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The Novel Human Temperature Regulation Mobile Wearable Sensor and Algorithm

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Abstract: Keeping body temperature is important to maintain vitality, improve immune function, and keep blood flowing smoothly. If there is any abnormality in thermoregulation function, body temperature should be regulated artificially. The wirelessly rechargeable wearable smart body temperature sensor in this study uses a Peltier element to regulate the temperature of the whole body by inducing a temperature change to a specific body part. As a result of inducing the temperature change by operating on the wrist when body temperature fluctuation caused by the surrounding temperature, the average increase rate of the 100 experimental data was 33.5 %, the standard deviation was 25.5 %, the average fall rate was 1.6 %, and the standard deviation was 0.7 %. The developed wearable smart body temperature induction sensor will help the body temperature control of various diseases such as elderly people and cholinergic urticaria, whose voluntary thermoregulation is limited or body temperature change is adversely affecting the body.

Keywords: Temperature sensor, Wearable sensor, Peltier element.

1. Introduction

Body temperature refers to the temperature of the body, which is the energy that occurs when body nutrients are burned by intracellular oxidative metabolism. Humans maintain a certain body temperature through the thermoregulatory function, and the normal body temperature of human body is approximately 36 to 37 °C. Body heat is always produced in the body and this heat is constantly being lost to the outside from the body surface. Thus, in order for the body temperature to remain constant, a balance must be established between the heat produced in the body and the heat lost to the surrounding environment. Heat production methods include basic metabolism and food intake, muscle movement, involuntary tremor, thyroid hormone (thyroxine), and stimulation of sympathetic nerves, etc. On the other hand, heat dissipation is caused by radiation, conduction, convection, and evaporation as physical phenomena that exchanges heat with the surrounding environment.

When the body temperature is 37 °C, not only the vitality and immune function is improved, but also the blood flow gets better. So, it is important to maintain the normal body temperature. If the body temperature drops by 1 degree, the immunity decreases by 30 %. A drop in body temperature can increase the risk of cancer as well as viral disease. When the body temperature drops, the heart rate cannot be normalized, it tends to be irregular, and the secretion of hormones is significantly lowered. Therefore, the overall muscular athletic ability and metabolic ability are greatly reduced. Maintaining the standard temperature is crucial for the patients with cholinergic urticaria whose body temperature increase can be lethal. According to the Ministry of Health and Welfare, if the patient is presumed to have hypothermia, maintenance and elevation of body temperature are the most important. However, if trying to warm up the cold hands and feet with hot water or a hot pack, the cold blood may move to the heart and the body temperature may dramatically decrease. Therefore, action should be taken to increase body temperature throughout the body. As the body temperature falls, blood vessels contract and the blood supply decreases. As a result, the heart will move faster to raise the decreasing body temperature, which can cause increase of the blood pressure and overload of the heart. Therefore, in hypertensive patients, there is increasing possibility of collapse by cerebral hemorrhage due to rapid increase of blood pressure. Thus, the importance of maintaining normal body temperature and controlling body temperature can be confirmed.

The ultimate center of thermoregulation to maintain body temperature is the hypothalamus in the diencephalon. Under the control of the diencephalon hypothalamus, the amount of heat generation in the body and the amount of heat dissipation through the surface of the body is regulated by negative feedback action. After the thermoregulatory center receives the information about the body surface and the body core temperature and analyzes it, it plays a role of keeping the body core temperature stable by generating appropriate reaction to the effector. Methods of thermoregulation include neural control, skin control, sweat gland control, and behavioral control.

2. Trend of Temperature Control Sensor

As described earlier, maintenance and regulation of body temperature are closely related to several diseases. Techniques using the thermoregulatory mechanism above are increasing to prevent the onset of illness and to make daily life convenient. Most of them are artificial thermoregulatory devices, which regulate body temperature using body temperature of the local region.

The cold and hot pad device for thermoregulation controls the body temperature by using a body temperature sensor to measure the body temperature, and cooling/heating the water through the thermoelectric module, and circulating it to the pad part. If a temperature abnormality occurs and the user sets the body temperature increase/decrease mode, the water temperature of the pad part is lowered/raised by the thermoelectric module. Therefore, by controlling the operation of the cooling /heating section and the circulation pump individually in accordance with the change of the body temperature, the body temperature can be raised or lowered to maintain the normal body temperature precisely.

