Active sensing of texture of surface by use of distributed tactile sensors inside an elastic finger

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ABSTRACT:

Dynamic sensing of texture of object surface is one of the most important issues in design of robots and evaluation of human-machine interface. Hence, author has developed a tactile sensor inspired by the structure and mechanisms of tactile sensation of human finger. The developed sensor has a ridge-like surface in order to detect the vibration due to the interaction between the finger and the touched object. It also has distributed sensor inside the elastic finger made of silicone rubber in order to detect the change in pressure. As a result of texture perception test, it is shown that the developed sensor can detect the texture, softness and friction of various objects. It can be used to feel the texture of various objects.

INTRODUCTION

Tactile sensors are needed in two area of research and development. First one is a division in company to develop products including cosmetic products, human-machine interface of computers, stationery and car equipments that are often touched by humans. In order to design the surface of those equipments and products, feeling of touch is one of the important design parameters. Usually sample products are tested by human subjects. However, it is not easy to obtain qualitative data because evaluation by humans differs. Hence, tactile sensor that can detect the feeling of touch has been needed. Second one is to equip tactile sensors in robot hands used with humans. Master-slave robots should have tactile sensors inside the slave robot hand in order to send the touched information to the operator manipulating the master hand. Autonomous robot that will be used in future home, medical and welfare field, should have tactile sensors underneath the skin of their hands in order to understand the situation of its own and decide the action followed. For those robots, numbers of force sensors have been developed. Several tactile sensors have also been developed. However, texture sensor has not been realized. Hence, in the present study, texture sensor that can detect the feeling of touch by moving the sensor on the testing surface is developed. First, feature of human finger is described. Then, the design, manufacture and experiment of the tactile sensor is described.

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LEARN FROM THE DESIGN OF HUMAN FINGER

Figure 1 shows a finite element (FE) model of section of human finger developed by author [1]. Human finger has epidermal ridges (finger print) at the surface. Inside the epidermal ridges, there are papillae. At the top and the bottom of the papillae, there are mechano-receptors, Meissner's corpuscles (FA I receptors) and Merkel's discs (SA I receptors), respectively. In much deeper area, there are Pacinian corpuscles (FA II receptors). It is known that those receptors make impulsive signal when the strain energy of the skin is enlarged by stimuli at the surface of the skin. Hence, by use of this FE model, response of those receptors are estimated.

By using this FE model, authors have clarified that the epidermal ridges are playing an important role for tactile sensation. It is found that they have effect to enlarge the sensitivity of the tactile receptors [1].

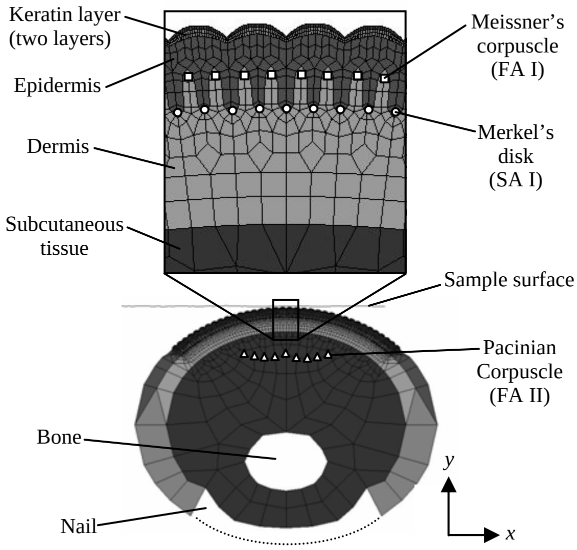
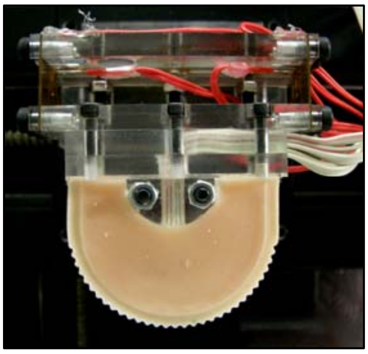


Figure 1: Finite element model of section of human finger

DEVEELOPMENT OF THE SENSOR

Tactile sensor imitating the feature of the human skin is developed. Figure 2 and Figure 3 show the developed sensor. Skin of the sensor is made of layered silicone rubber. At the surface of the tactile sensor, there is an epidermal layer with epidermal ridges. Epidermal ridges are for creating vibration when the sensor is in contact with objects having different texture. Young's modulus of the epidermal layer is larger than those in inner layer same as human skin. At the interface between inner and outer layer, there are five strain gages in order to detect the deformation of the skin.



