

TEXTURE MEASUREMENT FOR FABRICS INCLUDING WARM/COOL AND FLUFFINESS SENSATION BY MULTIMODAL MEMS SENSOR

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ABSTRACT

In this paper, we report that the texture measurement of warm/cool sensation of the fabrics has been carried out by a multimodal MEMS sensor. This MEMS sensor can detect force as resistance change of the strain gauge on the micro-cantilever of the sensor and light as impedance change of the Si layer by the photoconductive effect. The sensor can also detect a temperature drop by heat transfer from the sensor to the contact object as resistance change of the strain gauge and impedance change of Si. It is demonstrated that the texture features of fabrics including tactile and visual, in addition, warm/cool sensation can be characterized by a single MEMS sensor.

KEYWORDS

Multimodal texture measurement, Warm/cool sensation, Tactile sensor

INTRODUCTION

In late years, texture designs have become more important for high-value-added products, for example, clothes, furniture, and automobiles [1]. In apparel industries, there are many studies being performed to develop high-value-added products with novel texture or function. Furthermore, the online purchase of clothes through only photographs without looking at the real thing have increased. However, it is difficult to distinguish the fine texture or color difference of products only by photographs or adjective words such as fluffy, warm, and so on.

Texture is a complex perception including various sensory sensation. Humans sense the texture of objects by exploratory activity according to his purpose. Typically, texture of objects has been characterized by the human sensory evaluation. However, there is a lack of quantitative and reproducible data in sensory evaluation, because the evaluation result depends on own senses and physical conditions of subjects. Therefore, many sensor devices have been proposed for quantitative texture measurement. Mazid and Russell have measured texture as surface roughness using a tactile sensor [2], and Kuramitsu et al. have reported a texture measurement method based on the difference in surface friction using a human finger model [3]. However, texture is a complexly perception affected by roughness, coolness, hardness, moistness, and visual sense, as previously mentioned. Hence, multimodal texture measurement is required to obtain more realistic texture of an object like human sense it by using a sensor device. In our previous work, we have developed a multimodal MEMS tactile sensor that can detect normal and shear

force using strain gauge film on microcantilevers and light by a photoconductive effect in the Si layer of the sensor [4]. The tactile and visual texture characterization method using the sensor have been also proposed [5]. The surface texture of various objects has been evaluated by active touching measurement using the sensor and the different sensor outputs have been given for each object with different colors. Moreover, we have proposed the warm/cool sensation evaluation for objects using the sensor experimentally [6]. For cloths also, warm/cool sensation is very important as a factor of texture comfort as well as tactile sensation based on mechanical stimuli. In this work, we explore a possibility for measurement of texture including warm/cool sensation to various fabrics by the developed sensor.

THEORY AND METHOD

Structure of sensor and measurement principle

Figure 1 shows a photograph of a proposed sensor and a conceptual of multimodal sensing. The sensor has three microcantilevers (290 μm long, 200 μm wide, 2.5 μm thick) which have a NiCr strain gauge layer on its surface. They have an inclined shape because of residual stress of thin film deposited on its surface and are embedded in thin PDMS layer. A hemispherical shaped PDMS (diameter: 2.1mm) is put over the microcantilevers through thin PDMS layer. This sensor can detect force as the resistance change of the strain gauge and light and temperature change as the impedance change of the Si layer by the photoconductive effect or the thermal excitation.

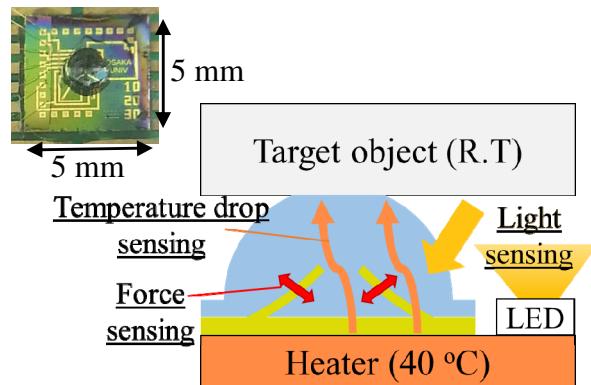


Figure 1: A photograph of the proposed MEMS sensor and a conceptual of multimodal sensing of force, light, and temperature change.

Measurement system and target objects

Figure 2 shows photographs of (a) the measurement

setup and (b) target objects. 6 kinds of fabrics were employed as the target object. A fabricated MEMS sensor mounted on a commercially available printed circuit board was installed on an xy horizontal motorized stage and heated to around 40°C , which is similar to the deep body temperature of human. The target object was attached to a z vertical motorized stage through an acrylic jig at 20 mm high from the sensor surface and a 6-axis force sensor (Nitta Corp.) used as a force reference. The target object was approached to the sensor surface by moving the z stage in the vertical direction at 1 mm/s and then pressed until the force reference output amounts to 0.5 N. The resistance and impedance change were measured using a digital multimeter (R6581, Advantest) and an LCR meter (3532-50, Hioki), respectively. The experiment was conducted in a darkroom. Therefore, the impedance of the sensor changes only by the temperature change of the sensor. Moreover, the heat flow sensor (LR8432, Hioki) was used in order to explore the heat flow from the sensor to an object.