As another device, the portable hypothermic therapy device can perform hypothermic treatment in which the body is cooled by the thermoelectric element included in the pad part to maintain the hypothermic state. In addition, the hypothermic therapy device including the pad part is portable, so immediate hypothermic treatment can be performed. In this case, since the body temperature of the patient is measured through the control system and the temperature of the thermoelectric element is controlled, the effect of the treatment can be improved by continuously maintaining the low temperature state.

Third, there is a wearable thermoregulatory device that maintains the body temperature of a user constantly by adjusting the current application method. It regulates the user’s pulse by using a principle of thermoreceptors in the body to apply a constant current to the user's skin. By allowing the skin to feel as if it releases or absorbs heat, the body temperature can be kept constant throughout.

In this study, we aimed to regulate the body temperature of a user by developing a wearable smart thermoregulatory sensor, and by applying the cold side and hot side of the Peltier element to the local region.

3. System Configuration

3.1. Peltier Element

As shown in left picture in Fig. 1, when applying DC voltage to both ends of two different elements by using a thermocouple principle, one side of the Peltier element absorbs heat to form a cold side while the opposite side becomes hot by generating heat. This is called the Peltier Effect. In addition, the Peltier element serves as a heat pump that absorbs heat to the lower temperature side and releases heat to the higher temperature side to push the heat away from the lower temperature side toward the higher temperature side.

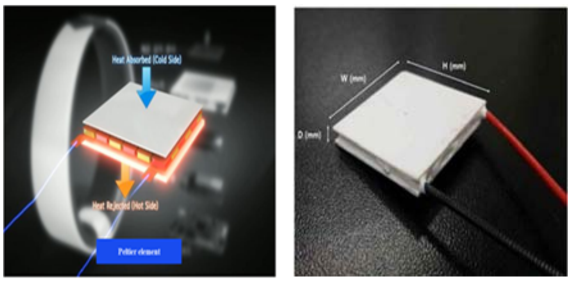

Fig. 1. Left: Principle of operation of a Peltier element, Right: A Peltier element used in the sensor.

The Peltier device is a semiconductor device that can freely cool, heat, and control temperature because it changes the direction of the heat pump and amount of current when the polarity of the current changes. The reasons for choosing a Peltier element in this experiment are that it can be manufactured to any shape desired due to its small and light properties, it reacts quickly to temperature change, and it has the longest life and reliability as a cooling means because it does not suffer mechanical fatigue or damages the parts. The right picture in Fig. 1 is the Peltier element used in this study, and its size is 30 mm (Width) × 30 mm (Height) × 3.16 mm (Depth).

In this study, to investigate the temperature change of the heat generating part and the endothermic part of the Peltier element, the electrode of the Peltier element was connected and then a voltage of 12 V was applied through the power supply. A thermal imaging camera and the software FLIR ResearchIR were used to measure the temperature rising or falling due to the applied voltage. As shown in Fig. 2, the temperature change of the Peltier device was confirmed through image, data and graph in real time through the FLIR ResearchIR connected to the camera while photographing the Peltier element with the thermal camera.

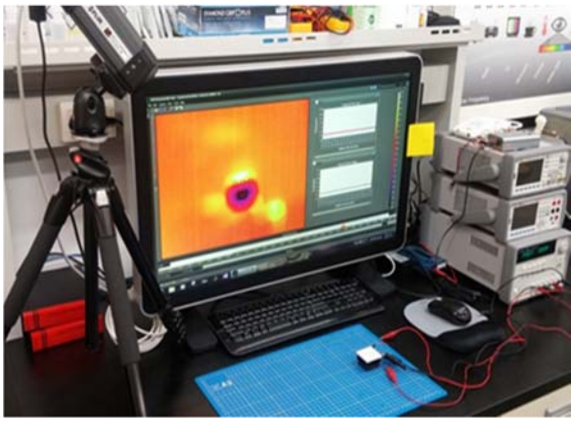

Fig. 2. Temperature measurement of Peltier Element.

The Peltier element is a thin plate in which both sides function as a heat absorbing /heat generating part respectively. When the voltage is applied, the endothermic part absorbs the surrounding heat, and falls below the room temperature. On the other hand, the heat of the endothermic part and the lost electrical energy all radiate from the heat generating part and usually soar up to more than 100 °C.

