time. Moreover, the real emotional state was analyzed according to the behavioral expressions and dialogues in the videos. The former was tested and the classification system standards were adjusted based on the data of the latter (Table 3).

Table 3. Comparison table of body temperature and emotion

Region	Temperature	Electric current	Discoloration	Emotion
□	36.0°- 36.3°	2v-5v	Blue - green	Soothe
□	36.4°-36.7°	2v-5v	Dark green - rose	Fear
□	36.8°-37.1°	2v-5v	Black - orange	Hilarious
□	37.2°-37.5°	2v-5v	Black - red	Anger

3.2 Experimental data preprocessing

Experiment process as Figure 7 show. The experiment was conducted from January 10 to January 28, 2021. The experiment subjects were 50 college student volunteers aged between 18 and 25.

At the beginning of the experiment, the subjects were determined to be in a gentle mood through consultation and observation. Besides, the initial body temperature was measured to be between 36.0℃and 36.3℃. Once the experiment began, a student was invited to put on the costume and go into a single room to watch a short video on a computer every 15 minutes, with a random choice of themes. The color changes on the clothing were observed with an automatic camera. Immediately after watching the video, the subjects were asked to fill out a questionnaire about their emotions, and directly describe their moods with words.

The researchers had to isolate themselves in another room and select three to five college students whose responses to external stimuli were clear with their data as a base sample.

Results

After collecting 50 sets of temperature data under these four emotions, the graphs were made respectively (Figure 8).

Due to factors such as sensor wearing position, measurement error and energy metabolizer problems during human activities, data deviation may be caused. Therefore, it is of necessity to conduct significant difference test on 50 groups of samples first. T test can be used to detect the deviation degree of samples. The row data was fitted using the sinusoidal function HBS. The results were presented in Table 4, and no significant difference was found in all the data.

Table 4. Variance and accuracy of smart clothing

emotion	variance	Discrimination accuracy
Hilarious	0.025	91．8%
Anger	0.036	87．1%
Soothe	0.0107	80．2%
fear	0.021	84．7%

Mood 50 group is the actual results that correspond with the students. According to the findings, under the condition of the products in this study, the color rendering accuracy of joke team is 91.8%, and that of anger team is 87.1%. It is 80.2% for soothing team, 84.7% for the fear team (see Table 3). The results of this experiment confirmed that the product has certain practical value, it can reflect the changes of human body temperature and mood under certain environment and conditions.

Discussion

With the development of textile and garment technology, sensor technology and communication technology, there are a lot of research achievements of intelligent wearable at home and abroad. Nevertheless, the technology of industrial application is limited. High cost, durability and comfort need to be optimized, which are the internal factors restricting intelligent wearable. Based on the background of sustainable design, this study designed a wearable intelligent device from the perspective of environmental protection. Through absorption, body temperature is converted into electrical energy. This improves special temperature sensor identification, amplifies thermoelectric generator current signal, transfers machine management areas, and makes the temperature pigment clothing according to different temperatures, and intelligent chromogenic reaction in different areas in the clothing. Thus, adults' emotions can be understood through the color changes of the designed clothing.

Conclusion

The simulation results show that the product can accurately detect the temperature change of people under the emotions of laughter, fear, relief and anger, so as to realize four different color changes of clothing including dark red, light red, dark blue and light blue. The product is conducive to adult health judgment and social development. Additionally, it is also suitable for the monitoring and detection of the elderly and infants. Under the special background of COVID-19, the product has certain practical significance.

However, current research also has limitations. To be specific, more studies should be performed on conversion rate, circuit design and waterproof performance. Industrial application be achieved only after commercial testing.

Declarations

Author Contributions: Conceptualization, Dai Jingyu and Duan Ling; formal analysis, Dai Hongyu.; writing—original draft preparation, Dai Jingyu and Xie Yutong; writing - review and editing, Dai Jingyu and Duan Ling;All authors have read and agreed to the published version of the manuscript.