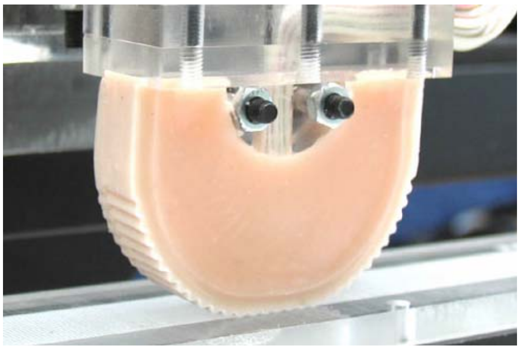
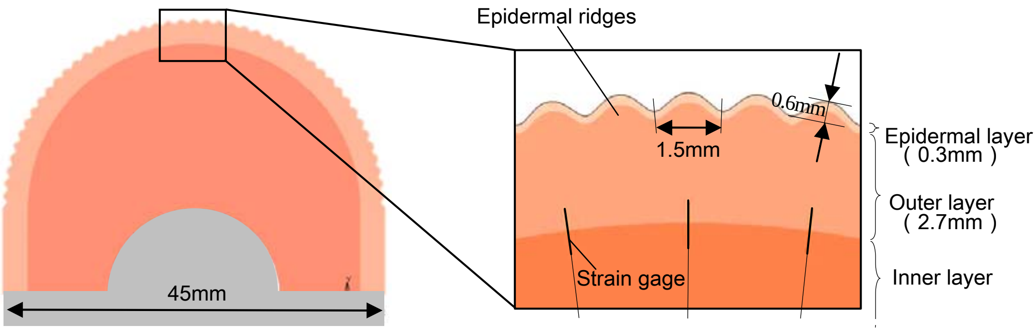


Figure 2: Pictures of developed tactile sensor



(a) Entire view (b) Partial sectional view

Figure 3: Developed tactile sensor

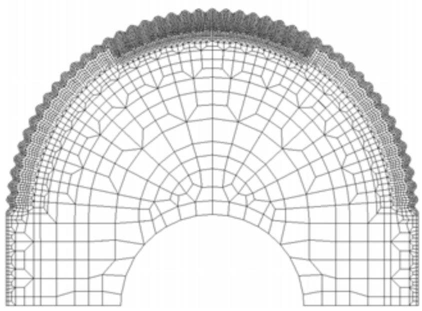


Figure 4: Finite element model of developed tactile sensor

Figure 4 shows a FE model of the sensor in order to confirm that the sensor can detect the softness and texture of object in contact with the sensor.

Figure 5 shows an example of the results of calculation. Those three figures show that the deformation and the strain of the sensor when the sensor is indented into the object are different when the Young's modulus of the object differs. As shown in the Fig. 5 (a), when the object has a large Young's modulus, deformation od the sensor is large. Strain detected by five strain gages distributes, i.e. strain at the central strain gage is large and the one at the side are small. Hence, by monitoring the strain distribution in the five strain gages, we can estimate the softness of the object that is in contact with the sensor.

Next, it is calculated if the strain gages' vibration has information on texture of the object surface when the sensor slides on the surface. Figure 6 shows a spectrum of the central strain gage. It is shown that vibration of the strain gage contains certain frequency components. This kind of calculation is conducted for seven different material surface including fabric, leather, paper, wood, metal and rubber. As a result of calculation, it is shown that the frequency components are different when the material is different. Hence, we can conclude that this sensor can classify materials by calculating spectrum when the sensor slides on the texture.

Then the sensor is manufactured. It is tested if the softness and texture can be measured same as simulation. As a result of measurement, it is confirmed that they can be measured.

