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MONO-MATERIAL PRESSURE-CONDUCTIVE RUBBER SENSOR WITH TEMPERATURE SENSITIVITY FOR REALIZING ARTIFICIAL SKIN SENSING

○ Jun-ichiro Yuji* and Katsunori Shida*

* Dept. of Electrical and Electronic Eng., Saga Univ., Honjo-machi 1, Saga 840, JAPAN
Tel:+81-952-28-8637; Fax:+81-952-28-8651; E-mail:96td44@cc.saga-u.ac.jp

Abstracts For realizing artificial skin sensing as a final goal, a mono-material pressure-conductive rubber sensor which is also sensitive for temperature is described. Firstly, discrimination of the hardness and the thermal property of material using a proposed sensor is presented. Furthermore, a tactile sensor consints of four pressure-conductive rubber sensor to discriminate surface model which imitates the surface roughness of material is proposed.

Keywords Pressure-conductive rubber, Tactile sensor, Hardness, Thermal properety, Surface roughness

1. INTRODUCTION

The human skin, especially, the palm of hand has many tactile sensing function for recognizing material properties, such as hardness or softness, thermal property, uneveness of surface, and so on. In recent years, intelligient tactile sensor with sensing abilities of the palm have been investigated by many research groups [1]~[4]. However, these researchs are almost aiming to obtain a single information about object using a single sensor or multi information using different composite sensor.

First of all we introduce an idea as shown in **Fig.1**[5] for realizing artificial skin sensing in the future. This idea regard a small part of the human skin as a group of a large number of tactile sensors, and then one of these tactile sensors as a large number of pressure-temperature sensitive sensor. It is desirable that this sensor is fabricated by a mono-material, because it would be difficult to integrate and/or miniaturize this sensor as composite type which consists of various sensors using a micro-machining tecnology.

In this paper, a mono-material pressure-conductive rubber sensor which is sensitive for temperature called as a PCR sensor here is proposed. This PCR sensor is actually used as a pressure-temperature sensitive sensor in Fig.1 which can discriminate simultaneously differences of hardness and thermal property of material.

In addition a tactile sensor consints of four PCR sensors to discriminate surface model which imitates the surface roughness of material is described. As experimental results using the various typical test materials containing different hardness, thermal property and surface model, it was shown that the test material with some different surface model could be separately discriminated by our proposed mono-material tactile sensor.

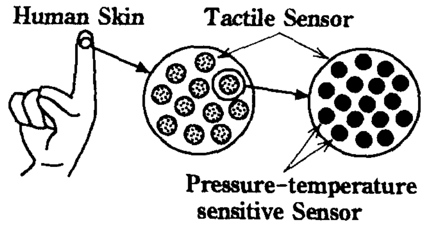

Fig. 1. An idea to realize artificial device imitating sensing ability of the human skin

2. MONO-MATERIAL PRESSURE-CONDUCTIVE RUBBER SENSOR

2.1 Structure of PCR sensor

Pressure-conductive rubber sheet[6][7] is a flexible material with a function of a pressure p converts into a electrical resistance r. Resistance r of this rubber sheet per unit area in a certain constant temperature is expressed as following,

$$r = kp^{-n} \tag{1}$$

where k is constant and n is sensitivity to pressure. Further, this rubber sheet is available to a multi-functional sensing device with pressure and temperature sensing function since the rubber sheet is also sensitive to temperature change.

When a sensor output signal is affected by two kinds of external quantities, the sensor can not indicate two quantities independently at the same time with only one sensor output signal. Therefore, we made a mono-material PCR sensor with two different output signals of resistance as shown in **Fig.2**[8]. This PCR sensor is consisted of a

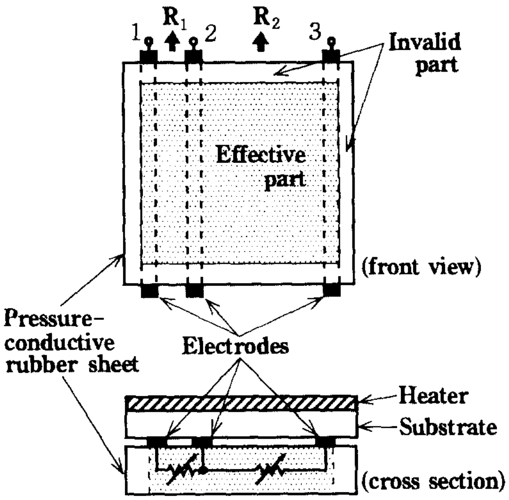

Fig. 2. Structure of a mono-material pressure-conductive rubber sensor with two output signals