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Figures

Figure 1

Conductive wire and pattern sample

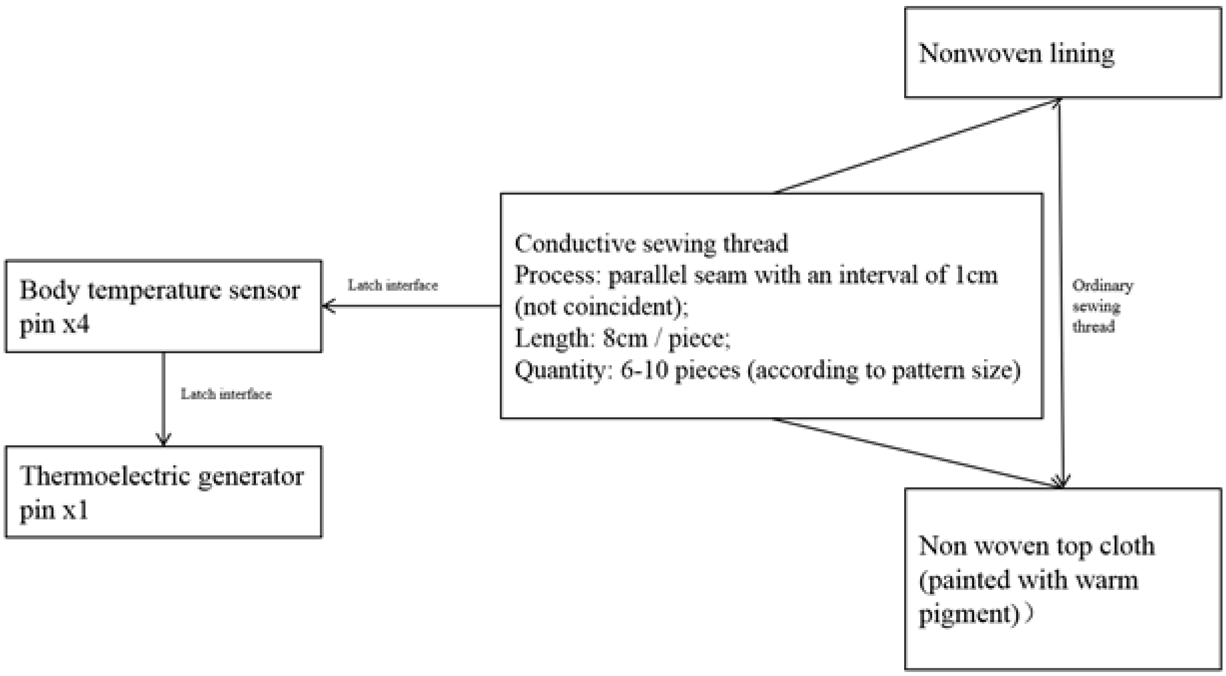

Figure 2

