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Development of Thermal Sensor to Simulate Human's Contact Temperature Sensation

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Abstract. In this study, a new temperature sensor was prototyped with the goal of giving a robot the same temperature sensation as a human's. In order to measure temperature under conditions closer to human skin, we created a sensor with body temperature not found in previous temperature sensors. The sensor incorporates a Peltier element to provide body temperature and PVDF film to measure temperature changes. The voltage value obtained from PVDF film was compared with the subjective evaluation value when a person touched the object, and it was confirmed that it had similar characteristics. Moreover, compared with the result measured in the state which does not have body temperature, without controlling by a Peltier device, it has confirmed that it had the characteristic close similar to a human subjective evaluation value. Creating a sensor with body temperature would be effective for simulating the human temperature sensation.

1. Introduction

In recent years, in order for robots and humans to coexist, research has been conducted to give robots the same feeling as humans. On the other hand, the mechanism by which humans sense temperature is not yet fully understood. When a person touches different objects of the same temperature, for example 50°C, he/she may feel differently, "warm" or "hot", depending on the material of the objects. This difference cannot be detected by currently available temperature sensors, which gives the result of 50°C, "the same temperature" regardless of the material. In other words, currently available temperature sensors cannot recognize the difference in human temperature sense.

Making use of the pyroelectric property of Polyvinylidene difluoride (PVDF), Wang et. al. proposed a temperature sensor using PVDF film to imitate human temperature sensation [1]. It is confirmed that the sensor can provide not only information about temperature difference between the sensor and an object that the sensor contacted, but also information about the thermal properties of the object. Aiming to better simulation of a human's contact temperature sensation, in this study, by adding body temperature to our previous sensor, we propose a new temperature sensor that simulates and realizes human contact temperature sensation.

2. Sensor Structure and Measurement System

2.1 Sensor Structure

As a principles of heat conduction, it is known that the amount of heat flux that moves from a high temperature part to a low temperature part in a uniform object changes depending on both the high temperature part and the low temperature part of the object. Therefore, it would be possible to measure under conditions closer to that of the human body, and we prototyped a sensor that had the same body temperature as a human, and that was not found in existing temperature sensors.

Peltier element, which is a kind of thermoelectric element, was used for temperature control to give body temperature. PVDF film was used to measure temperature change when in contact with the object.

A prototype sensor structure is shown in Fig. 1.

