Sensing the Texture of Surfaces by Anthropomorphic Soft Fingertips with Multi-Modal Sensors

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Abstract

This paper describes the development of a human-like multi-modal soft finger and its ability to sense the texture of objects. This fingertip has two silicon rubber layers of different hardness; strain gauges and PVDF films are randomly distributed as tactile sensors. Owing to the dynamics of the silicon between sensors, the fingertip is supposed to have several sensor modalities. Preliminary experiments show that the fingertip can detect the difference between the textures of objects (paper and wood).

1 Introduction

We, humans can manipulate various objects because of the dexterity of our hands. For instance, we can pick up objects that have wide varieties of stiffness from soft to hard. We can also sense the texture of the object and change grasping force to avoid slippage without damaging the object. Although many attempts have been made to reproduce this kind of adaptive behavior by robot fingers so far, the performance is not satisfactory.

One reason is that much research is performed hard fingers (for example, [1, 2]). By using hard fingers, it becomes easy to calibrate them, and to analyse the manipulation. However, the benefits brought by the softness such as stability, manipulability, robustness, and sensibility of the surface cannot be utilized. On the other hand, these advantages are enjoyed by the soft fingers; however, it is difficult to calibrate the sensors in the soft skin. Actually, existing works on soft fingers [3, 4, 5, 6, 7, 8] have tried to embed the sensor placements regularly to avoid such calibration.

Another reason is that only a few sensors are embedded into the finger, which is also related to the regularity of sensor placements. It is very hard to install many sensor placements regularly into the limited volume of the finger. There is little research that risks placing sensors into the fingertip randomly [9, 10]. If sensors are allowed to be embedded randomly, it is easier to increase the number of sensors than if they are embedded regularly. Consequently, the sensing ability of the fingertip will increase substantially.

Let us consider human skin. Human skin has a few layers and several kinds of tactile receptors. Even the same sensors embedded in different parts may sense different physical quantities. Consequently, the human skin is supposed to have various sensing modalities. Existing work on randomly distributed sensors [9, 10] did not address the fact that the dynamics of the skin between sensors play important roles.

This paper describes the development of a soft fingertip with distributed sensors and its ability to sense the texture of the object. The soft finger is basically imitating the structure of a human finger, that is, consisting of an epidermis and a cutis layers. Several strain gauges and PVDF (polyvinylidene fluoride) films are embedded randomly in the fingertip. Preliminary experiments show that the fingertip can detect the difference between the textures of the object by two PVDF films thanks to the skin dynamics between them.

2 Anthropomorphic soft finger

2.1 Structure of the finger

A cross sectional view of the developed soft fingertip is shown in Figure 1. The fingertip has two layers made of different kinds of silicon rubber basically imitating the human finger, a cutis layer and an epidermis one. The rubber used for the epidermis is harder than that for the cutis. A bolt is inserted at the center of the fingertip to play the role of the bone. Several strain gauges and PVDF films are embedded in both silicon layers.

This fingertip has two layers of different hardness, and the tactile sensors are randomly distributed. Because of the features, the same sensors embedded in the different positions may sense different physical quantities. A strain gauge embedded near the surface of the skin is expected to sense the local static strain between the skin and the object surface, whereas a gauge embedded near the bone is expected to sense the total force exerted on the finger and is expected to be insensitive to the local texture of the object. A PVDF film is expected to sense the strain velocity, which means that it is more sensitive to the transient/small strain (or stick slip) than the strain gauges. The silicon layer between two PVDF films is expected to act like a low-pass filter; therefore, the difference between the signals is expected to represent the local stick slip phenomena. In this sense, we can suppose that the developed finger has several modalities of sensors.

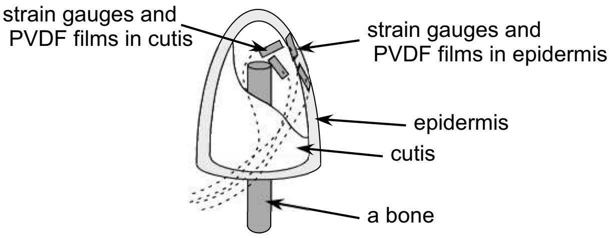

Figure 1: *A cross sectional view of the developed soft fingertip. The fingertip has two layers made of different kinds of silicon rubber basically imitating the human finger with its cutis and epidermis layers.*

2.2 Procedure to make a fingertip

Figure 2 shows the procedure to make the fingertip. First, the liquid silicon rubber is cast into the mold, and the strain gauges and the PVDF films are put into it. The bolt is also inserted, and the mold is put into the vacuum to remove bubbles, and is baked in the oven to be solid. It is put into another mold, that is slightly bigger than the former. Then, the soft fingertip is made by repeating the above procedure. Figure 3 shows a complete soft fingertip. Its diameter and length is 2cm and 5.5cm, respectively.