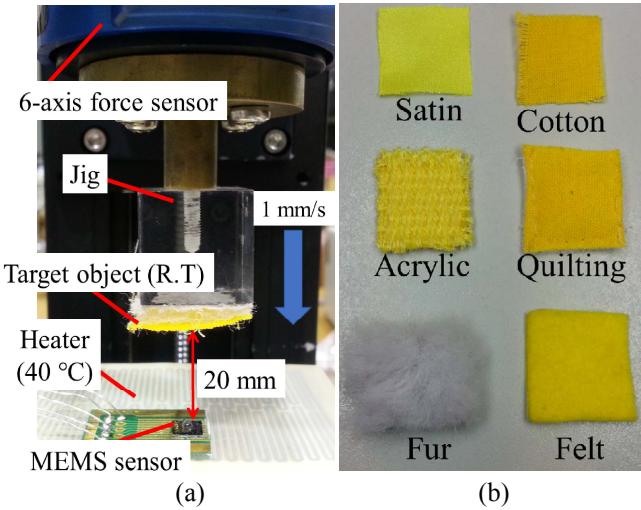


Figure 2: Photographs of (a) the measurement setup and (b) target objects.

Human sensory evaluation

The human sensory evaluation was conducted for ten males in their twenties to the target objects in order to obtain objective data of texture of the target objects. The semantic differential method was adopted for the evaluation method and 19 adjective-and-antonym pairs were chosen for the measurement scale, for example warm-cool, hard-soft, and thin-thick. Test subjects touched a target object and then scored out of one to seven for each evaluation item. Figure 3 shows the average score of coolness for each object. Because the objects were cloth, the score was biased toward the warm side, however, the coolness score is even different among the type of cloth. For example, the coolness score of cotton is higher than that of fur, thus, subjects feels the cotton to be relatively more cool than fluffy cloth such as the fur.

RESULT AND DISCUSSION

Coolness evaluation by impedance change

Figure 4 shows the impedance change of the sensor and the output of the heat flow sensor for satin and fur. In

the case of both objects, the impedance of the sensor increases after the contact. The amplitude of impedance change depends on the type of fabric. Fur obviously contains a lot of air and is thick more than satin. Thus, the impedance change is relatively small as shown in Fig. 4, because the sensor temperature change is less. On the other hand, in the case of satin, the impedance change is relatively large because of the efficient heat transfer from the sensor to the fabric side. From the output of the heat flow sensor, impedance change for each fabric is corresponding to the heat flow from the sensor to the object. Therefore, it is found that the impedance change of the sensor depends on the heat transfer accurately. The maximum impedance change rate measured by the sensor can be used as a scale of the warm/cool sensation.

Figure 5 shows the scatter diagram of the maximum impedance change rate of the sensor and the average score of coolness obtained by the human sensory test as shown in Fig. 3. As shown in Fig. 5, subjects feel cool sensation for objects that show the larger maximum impedance change rate such as satin and cotton, on the other hand, they feel warm sensation for objects that have the smaller maximum impedance change rate such as fur. The value of the correlation coefficient between the warm/cool sensation obtained by the sensory test and the measured warm/cool sensation by the sensor is 0.98, thus, they have a strong correlation.

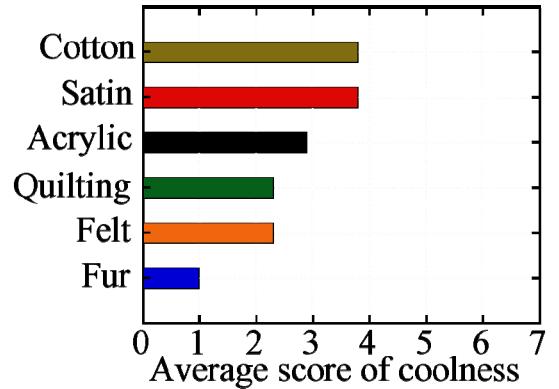


Figure 3: Average score of coolness that obtained by human sensory evaluation for the objects.

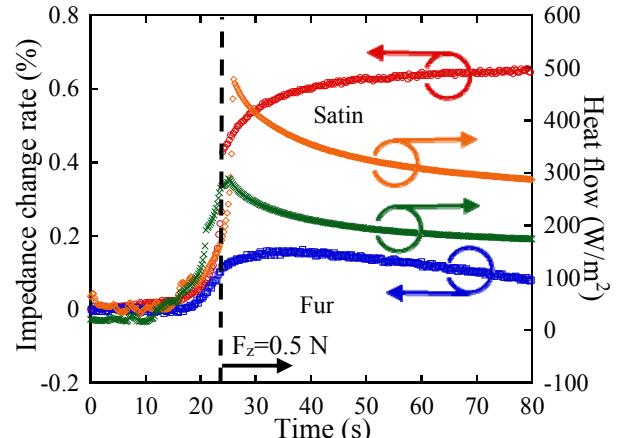


Figure 4: Relative impedance changes of the heated sensor and the output of the heat flow sensor as a function of time when the sensor is touched the target object.