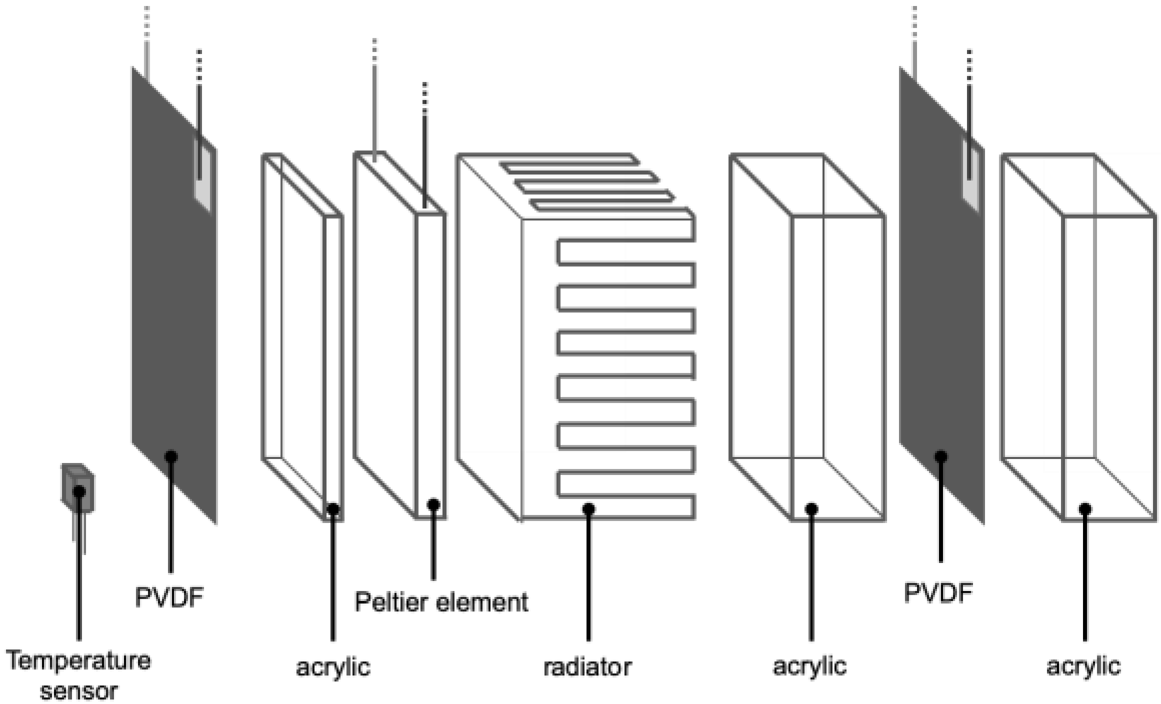

Fig. 1. Sensor Structure

The upper part of the PVDF film of the size of 40 [mm] in width and 50 [mm] in length with the temperature sensor attached is the contact surface with the object. Temperature sensor is used for feedback control of the Peltier element. Peltier element of the size of 40 [mm] in width and 40 [mm] in length and a radiator of the size of 40 [mm] in width and 40 [mm] in length were installed on the back side of the PVDF film to keep the body temperature. In addition, an acrylic plate of the size of 40 [mm] in width, 40 [mm] in length, and 2 [mm] in thickness was placed between the PVDF film and the Peltier element so that the feedback control value did not change abruptly when contacting the object. Another PVDF film of the size of 40 [mm] in width and 50 [mm] in length sandwiched between an acrylic plate of the size of 40 [mm] in width, 40 [mm] in length, and 10 [mm] in thickness was placed on the back of the radiator for pressure detection.

2.2 Measurement System

A schematic diagram of the measurement system is shown in Fig. 2.

First, the temperature of the sensor is stabilized at 30 [℃] as the temperature of the human hand by the sensor controller created with microcomputer board (Arduino Uno, Arduino Co.) and PWM driver (MD13S, Cytron Technologies Co.). After the stability is confirmed, the actuator (ES4-12-0200B-TS/35P-D00-S3, THK Co.) is moved by the actuator controller (TSC-015B-MOD-ES4-12-D, THK Co.) to bring the object into contact with the sensor. The amount of movement of the actuator at this time is adjusted in advance so that polarization due to pressure does not occur in PVDF film. After touching for 1 second, separate the object from the sensor. The sensor output waveform at this time is measured by a data recorder (EZ7510, NF Co.) through a charge amplifier (4001B-50, Showa Sokki

Co.) and a low-pass filter (3628, NF Co.).