Fig. 3 below shows the Peltier element measured using a FLIR thermal imaging camera. (1), (2) is the heat absorbing part of the Peltier element, (3) is the Peltier element which is not applied current, and, (4), (5) is the heating part of the element. When the voltage was applied to the Peltier element, it was confirmed that the temperature of the heat absorbing part was lowered to 23.8 ℃ and then 21.9 ℃ from the original 26-27 ℃. It was also confirmed that the temperature rises to 45.3 ℃ and then 60.1 ℃ according to the time.

If the heat generation of the Peltier element itself cannot be solved, it is necessary to solve this problem because it becomes hot regardless of the heat absorption/heat generation part. As shown in the left graph of Fig. 4 below, the Peltier element without heat dissipation increases the temperature of the endothermic part gradually by the exothermic part even if the temperature of the endothermic part initially falls. Therefore, to dissipate the heat of exothermic part of the Peltier element, a heat sink and a fan are attached to dissipate the heat to the surroundings to solve the heat generation of the Peltier element itself. As shown in the right graph of Fig. 5, we succeeded in lowering the temperature rise of the endothermic part to below 15 °C.

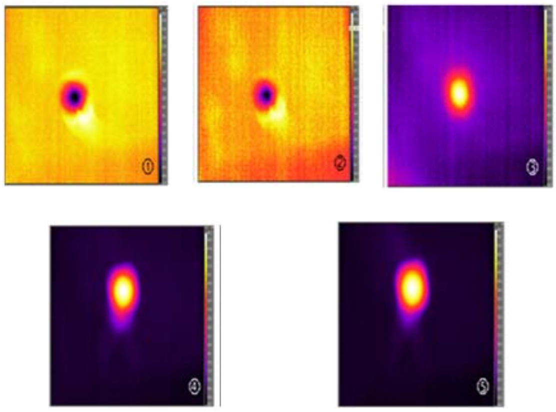

Fig. 3. Heat absorption and heat generation of Peltier element photographed by FLIR thermal camera.

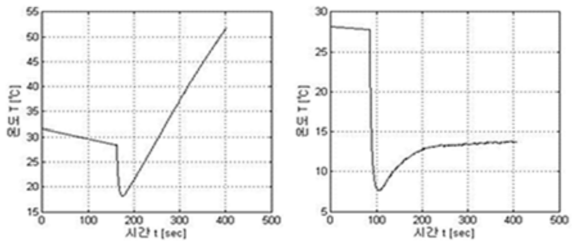

Fig. 4. Left: Heat absorption of Peltier element Right: Exothermic temperature graph.

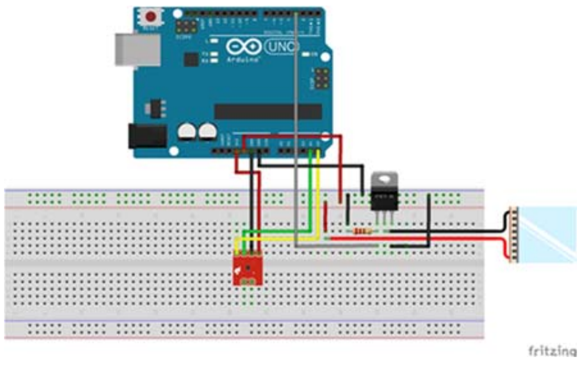

Fig. 5. Control of Peltier device through temperature sensor.

3.2. System Control

In Fig. 5, Peltier element was controlled through a digital temperature sensor to run it to the user's body temperature. The principle is that the temperature sensor is operated to measure the ambient temperature, and when the temperature rises above the set temperature due to the ambient environment in the non-operating state of the Peltier element, power is supplied to the Peltier device to be run. In addition, in order to prevent overheating, the operation cycle was set by stopping operation for 5 seconds after temperature change for 5 seconds.

The thermoregulatory wearable device is a thermoregulatory device that can raise or lower the body temperature according to changes in the body temperature to maintain a normal body temperature. The thermoregulatory device includes a sensor for measuring the user's body temperature, a cooling unit/heating unit including a thermoelectric module for switching the cooling/heating direction according to the applied power polarity, a body temperature measured from the temperature sensor, and a control unit for controlling the operation of the cooling unit / heating unit according to the body temperature measured from the body temperature sensor and the body temperature set.