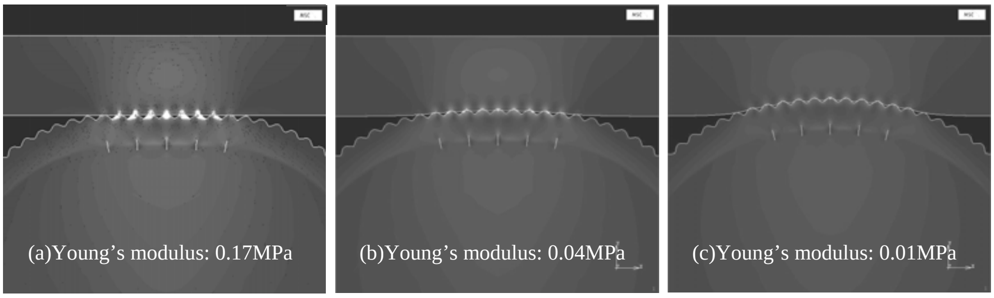


Figure 5: Results of finite element analysis

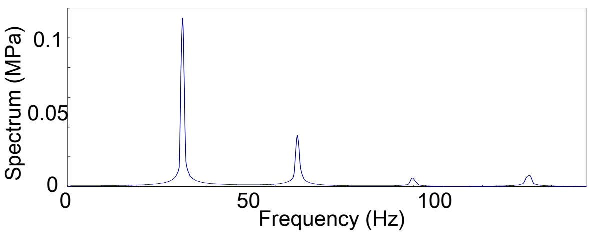
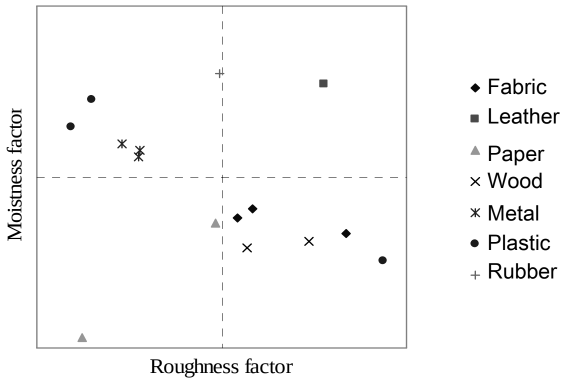


Figure 6: Result of spectram analysis of stress history at the central strain gage

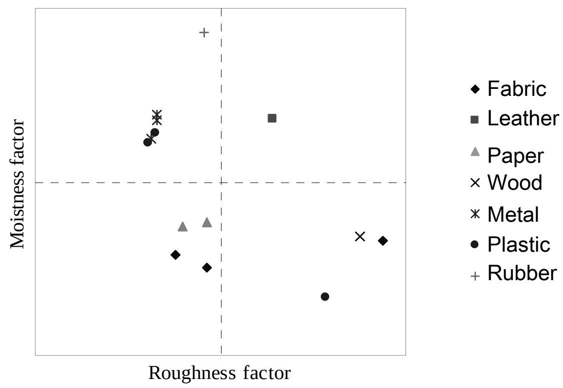
Also moistness is measured by the force sensors attached next to the tactile sensor. Time histry of normal and tangential forces are measured separately. By dividing the tangential force by normal force, dynamic friction coefficient is obtained. This value is in relation to a moistness factor.

Figure 7 shows a comparison between the human's feeling of texture and the sensor's. Figure 7 (a) shows an example of a SD method test of humans. Twenty human subjects touch fourteen object surfaces. Physical properties including roughness, Young's modulus and friction coefficient are measured. Then multivariate analysis is conducted. As a result of factor analysis, it is found that human's feeling of touch can be described by four factors, roughness, moistness, softness and temperature factors. Figure 7 (a) is one of the results. Materials' roughness factor and moistness factor is plotted. It is shown that each material has its own value.

Figure 7 (b) is to compare the result obtained by tactile sensor with those of humans. Roughness factor is calculated by spectrum of strain gage when the sensor slides on the object surface. The moistness factor represents the friction coefficient measured by force sensors.



(a) Example of distribution of factor scores of human's texture perception



(b) Distribution of factor scores of the developed sensor

Figure 7: Comparison between factor scores of texture by human and developed texture sensor

It is shown that both distributions are somewhat similar. From this, we can conclude that the developed sensor can detect the information similar to those humans detect.

CONCLUSIONS

The tactile sensor inspired by structure and mechanism of human finger is developped. As a result of FE analysis and measurement, it is shown that the developped sensor can detect values similar to what humans detects.

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