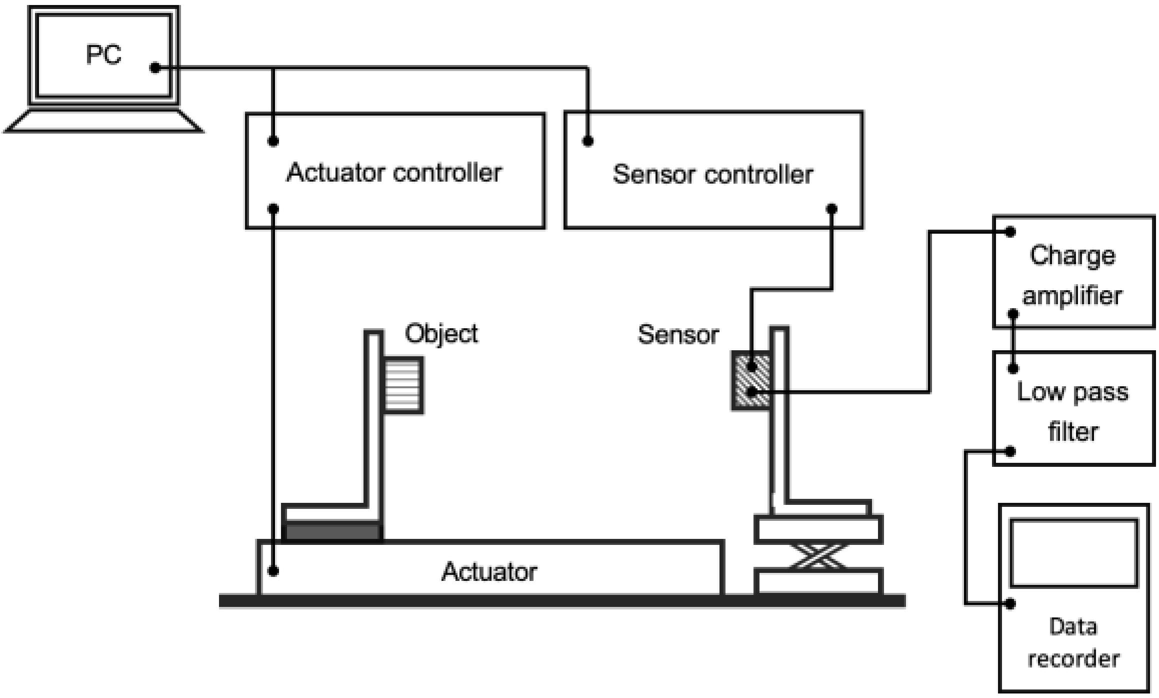

Fig. 2. Measurement system overview

3. Experiments

With the measurement method shown in 2.2, the PVDF film output waveform was recorded when the material and temperature of the object were changed. As objects to be measured, a block having the same volume (40 × 50 × 20 [mm]) made of seven kinds of materials such as aluminum, copper, brass, stainless steel, PET, PE, and PVC was used. The temperature of the objects was set as from 10 [℃] to 50 [℃], at intervals of 5 [°C]. The temperature during the experiment was maintained at about 25 [℃].

4. Result

An example of the result is shown in Fig. 3 and 4.

Fig. 3 shows the measured waveforms when the temperature is set to 50 [°C] for a block of seven types of materials. It was confirmed that even with an object at the same temperature, the sensor output voltage varies depending on the material. In particular, it was confirmed that the voltage of the metal changed greatly compared to the non-metal.

Fig. 4 shows the measured waveforms when the temperature of the block made of aluminum was changed for the sensor. It was confirmed that if the temperature of the object is higher than the temperature of the sensor, the voltage is positive, and if the temperature of the object is lower than the temperature of the sensor, the voltage is negative. It is also previous that absolute value of the sensor output voltage increases with the difference between the temperature of the sensor and the objects. Further, it was confirmed that almost no change in voltage was observed when the temperature of the object and the temperature of the sensor were the closest 30 [°C].

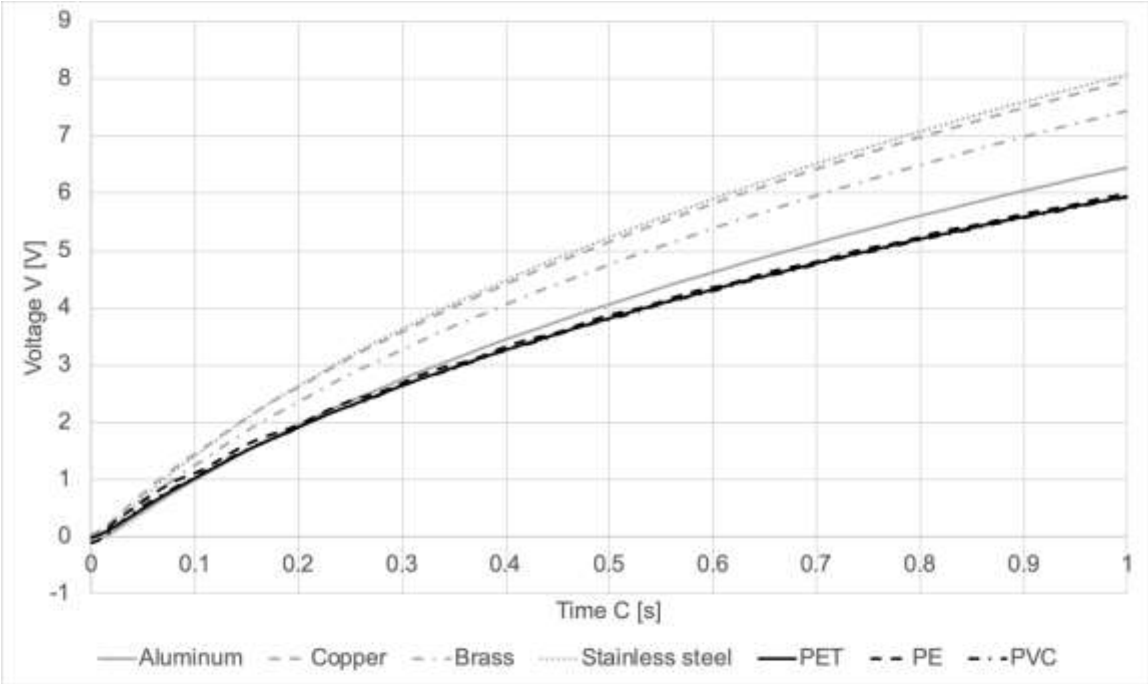

Fig. 3. Contact waveform with objects of 7 kinds of materials at 50 [℃]