When the body temperature is higher than the body temperature set by the sensor attached to user's body, the device worn on the user's wrist is set to the body temperature lowering induction mode, the cooling operation of the cooling/ heating unit of the device is activated and the body temperature is induced to the set body temperature set value. On the other hand, when the body temperature is lower than the set temperature by the sensor attached to the body of the user, the device worn on the wrist of the user is set in the body temperature rise induction mode, and induces the body temperature set by activating the heating operation of the cooling / heating part of the device.

3.3. Feedback Control

Feedback control plays a control role in reaching a certain output constantly by inputting a certain signal. As shown in Fig. 6, if a signal is more or less than the required value for the output when a signal is sent to the output Y (s) from the input R (s), it is returned to H by a large amount (s) when it exceeds the target value of the output in the circuit diagram G (s) When the target value is insufficient, the amount sent from G (s) to H (s) is added again to G (s), and sends a certain amount of target values to Y (s). In other words, it is an automation system in which a system continuously detects changes in the external environment or changes in its own system, thereby eliminating the error itself.

In Fig. 8, when the feedback control system is applied to the wearable thermoregulation sensor, R (s) can be the desired normal body temperature, G (s) is the body. Y (s) is the body temperature, and H (s) is the temperature sensor. When normal body temperature starts to rise, it is detected by a temperature sensor. And then the wearable thermoregulatory device is operated while the desired body temperature R (s) is continuously inputted, controlled by the temperature sensor H (s) and the body G (s) until the body temperature Y (s) reaches the target value.

3.4. Feedback Control

As shown in Fig. 9, the left picture is a wearable smart body temperature sensor developed in this study. The size of this sensor is 240 mm (length) × 68 mm (width) × 35 mm (height). The front part of the sensor has a power switch and a switch that can set the temperature rise and fall. The back side of this sensor touches the skin, which has a digital temperature sensor and a Peltier element for heating and cooling. As shown in the right picture of Fig. 7, the sensor is designed to be worn on the user's wrist in the form of a watch.

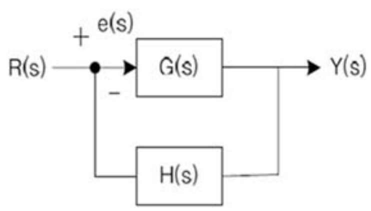

Fig. 6. Feedback control system.

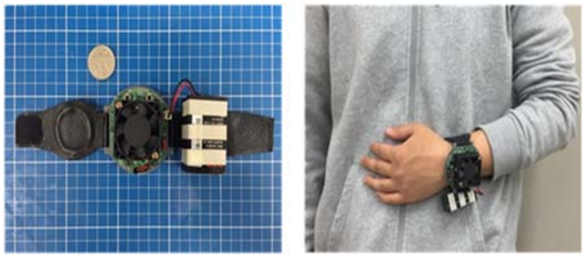

Fig. 7. Left: The wearable heat and cool stamp sensor, Right: Wearing the proposed sensor.

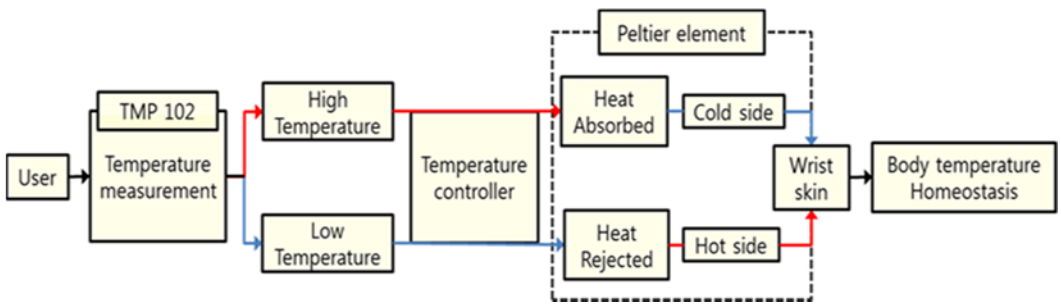

Fig. 8. The block diagram of the proposed method.

