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Invited Paper

Development of a Thermal Sensor Imitating Human Tactile Temperature Sensation

Feng Wang[1, a], Yuri Chiba[2, b], and Nobuaki Nakazawa[3, c]

[1]Faculty of Engineering, Maebashi Institute of Technology, 460-1 Kamisadori-Machi, Maebashi City, Gunma, 371-0816, Japan

[2]Graduate School of Engineering, Maebashi Institute of Technology, 460-1 Kamisadori-Machi, Maebashi City, Gunma, 371-0816, Japan

[3]Faculty of Science and Technology, Gunma University, 29-1 Hon-Cho, Oota City, Gunma, 373-0057, Japan

[a]<f.wang@maebashi-it.ac.jp>, [b]<m1756006@maebashi-it.ac.jp>, [c]<n.nakazawa@gunma-u.ac.jp>

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Abstract. This paper proposes a new type of thermal sensor that imitates human tactile temperature sensation, that is, unlike presently existing temperature sensors that only evaluate temperature, the proposed sensor can evaluate thermal properties such as thermal conductivity, thermal capacity, etc. of an object it touches, as well as the temperature of the object. By making use of its pyroelectric property, PVDF (Polyvinylidene difluoride) was used as sensitive receptor of the sensor. Testing experiments were carried out with objects made of six kinds of materials of different thermal properties. Relationship between sensor output and temperature of objects, and between sensor output and thermal properties of the objects were discussed in the paper. The results suggest that the proposed sensor can imitate human tactile temperature sensation.

1. Introduction

Super ageing society like Japan faces many serious social problems, one among them is the shortage of labor force, especially in health care and welfare field. Fortunately, recent advancement in robotics and AI technologies makes it possible that this shortage be filled up by human friendly health care and welfare robots interacting and cooperating with human beings. For a health care or welfare robot to interact and cooperate with the human beings, possessing the same sensations of human beings is of great importance. Towards the realization of human friendly robots, many researches have been done on robot-human interactions, and many efforts have been made in the development of sensors, especially tactile sensors for robotic application [1~5]. However, in the tactile sensor research field, an important subject has been neglected and seldom dealt with, that is, tactile temperature sensation [6]. At present, although various kind of temperature sensors are available, they only measure the temperature of an object. Image that when a human being touches two blocks at the same temperature of 50°**C**, he/she may feel 'hot' for an iron block, but 'warm' for a wooden one. That means that a human being's temperature sensation depends not only on the temperature of an object he/she touches, but the thermal properties such as thermal conductivity, thermal capacity, specific heat, etc. of the object [7]. However, a robot equipped with any existing temperature sensor feels simply the same temperature of 50°**C**. Therefore, such a robot, if used in health care or welfare application, cannot be regarded as a human friendly robot, in some cases it may even endanger or harm a human being whom it is supposed to care.

Keeping these in consideration, in this study, we proposed and developed a new type of temperature sensor imitating human tactile temperature sensation, that is, not only detect temperature of the object it touches, but also the thermal properties of the material of what the object is made of.

2. Sensor structure and measurement system

2.1 Sensor structure

PVDF (Polyvinylidene difluoride), a kind of polymer well-known for its piezoelectric property, is often used in tactile sensors [2, 8, 9], and for in-sleep cardio-respiratory monitoring [10]. In this study, making using of another property of PVDF--pyroelectric property, we tried to develop a temperature sensor which imitates human tactile temperature sensation.

A sheet of PVDF film of the size of 8 mm in width and 12 mm in length and 0.028mm in thickness is used as sensitive receptor in the study. It is glued on an acrylic plate with a thickness of 2 mm as sensor protrusion, the plate is fixed to an acrylic board using as the sensor base (Fig. 1).

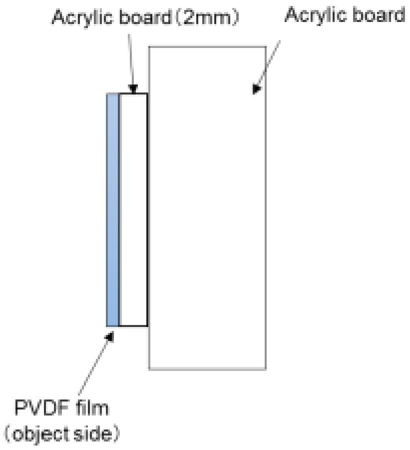

Fig. 1. Sensor structure.