Installation flow chart

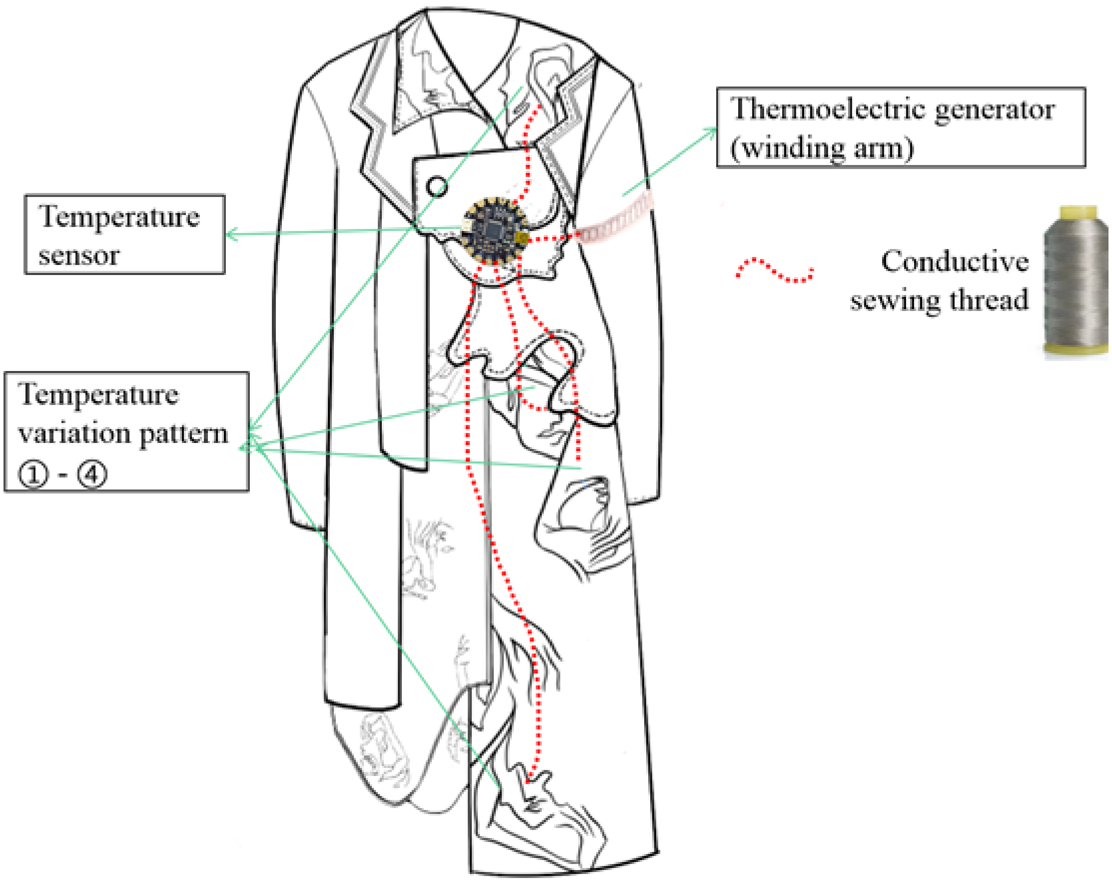

Figure 3

Clothing style structure diagram

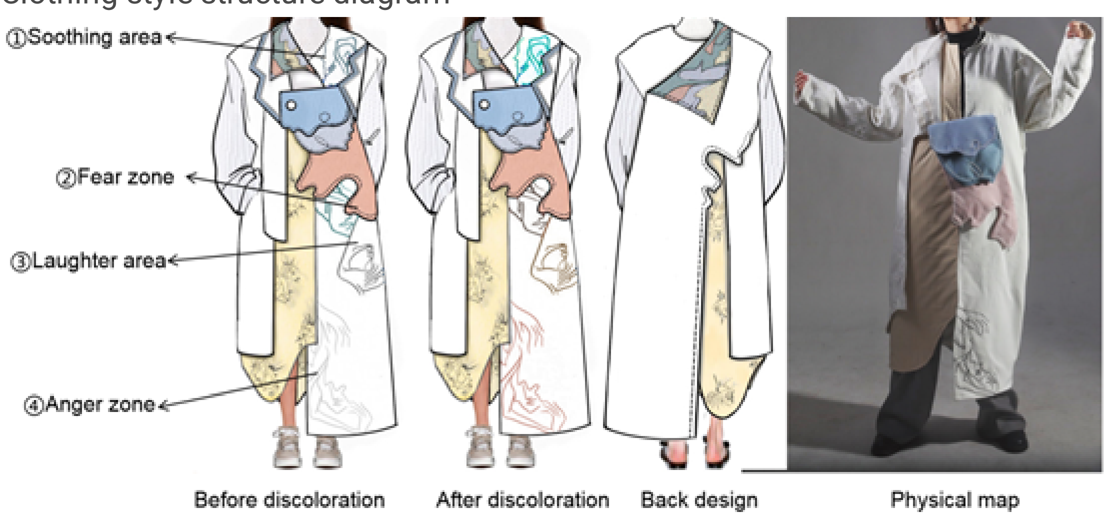

Figure 4