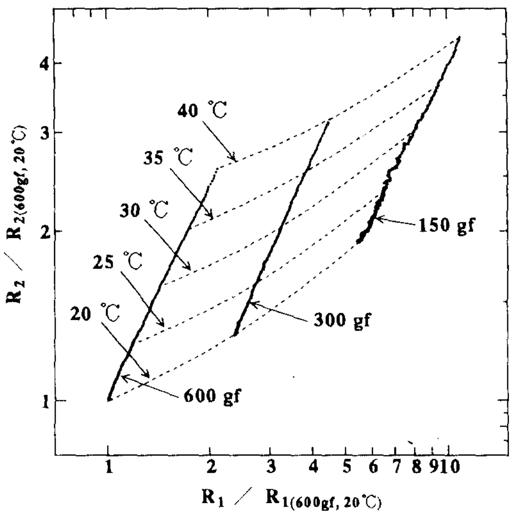

Fig. 3. Temperature characteristics in three kinds of contact forces

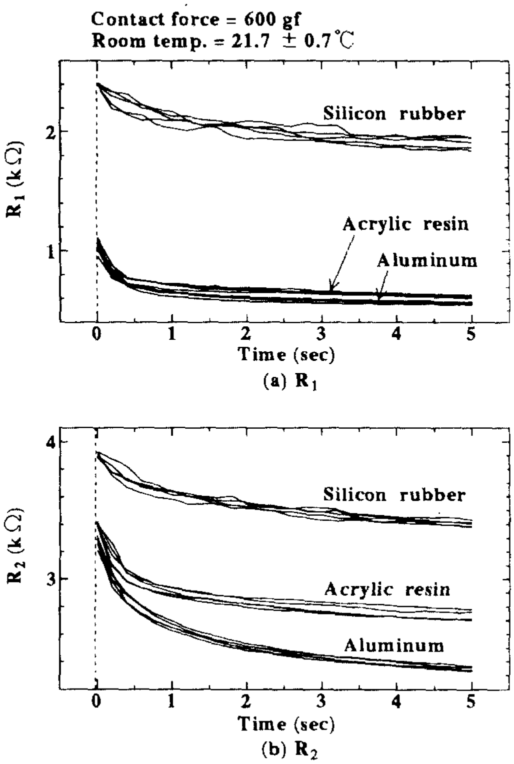

Fig. 4. Time responses of R_1 and R_2 of PCR sensor after contact with test materials

rubber sheet with 0.5mm thick and 30mm square, heating its substrate kept at constant temperature of 36 ℃ as the human body temperature and putting three parallel line electrodes of 1mm wide with two different spaces, 0.5mm and 16.5mm on the surface of rubber sheet. This rubber sheet on the substrate is fixed by covering with insulating thin film. When the PCR sensor contacts with a test material whose temperature is lower than that of the sensor, the resistance R_1 between terminal 1 and 2, and the R_2 between terminal 2 and 3 of sensor output signals change by both the reaction force given in effective part shown in Fig.2 and the temperature drop of rubber sheet.

2.2 Basic characteristics

Fig.3 shows the temperature characteristics from 20 ℃ to 40 ℃ of R_1 and R_2 in three kinds of contact forces, 600 gf, 300 gf, 150 gf, which are normalized by each resistance value in the condition of 600 gf and 20 ℃. R_1 with a narrow space between of both electrodes has a large dependencey on contact force more than R_2 with wide space of electrodes. On the other hand, R_2 has a large dependence on temperature more than that of R_1. Sensitivity n of (1) was about 1.2 on R_1 and about 0.4 on R_2. It was confirmed that simultaneous sensing of force information and temperature information was possible by changing the space of electrodes in spite of one mono-material sensor.

2.3 Discriminating experiment for hardness and thermal property

The hardness and the thermal property of material are divided broadly into four groups as follows.

I. hard and good thermal property
II. hard and bad thermal property
III. soft and good thermal property
IV. soft and bad thermal property

Soft materials with good thermal property, however, exist few. Therefore, for discrimination of the hardness and the thermal property, we prepared three kinds of rectangular typical test materials with 10mm thick, 50mm square and flat surface. These are aluminum as a hard material with good thermal property, acrylic resin as a hard material with bad thermal property and silicon rubber as soft material like an eraser with bad thermal property.