2.2 Measurement system

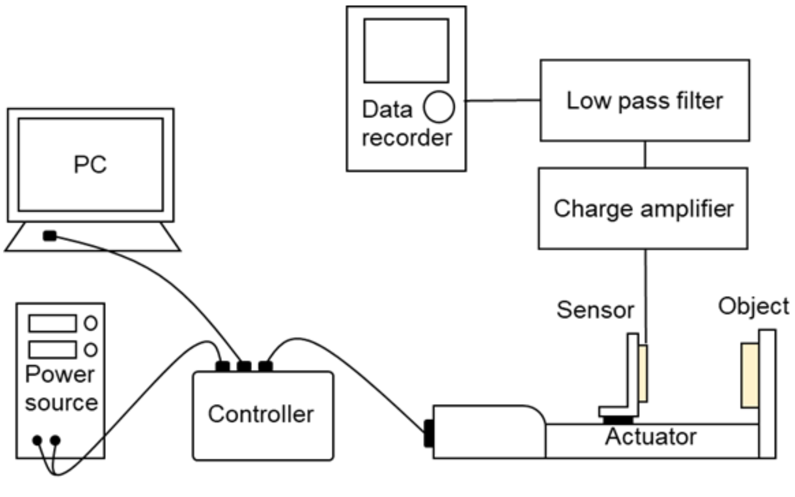

Fig. 2. Measurement system.

The measurement system is shown in Fig. 2. The sensor base is fixed in a linear actuator (ES4-12-0200B-TS/35P-D00-S3, THK Co.), which is controlled by a PC via a motor controller (TSC-015B-MOD-ES4-12-D, THK Co.). Charge output of the PVDF film of the sensor was first amplified and converted into voltage using a charge amplifier (4001B-50, Showa Sokki Co.), then low-pass filtered with the cut-off frequency of 40 Hz by a programmable digital filter (3628, NF, Co.), and digitized and recorded by a data recorder (EZ7510, NF Co.) at sampling rate of 1 kHz for further analysis.

3. Experiments

3.1 Experimental method

In order to test the function of the sensor, experiments were carried out on different objects at preset temperatures. During the experiments, the sensor was driven by the linear actuator to touch an object for about 0.5 s, and then retreated from the object for about 0.5 s, and then touch the object again. The same movements were repeated 5 times. Sensor and environmental temperature were set to 25 °C. The object temperature was preset to 15°C, 20°C, 30°C and 35°C with a thermostat (FMU-054I, Fukushima Industry Co.). Blocks of the same size (40.0 mm x 50.0 mm x 20.0 mm) made of aluminum (Al), iron (Fe), copper(Cu), polyethylene (PE), polyvinyl chloride (PVC) and acrylic glass were used as experimental objects. Their thermal characteristics are shown in Table 1.

Table 1. Physical Properties of Objects.

Object	thermal conductivity[W/m・K]	thermal capacity[J/K]
PE	0.5	79.4
PVC	0.15	64.5
Acrylic	0.21	69.4
Al	265.05	98.6
Fe	75.36	144.8
Cu	384	137.1

3.2 Experimental Results

As an example of experimental results, sensor output obtained from object Al at different temperature was shown in Fig. 3. Here the abscissa refers to the time, beginning with 0 s that is the time when the sensor first contacts the object and the ordinate refers to the sensor output in voltage.

In Fig. 3 the solid line is the sensor output at object temperature of 35°C, 10°C higher than sensor temperature. As the figure shows, from 0 second when the sensor first touches the object, sensor output begins to increase from original 0 V exponentially to about 1.5V at 0.5 second, when the sensor retreated from contact with the object, and then it begins to decrease exponentially. It begins to increase again at about 1 second, when the sensor touches the object again. This change of sensor output repeats 5 times, coincident with the sensor movement of touching and leaving the object five times. Similar trend of change in sensor output with a smaller amplitude is observed at object temperature 30°C. As for object temperature of 15°C and 20°C which are lower than the sensor temperature, sensor output changed in similar pattern but in the opposite direction. That is, the sensor has a positive output voltage when object temperature is higher than sensor temperature, and a negative voltage output when object temperature is lower than sensor temperature. The larger the temperature difference between the sensor and the object, the larger is the sensor output amplitude. This means that the sensor can detect the temperature difference between the sensor and an object it touches.