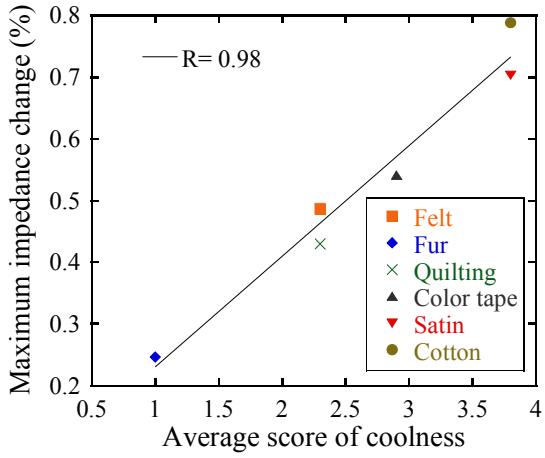


Figure 5: The maximum impedance change induced by touching with heated sensor as a function of relative average score for coolness estimated by sensory test.

Fluffiness evaluation by resistance change

Figure 6 shows the resistance change of the strain gauge of the sensor and the indentation depth with pressing by the object. In the case of each object, the resistance of the strain gauge decreases during increase of indentation depth, and then the resistance of the strain gauge is gradually increases, as shown in Fig. 6. The resistance decrease is caused by the contact force between the sensor and the object. On the other hand, the resistance increase is due to the temperature change of the sensor caused by thermal transfer from the sensor to the object similar to the impedance behavior shown in Fig. 4. In the case of fur, the indentation depth is very large because the fur is very soft and thick. On the other hand, the indentation depth in the case of satin is very small. The resistance decrease in the case of satin is larger than that in the case of fur. Since the reaction force is large because the satin fabric is very thin, the resistance change after contact is relatively large.

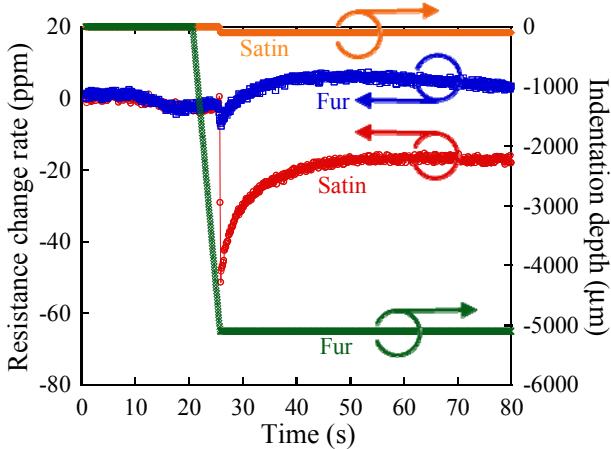


Figure 6: Relative resistance changes of the heated sensor and the indentation quantity when the sensor was pressed by fabrics as a function of time when the sensor is touched with the target object.

Figure 7 shows the scatter diagram of the maximum resistance change rate of the strain gauge and the average score of thin sensation obtained by the sensory test for each

object. The value of the correlation coefficient between the thick feeling and the maximum resistance change rate is 0.87, thus, they have a strong correlation, as with warm/cool sensation. It is demonstrated that the sensor output reflecting the thin sensation of fabrics is obtained when the sensor is pressed with constant force.

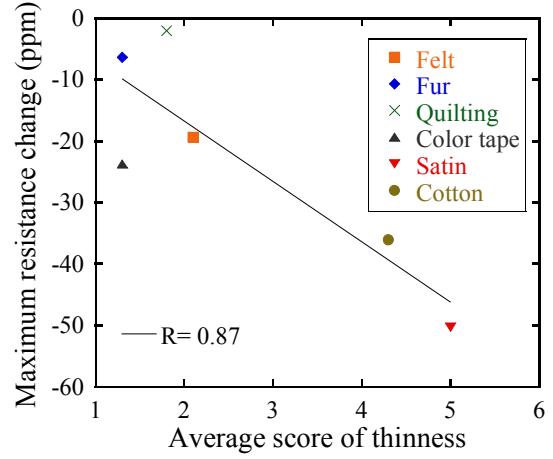


Figure 7: The maximum resistance change induced by touching with heated sensor as a function of relative average score for thin sensation obtained by the sensory test.

CONCLUSIONS

In this paper, a texture measurement of warm/cool and fluffiness sensation for fabrics by a developed MEMS sensor has been proposed. Warm/cool sensation was evaluated by the impedance change of the sensor and thick sensation was evaluated by the resistance change of the strain gauge. These sensor outputs reflecting warm/cool and thick sensations for fabrics have strong correlation with the coolness and thinness score obtained by the sensory test, respectively. It is demonstrated that proposed texture measurement by the developed MEMS sensor is useful for the great progress in quantitative characterization of human tactile sensation and the invention of novel texture design.

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