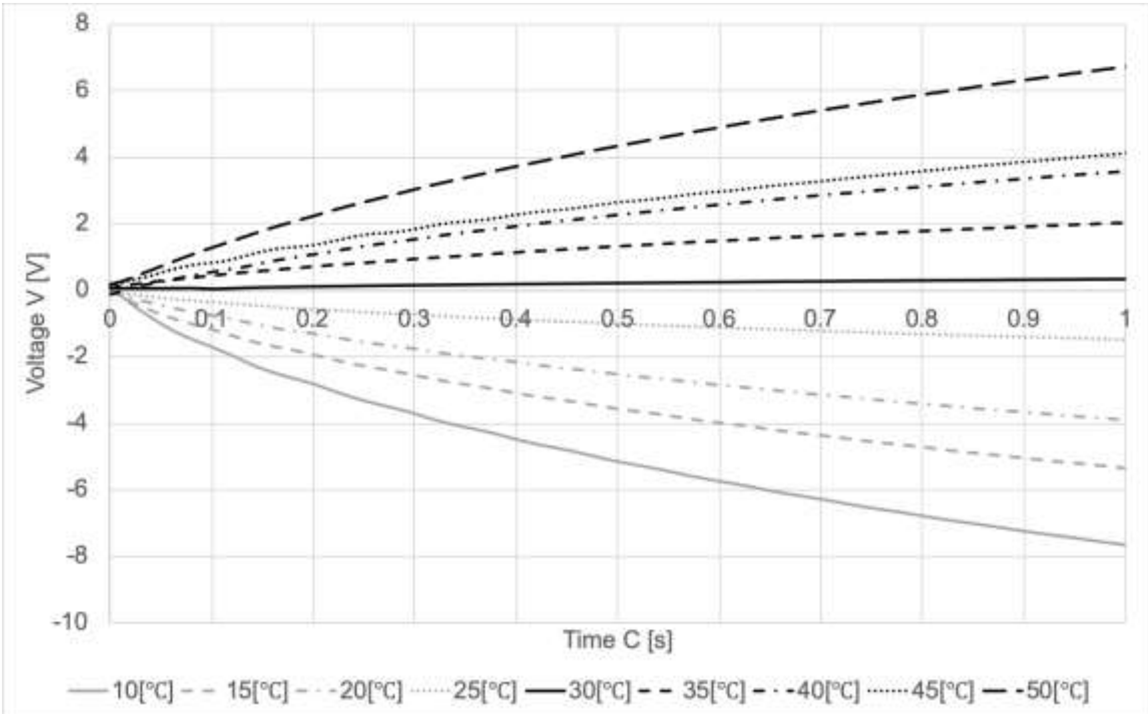

Fig. 4. Contact waveform with aluminum at different temperatures

For the sensor having a body temperature, a graph in which the maximum value of the measured voltage is plotted on the vertical axis and the temperature of the set object is plotted on the horizontal axis is shown in Fig. 5. It was confirmed that the voltage value of the approximate line was close to 0 at the temperature of 30 [℃] for the measurement with body temperature.