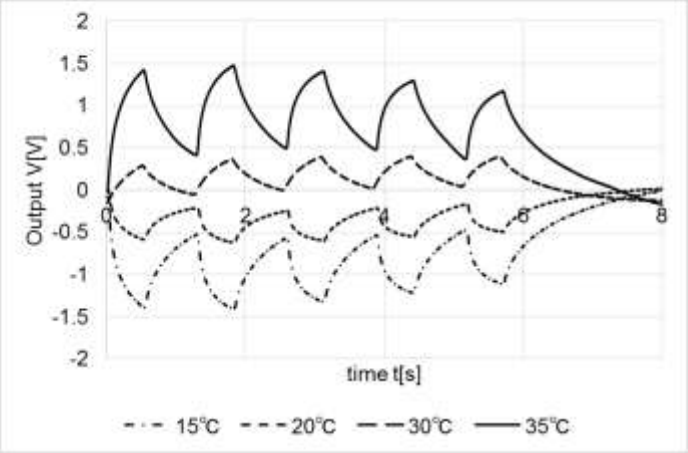

Fig. 3. Sensor Outputs Obtain from Object Al at Different Temperature.

Figure 4 shows the sensor outputs obtained from different objects at the same temperature of 35°C. The figure shows that sensor output wave forms are similar in shapes for all objects. More importantly, the figure also shows that even the objects were at the same temperature, the sensor output voltage obtained from different objects were different. Output voltage for object of Fe is almost twice of that for object PE. This means that like a human being, the proposed sensor responds not only to the temperature of an object it touches, but also to the thermal properties of the objects.

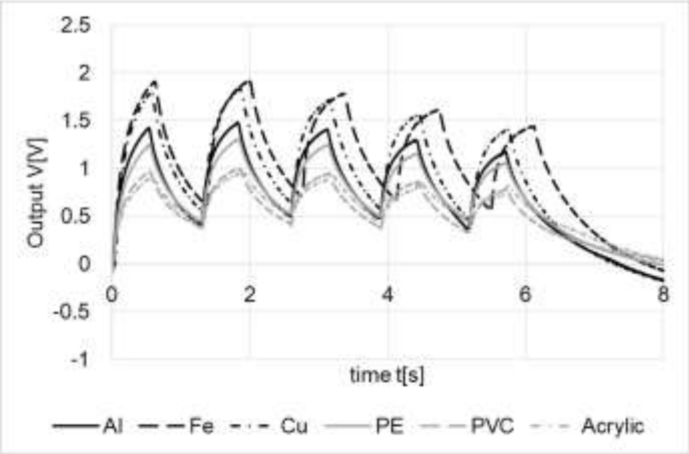

Fig. 4. Sensor Output of Different Objects at Temperature of 35 Degrees.

4. Discussions

As described in the previous chapter, for a specific object, the sensor output varies with the temperature of the object. On the other hand, for a specific temperature, the sensor output varies with the material of which the object is made of. These results suggest that the proposed sensor behaves very like the human tactile temperature sensation.

From Fig. 4, one notices that at temperature of 35°C, sensor output amplitude is in the sequence of Cu > Fe >Al > PE > Acrylic > PVC, which is exactly the same as the sequence of thermal capacities of the object as shown in Table1, Cu > Fe >Al > PE > Acrylic > PVC. In order to explore the relationship between sensor output and temperature difference between the sensor and the object, and relationship between sensor output and thermal properties of the object, a parameter was defined as the average amplitude variance of the sensor output voltage of five contacts. Figure 5 plots this parameter obtained from each object at different temperatures on the ordinate and the temperature difference between the sensor and the object on the abscissa. A negative number in the abscissa means the object temperature is below the sensor temperature, and vice versa. As Fig. 5 shows, this parameter of average amplitude is approximately linearly proportional to the temperature difference between the sensor and the objects, which means temperature of object can be evaluated using sensor. Also, since the proportion coefficients (slopes of regressive approximate lines) for each object are different, it is considered to be related to the thermal properties of the objects.