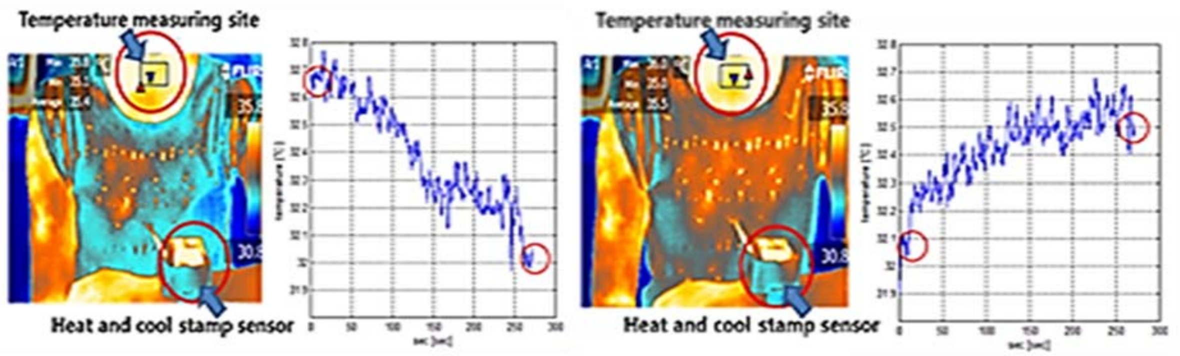

Fig. 9. Left: The result of the induction mode for lowering temperature Right: The result of the induction mode for raising temperature.

The developed wearable smart body temperature sensor works as shown in Fig. 8. It is Arduino based, and it measures the current body temperature with the digital temperature sensor TMP 102 at the wrist site directly touching the body. The value measured is converted into data and compared with the reference temperature on the main board. In the case of abnormal body temperature, the Peltier element is driven to control the temperature of the user by applying heating and cooling to the wrist. A heat sink and fan were attached to prevent overheating. In addition, it includes a wireless charging module and a wireless communication module, enabling wireless charging and wireless communication.

4. The Experiment

4.1. The Experimental Method

In this experiment, experiments were carried out with windows or doors closed, excluding all devices that could affect temperature except for the device. The power of the Peltier element and the fan was 3 V and 10 V, respectively. Subjects were 100 healthy college students and each subject was selected to participate in the experiment regardless of gender, age, or physique. In the experiment, two experiments were performed, and the body temperature of the subject is made abnormal by the external environment before the experiment. In the first experiment, the subject stayed outside for at least five minutes to decrease body temperature before starting. After this, when the body temperature is lower than the set temperature, the sensor worn on the user's wrist operates in the body temperature rise induction mode. Heat is applied to the hot side to increase the body temperature and control the body temperature. The second experiment is to raise the body temperature by raising and lowering the stairs to create a higher body temperature before starting, and then the sensor operates in the body temperature lowering induction mode if the body temperature is higher than the set temperature. It is cooled by the cold side to lower the body temperature.

4.2. Results and Discussion

The sensor was operated on the wrist, and the heat was applied to the finger and neck. The mean value of the finger and neck region was measured to minimize the undulation of the temperature change that deviated from the measurement site through the movement of the subject.

As a result of inducing body temperature drop and rise by using developed wearable smart body temperature induction sensor, both resulted in changes in body temperature of the user. Fig. 11 shows the first clinical trial. The left picture shows that the body temperature is lowered when cooling the wrist of a person with a high body temperature, and in Fig. 9, the right picture shows that the body temperature rises when heating is applied to a person's lower wrist.

As shown in Fig. 10, when the temperature change is compared at the time of the sensor being unattached and attached, it can be confirmed that the sensor induces the rise and fall to cause a change in body temperature.

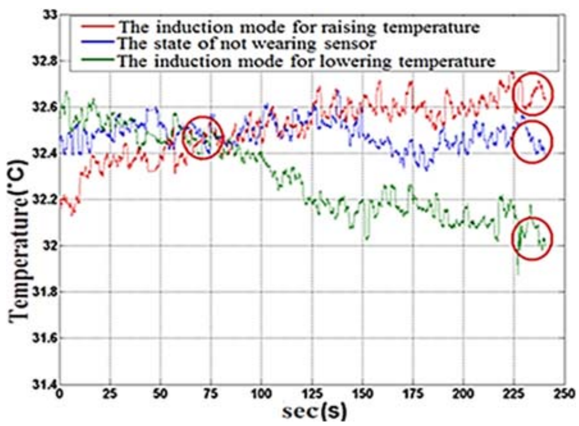

Fig. 10. The rate of temperature change with or without sensor.