Clothing style drawing and physical drawing

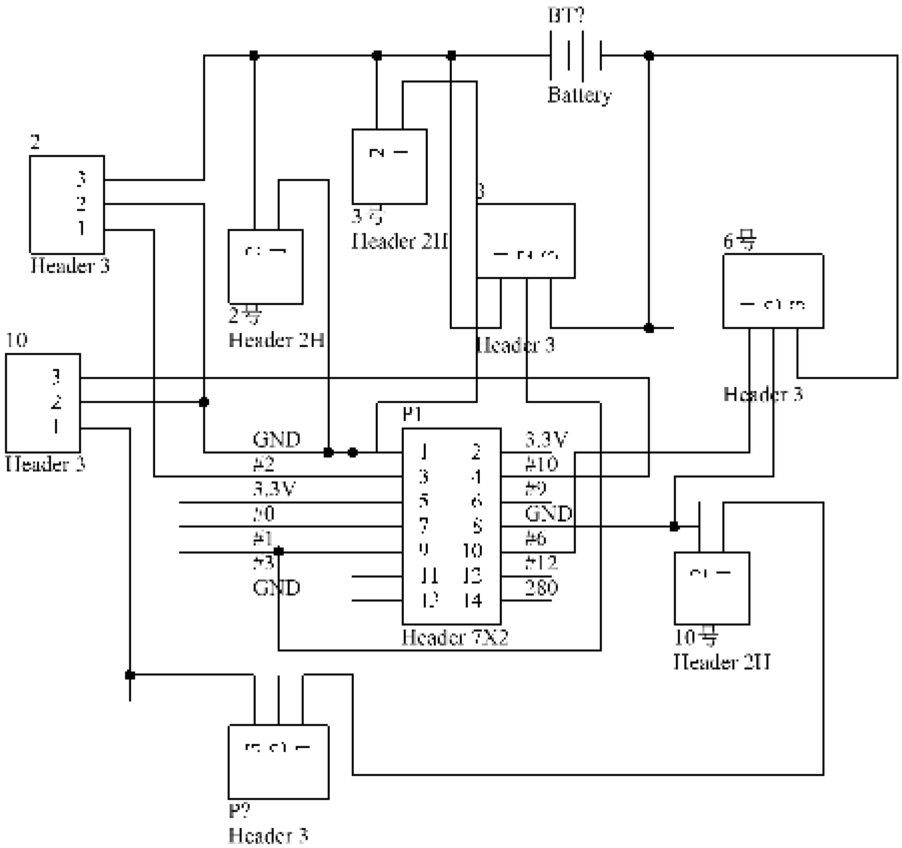

Figure 5

Circuit Flow Chart

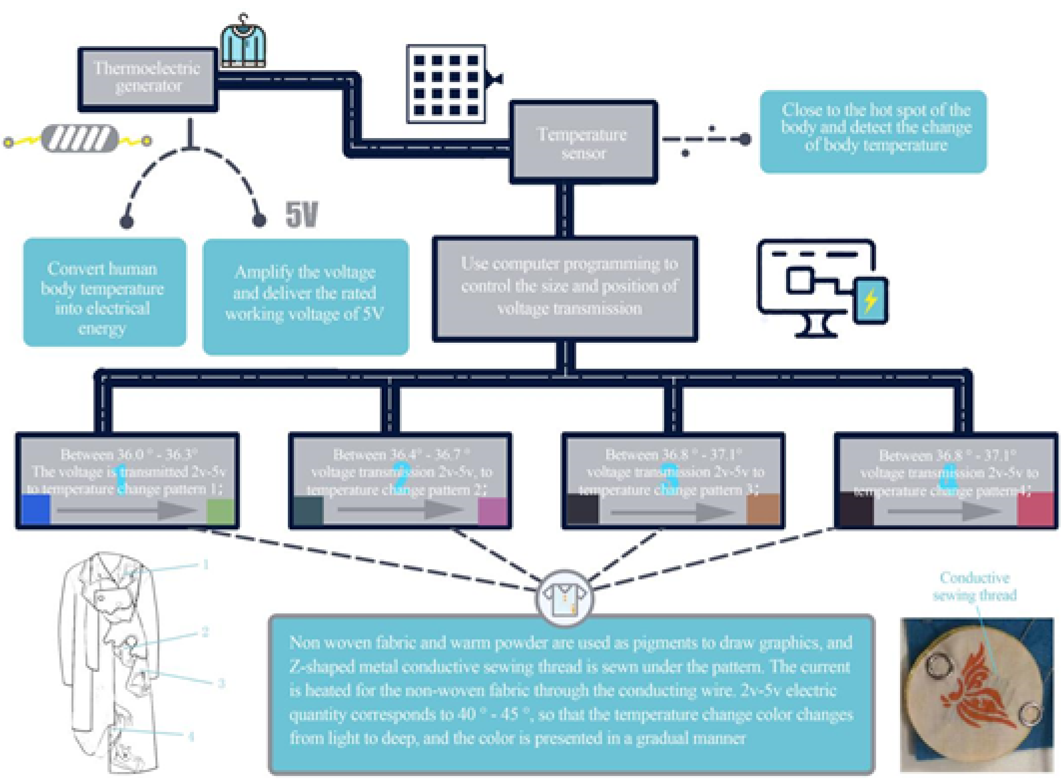

Figure 6