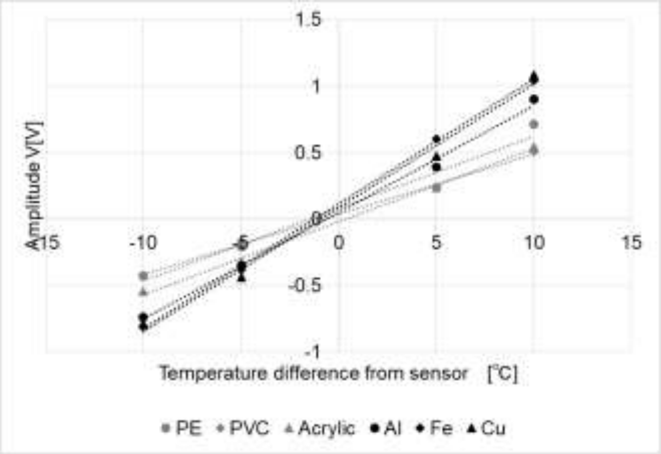

Fig. 5. Relationships of Amplitude Variance with Objects and Temperature.

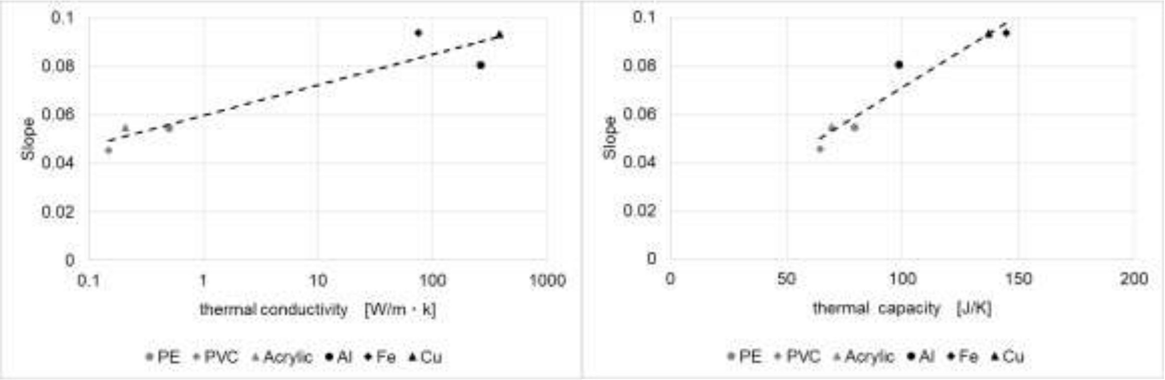

Fig. 6. Correlation between Slope of Linear Approximation of Amplitude and Thermal Conductivity (left), Thermal Capacity of Objects (right).

Finally, correlation between the slope of linear approximation of amplitude variance for each object in Fig. 5 and thermal properties of thermal conductivity and thermal capacity of the object were investigate. The results are plotted in Fig. 6, where the abscissa shows the thermal properties of the object and the ordinate shows the slope. Very high correlation coefficients of 0.947 for thermal conductivity and 0.964 for thermal capacity confirm the strong relationship between sensor output and thermal properties of objects. And this further confirms that like a human being, the sensor can also evaluate the thermal properties of an object it touches as well as the temperature difference between the sensor and the object.

5. Conclusion

In this study, a new type of temperature sensor that imitates human tactile temperature sensation was proposed and developed. Function verifying experiments using different objects were carried out. The results show that using the proposed sensor, not only temperature information but also information about the thermal properties of an object can be obtained from sensor output.

Study on parameters for quantitative evaluation of thermal properties are underway. Object type is to be expended, as well as experimental conditions. Furthermore, imitation of adaptation in human tactile temperature sensation is to be studied.

Acknowledgements

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