3 Experiment

3.1 Experimental equipment

To collect tactile sensor data when the soft fingertip rubs various objects, an experimental hand system with the soft fingertip is built. Figure 4 shows the experimental equipment. A robot finger has 3 DOF and the soft fingertip mounted at the end of the robot finger.

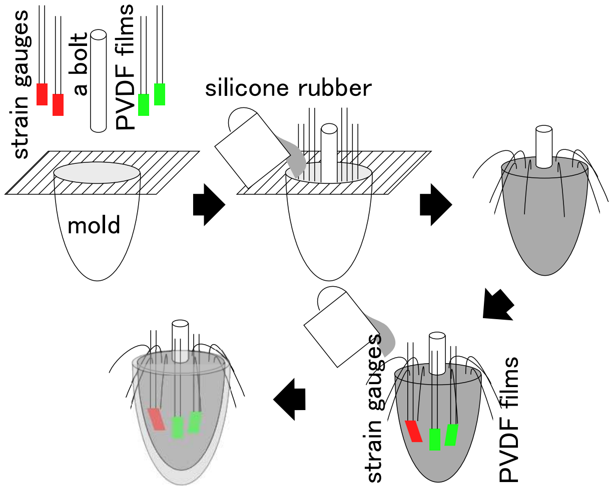

Figure 2: *A procedure to make the soft fingertip.*

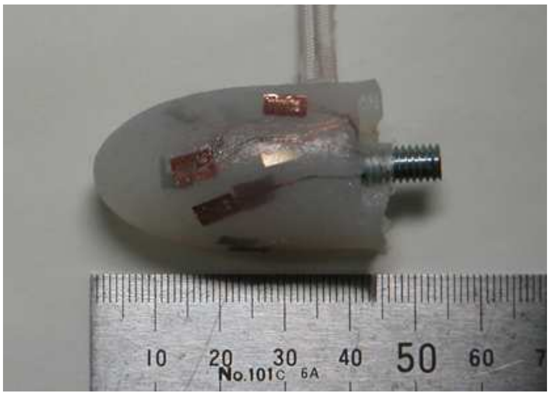

Figure 3: *A photo of the complete soft fingertip.*

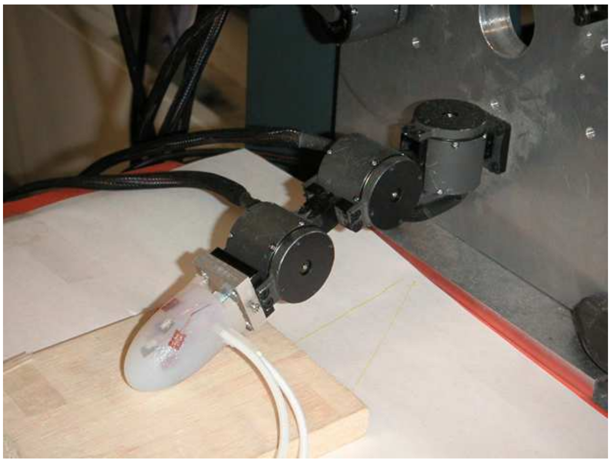

Figure 4: *A robot finger equipped with the soft fingertip.*

In the experiment, six strain gauges and six PVDF films are embedded in the soft fingertip. Three strain gauges and three PVDF films are embedded in the cutis, and other strain gauges and PVDF films are embedded in the epidermis. Sensor signals are amplified and fed to a host computer via an A/D converter.

The experimental procedure is as follows: First, the soft fingertip does not touch an object. Second, the soft fingertip presses the object by constant force. Finally, the soft fingertip rubs the object by moving the robot finger from left side to right side. The host computer collects sensory data when the robot finger executed a series of the procedures.

3.2 Sensory data by rubbing smooth paper

Sensory data obtained during the procedure is shown in Figures 5–7. The figures show a time course of all strain gauges, channel 5 of PVDF film, and channel 1 of the PVDF film, respectively. In these figures, the soft finger does not touch the paper for about 1 second after starting the experiment. Then, the soft finger only presses the object in constant force for about 2.7 seconds, and rubs the object for about 4.7 seconds. In this experiment, strain gauge channels 1, 2, and 5, and PVDF film channels 3, 4, and 5 are embedded in the epidermis, and the remaining sensors are embedded in the cutis.

According to Figure 5, sensor signals of the strain gauges are relatively stable through pressing and rubbing. However, the vibration of PVDF film channel 5, which originates from sensors embedded in the epidermis, is observed when the soft fingertip touches the paper (Figure 6). After the touch, the sensor signal becomes small. When the soft finger is rubbing the paper, the large vibration of PVDF film channel 5 is observed, and the vibration continues until the end of the rubbing. In contrast, PVDF film channel 1, which originates from sensors embedded in the cutis, is stable (Figure 7).

From these observations, the strain gauges are able to detect the slippage direction as suggested by our previous work [10]. Then, we suppose the PVDF films can be used for sensing change in the touch condition.