Fig.4 shows the time responses of PCR sensor of five

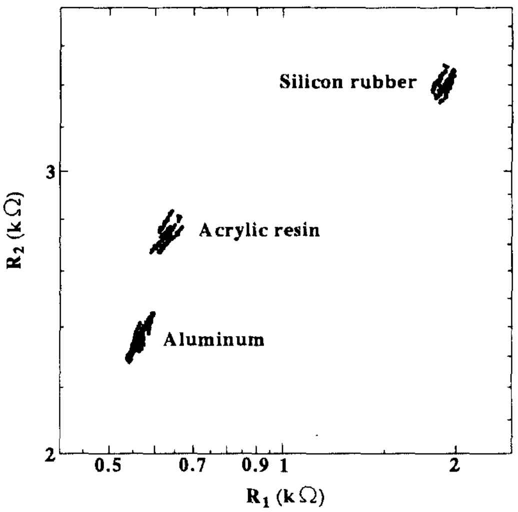

Fig. 5. Two-dimentional explanation of R_1 and R_2 of PCR sensor

times after contact with three test materials on condition that constant force of 600gf and constant room temperature of 21.7 ± 0.7 ℃. It is indicated that each resistance R_1 and R_2 of the PCR sensor varies in relation to both the hardness and the thermal property.

In order to make clear the discrimination of these test materials, two-dimensional explanation of R_1 and R_2 using the resistance values from three seconds until five seconds in this experiment is shown in **Fig.5**. Discrimination of the hardness and the thermal property in these test materials is possible in spite of dispersion in each experiment and creep effect in the rubber sheet itself and temperature drop.

3. EXTENSION TO PCR TACTILE SENSOR

3. 1 Surface model

For the discriminating experiment of surface roughness using a PCR sensor we classified broadly the surface roughness of materials to three kinds of surface roughness, that is, very rough, rough and smooth, as shown in **Fig.6** and represented them to three surface models which consist of the combination of some of four convex elements. These three surface models are the Model I with one convex element, the Model II with two convex elements and the Model III with four convex elements. The number of contacted surface of model is shown by m.

3. 2 Design of PCR tactile sensor

Corresponding to the surface model, the PCR tactile sensor was constructed with four PCR sensors connected electricaly in parallel as shown in **Fig.7**. Therefore, R_1 and R_2 of the tactile sensor are total parallel resistance of each PCR sensor contacting to the surface model.

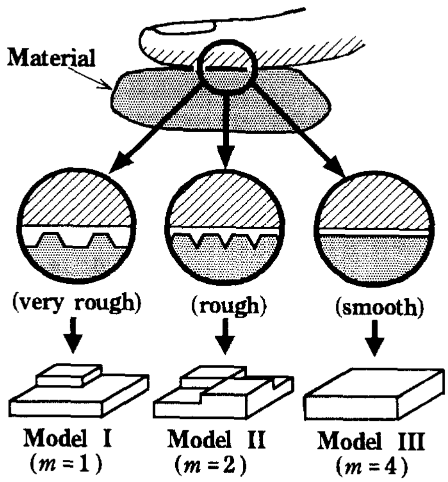

Fig. 6. Surface model

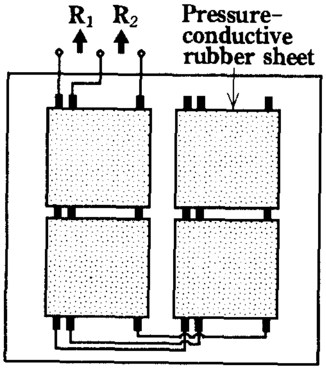

Fig. 7. Design of a PCR tactile sensor

3. 3 Discriminating principle

In this paragraph, it is explained that the principle of resistance changes of R_1 and R_2 of PCR tactile sensor corresponding to the number of PCR sensor contacting with surface of model, that is, m in a constant temperature[9].

If the PCR tactile sensor is in contact with surface model by m face, resistance R_i ($i = 1, 2$) of PCR tactile sensor is expressed as follows using (1) because reaction force P per one face is P/m.

$$R_i = \frac{k(\frac{P}{m})^{-n_i}}{m} = \frac{k}{P^{n_i}} m^{n_i - 1} \quad (2)$$

R_i is proportional to $m^{n_i - 1}$. Therefore, if n_i is equal to 1, R_i does not change by m, otherwise R_i increases with m when n_i is larger than 1, and decreases when n_i is less than 1.

3. 4 Discriminating experiment

To confirm the discrimination of surface model, the PCR tactile sensor based on the principle was tested in the same way as previous experiment shown in *2.3*.