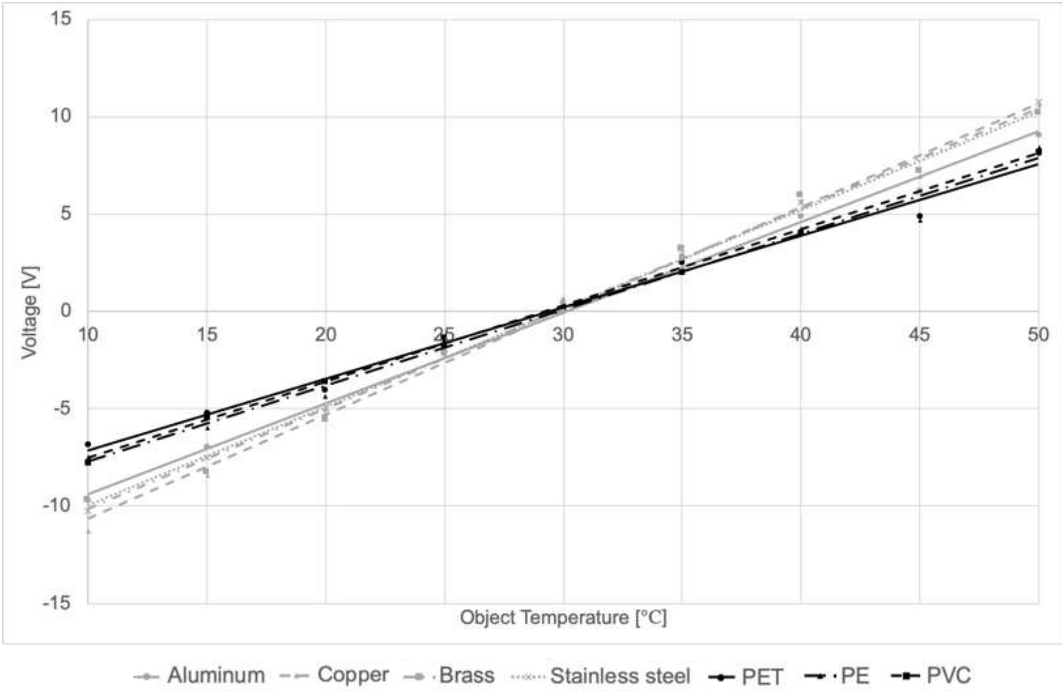

Fig. 5. Relationship between sensor output voltage and object temperature

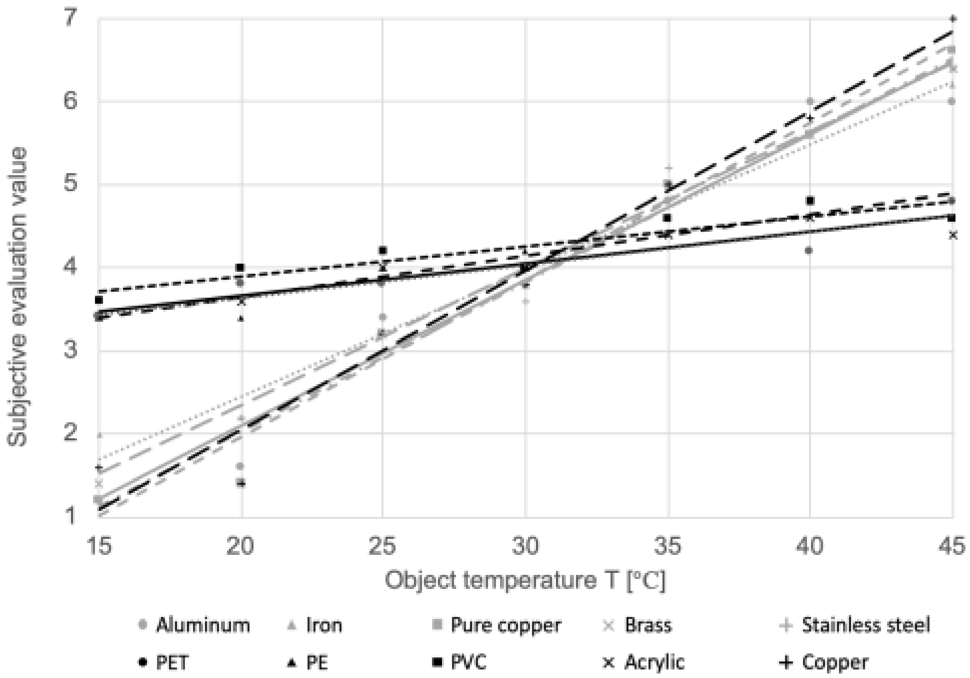

Fig. 6. Relationship between object temperature and subjective evaluation value

5. Discussions

For comparison, a graph in which the subjective evaluation value when a person touches the same object with a fingertip is plotted on the vertical axis and the temperature of the object is plotted on the horizontal axis is shown in Fig. 6. [2] The subjective evaluation was recorded as a numerical value from 1 to 7 based on the NRS, with the lowest value of 1 indicating “very cold” and the highest value of 7 indicating “very hot”. In the subjective evaluation, it was confirmed that the approximate straight line was closest to 4 "no warm or cold" at 30 [℃] near body temperature.

The results of Fig. 5, and 6 were compared, and it was confirmed that the voltage of the metal changed greatly compared to the non-metal. In addition, about 30 [℃], which is close to the human body temperature, the approximate straight line is closest to 0V in the sensor with body temperature, and the approximate straight line is closest to "not warm or cold" in the subjective evaluation. Therefore, the sensor with body temperature made this time made it possible to measure under conditions closer to the human body.

In our previous report, sensor output was 0 when the sensor and the object were at the same temperature. This means the sensor provided information of the temperature difference between the sensor and the object, as well as the thermal properties of the object. By adding a body temperature to the sensor, not only temperature difference, but also absolute temperature of the object as well as the thermal properties of the objects can be obtained.

6. Conclusion

Based on the results obtained this time, the technique of giving the sensor the same body temperature as that of a human is effective in simulating human contact temperature.

Acknowledgements

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References

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