Experiments were conducted on the subjects after confirming that the sensors induce the rise and fall and change the body temperature. Fig. 11 is a photograph of a thermal camera and a graph of the FLIR

ResearchIR program that induced the abnormal body temperature rise and fall for 300 seconds by the developed wearable body temperature induction sensor. Left induces the user's body temperature rise, and right induces the user's body temperature drop. On the left is the user's photo before and 300 seconds after using the sensor through the thermal camera and temperature induction can also be confirmed with the changes in the color of the hand. It also can be seen that the graph gradually rises for 300 seconds at the starting temperature. Right confirms that the user's body temperature is gradually lowered. Through this experiment, 100 pieces of data were collected.

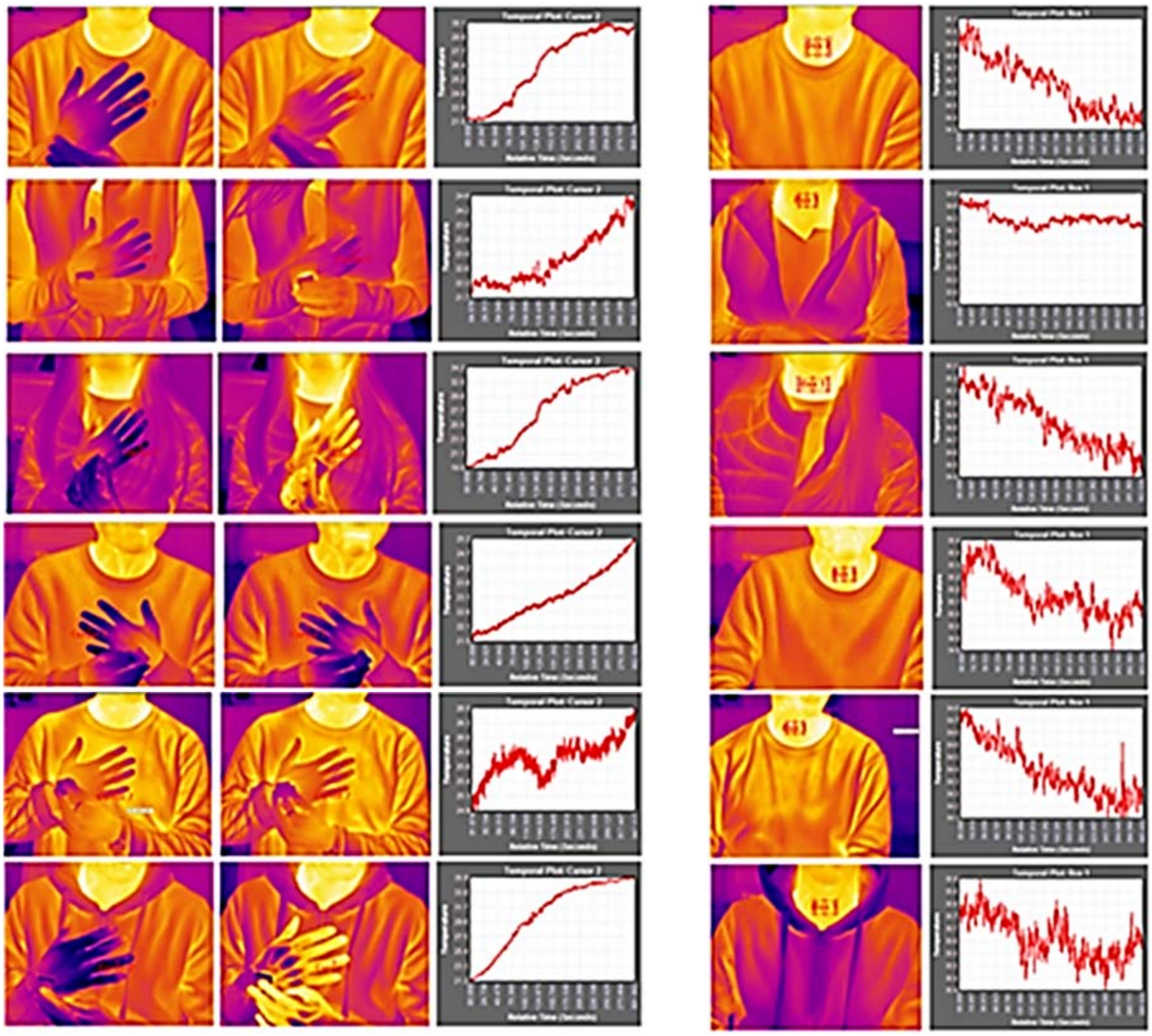

Fig. 11. Left: Induction of body temperature increase, Right: Induction of body temperature decrease.