Overall experimental process

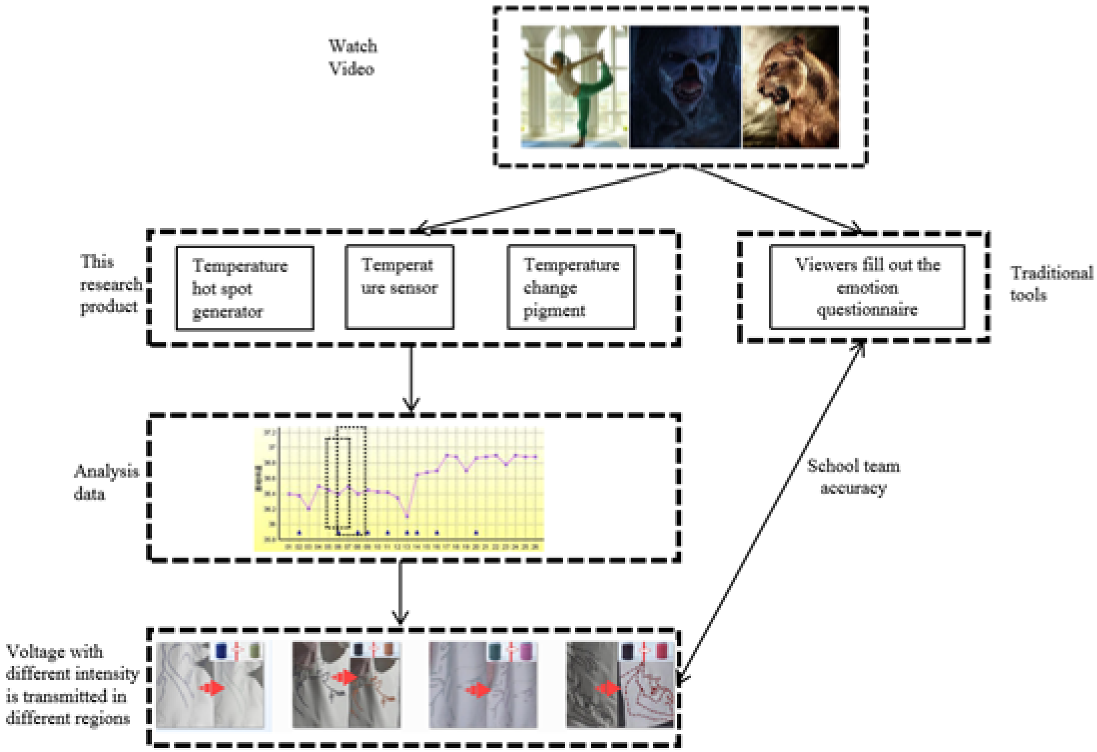

Figure 7

experimental flow

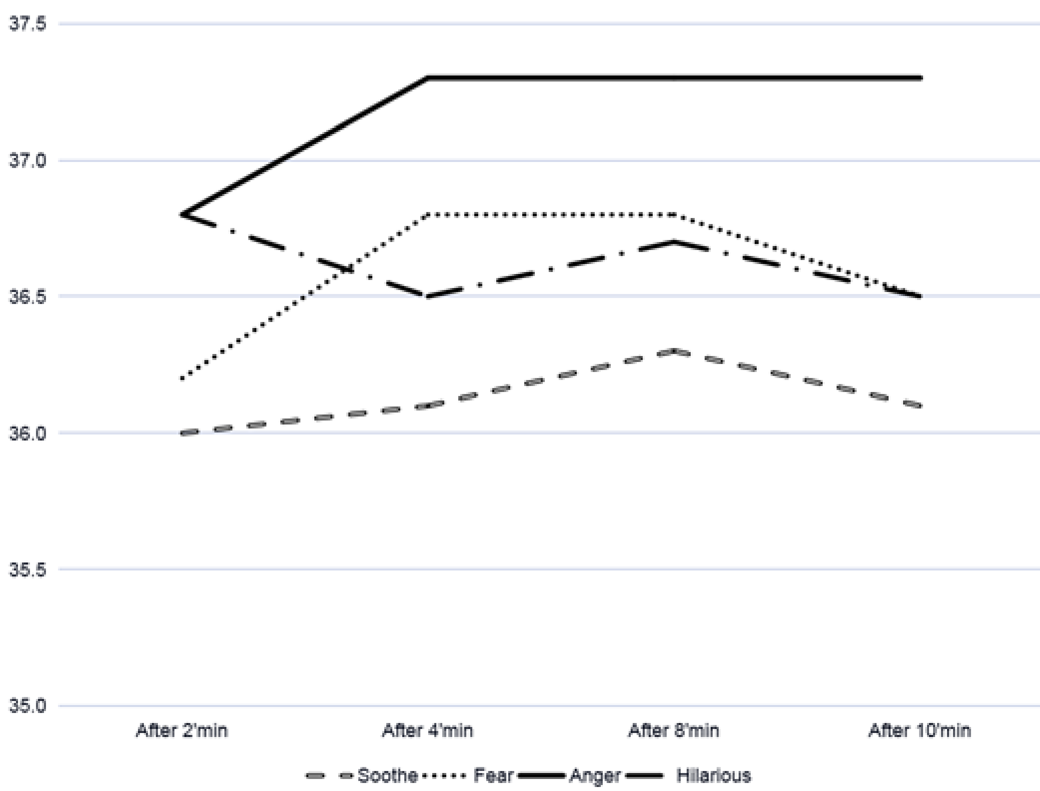

Figure 8

Temperature change effect