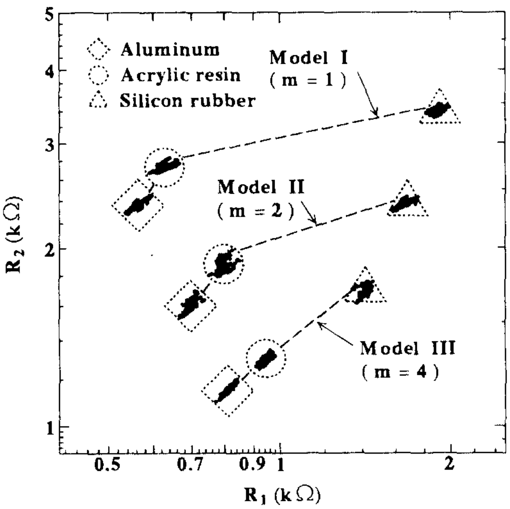

Fig. 8. Discrimination results of surface model in each test material

Fig.8 shows the discrimination results of surface model when the PCR tactile sensor is contact with each test material on condition that the contact force of 600gf. In case of hard material, R_1 increases with m and R_2 decreases with m because of $n_1 = 1.2$ and of $n_2 = 0.4$, respectively, which are described in 2.2. In case of soft material, however, both R_1 and R_2 decreased with m because of the sensitiviy n_1 of R_1 became value less than 1.

From Fig.8 it was found that the PCR tactile sensor was effective for discrimination of three material properties, that is, the hardness, the thermal property and the surface model.

4. DISCUSSION

In this study, we used three kinds of typical test materials and three surface models which have large differences to confirm the simultaneous discrimination of differences of the hardness, the thermal property and the surface model using only two output signal of a mono-material PCR sensor. Therefore, these test materials could be discriminated separately by our proposed mono-material PCR tactile sensor. However, the discrimination of actual materials will be difficult.

5. CONCLUSION

To realize an artificial sensing device imitated the human skin, this paper described a mono-material pressure-conductive rubber sensor (PCR sensor) which had two different resistance output signals R_1 and R_2 based on our proposed idea. This PCR sensor is sensitive not only to pressure but also to temperature. Discrimnation results of three typical test materials different from each other in the hardness and the thermal property were presented using the PCR sensor kept at temperature (36 ℃) higher than the room temperature in constant contact force.

Furthermore, a PCR tactile sensor consists of four PCR sensors in parallel connection to discriminate surface model which imitates the surface roughness of material is expected in the points that the information of three kinds of characteristics such as the hardness, the thermal property and the surface model can be obtained as the results of our experiment and then that the automatic discrimination can be realized using discriminating function such as multivariate statical method.

REFERENCES

[1] P.Dario and D.D.Rossi : "Tactile sensors and the gripping challenge", *IEEE SPECTRUM*, AUGUST, pp.46-52, 1985

[2] S.Omata, Y.Terunuma and Y.Horiuchi : "Development of New Tactile Sensor for Detecting Hardness of Living Tissue and Its Applications for Biomedical Engineering", *Technical Digest of the 11th Symposium*, **I1-1**, pp.205-208, 1992

[3] R.A.Russel and F.J.Paoloni : " A Robot Sensor for Measuring Thermal Properties of Gripped Objects", *IEEE Trans. on Instrumentation and Measurement*, **Vol. IM-34**, No.3 pp.458-460, 1985

[4] D.G.Caldwell and J.O.Gray : " 'Dynamic' Multi-Functional Tactile Sensing", *Lecture notes in control and information sciences*, **Vol.187**, pp.189-198, 1993

[5] K.Shida and J.Yuji : " A Mono-Material Tactile Sensor with Multi-Sensing Properties", *Proc. of the 9th Korea Automatic Control Conference*, **IS-29**-1, pp.587-592, 1994

[6] W.E.Snyder and J.St.Clair : "Conductive Elastomer as Sensor for Industrial Parts Handling Equipment", *IEEE Trans. on Instrumentation and Measurement*, Vol.**IM-27**, No.1, pp.94-99, 1978

[7] M.Shimojo : "Hysterisis Characteristics of Pressure-Conductive Rubber", *Trans. JSME*, **Vol.59**, No.564, C, pp.2464-2469, 1993 (in Japanese)

[8] J.Yuji and K.Shida : "Discriminating Technique of Hardness and Heat Conductivity of Materials by Pressure-Conductive Rubber Sheet Sensor", *Proc. of the ISTED Int. Conf. Robotics and Manufacturing*, pp.105-108, 1996

[9] J.Yuji and K.Shida : "Possibility of Multi-Functional Sensing Technique of Surface Roughness and Temperature on Material Surface Model", *Trans. of IEEJ*, **Vol.117-E**, No.5, pp.250-255, 1996 (in Japanese)