Fig. 12 shows the changes in body temperature for 300 seconds of the user in 100 experimental values as the rate of increase and decrease. The highest rate of increase data was 86.1 % with a change from 18.7 °C to 34.8 °C. The lowest rate of increase data was 1.2 % with a change from 24.6 °C to 24.9 °C with an average rate of 33.5 % and a standard deviation of 25.5 %. The highest drop rate in data was 3.5% with a change from 34.1 □ to 32.9 □ and the lowest drop rate data was 0.6 % with a change of 34.5 □ at 34.7 □ with an average fall rate of 1.6 % and a standard deviation of 0.7 %. It was confirmed that the wearable smart body temperature induction sensor of this experiment adjusts the temperature of the entire body by inducing a temperature change to the body limited to a specific region.

As a result of the experiment, the large standard deviation in the rate of increase is considered to be due to the difference in the experiment start temperature of the subjects and the subject's ability to regulate body temperature.

The lower fall rate does not seem to be significantly deteriorated by the fact that the starting temperature starts from the normal body temperature range and the body temperature is lowered by the sensor, thereby generating heat in the body to maintain the body temperature. It is necessary to carry out precise research according to the starting temperature of the experiment and the ability of the subject to control the body temperature.

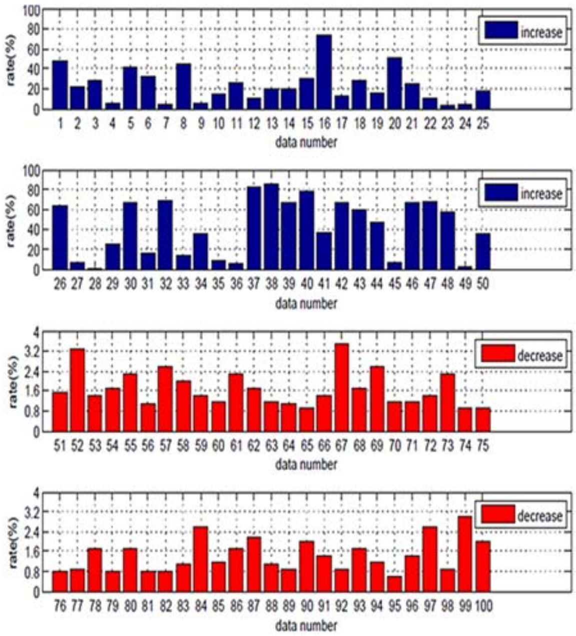

Fig. 12. The temperature change rate of 100 pieces of experimental data, Blue bar: The increasing of the induction mode for raising temperature, Red bar: The decreasing of the induction mode for lowering temperature.

5. Conclusion

Keeping body temperature is important to maintain vitality, improving immune function, and keeping the blood flowing smoothly. Therefore, if there is any abnormality in thermoregulation function, body temperature should be controlled artificially. In this study, Van Hoff's law, a typical method to artificially control body temperature, was used to adjust the body temperature of the user by applying the cold side and hot side of the Peltier element to the local region.

The developed wearable smart body temperature sensor is based on Arduino and measures the current body temperature with the digital temperature sensor TMP 102 at the wrist part directly touching the body. The value is converted into data and compared with the reference temperature on the main board. In the case of abnormal body temperature, the Peltier device is driven to control the temperature of the user by applying heating and cooling to the wrist. A heat sink and fan were attached to prevent overheating. Also, wireless charging and wireless communication including wireless charging module and wireless communication module were implemented.

As a result of clinical experiments using the wearable smart body temperature induction sensor implemented as described above, it was confirmed that the body temperature was maintained or arbitrarily changed by 100 pieces of data.

The developed wearable smart body temperature induction sensor will be useful for managing the body temperature of elderly and patients with various diseases such as cholinergic urticaria, whose voluntary body temperature is limited or body temperature change may have a deadly effect on the body.

Acknowledgements

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