3.3 Discrimination between paper and wood by the PVDF film

To demonstrate whether it is useful that the soft fingertip has the cutis and epidermis, the sensor signals of the PVDF films are collected by rubbing smooth paper and wood. The experiment is repeated twenty times.

Figure 8 shows a scatter diagram of variance of the PVDF films. The horizontal axis indicates the vari-

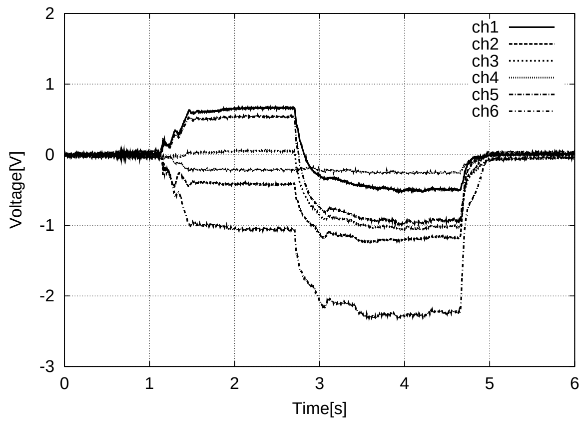

Figure 5: *An output example of the strain gauges by rubbing the smooth paper.*

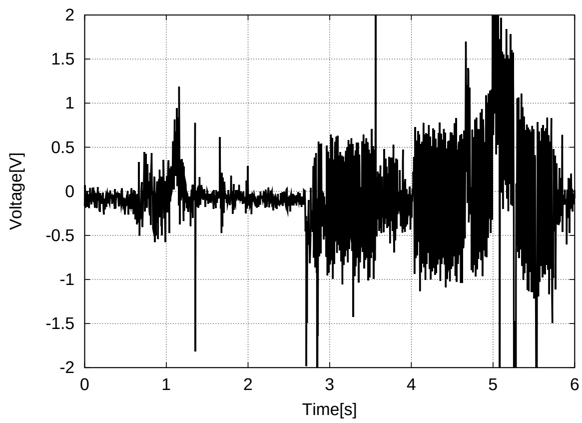

Figure 6: *An output example of PVDF film channel 5 which is embedded in the epidermis.*

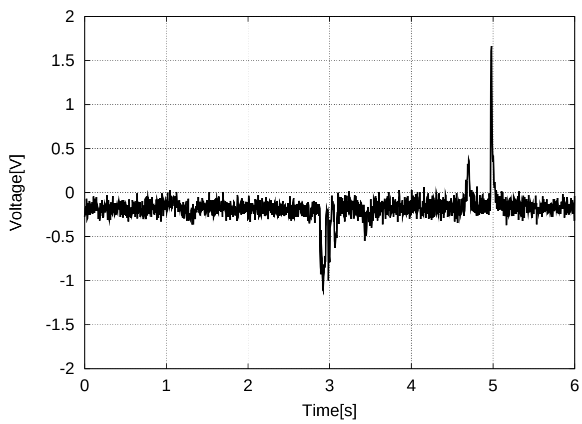

Figure 7: *An output example of PVDF film channel 1 which is embedded in the cutis.*

ance of the epidermal PVDF film channel 5, and the vertical axis indicates the variance of the cutis PVDF film channel 6. In the figure, "+" indicates variance when the soft fingertip rubs the smooth paper, and "×" indicates variance when the soft fingertip rubs the wood. In addition, the solid and broken ellipses indicate variance ellipses of the paper and the wood, respectively. From this figure, the soft fingertip can sense the textures of the objects by the differences between PVDF films that are embedded in the epidermis and the cutis.

Other scatter diagrams of the variance are shown in Figures 9 and 10. Figure 9 shows a scatter diagram of the variance of the PVDF film channels 3 and 4, which are both embedded in the epidermis. This figure denotes that it is difficult to discriminate between the textures by the PVDF films which are embedded in the same layer. Figure 10 shows another difficult case of discrimination. In the figure, in spite of using the PVDF films which are embedded in the epidermis and the cutis, it is difficult to discriminate between the textures. This exceptional example occurs when the placement of the PVDF films is near position.

4 Conclusion and future work

In this paper, a fingertip is developed that has two layers of different hardness with two kinds of sensors randomly distributed: strain gauges and PVDF films. Through the preliminary experiments, it is shown that the fingertip can detect the difference between the textures of paper and wood with two PVDF sensors.

The main difficulty of such a fingertip with randomly distributed sensors is how to calibrate them. From the results of the preliminary experiments of this paper, we have revealed the ability of the fingertip to distinguish paper and wood. However, if the contact conditions such as contact force and/or contact position change, the sensing map for discrimination also changes. It would be very tedious to calibrate all the sensors with respect to the given Cartesian space, and the resultant system will be weak against disturbance. Such an architecture as proposed in [10] is necessary to train the sensory network to acquire meaningful measures through performing tasks.

Furthermore, the result shown in this paper is only about the possibility to sense two different textures. As we mentioned, the sensor is supposed to have several modalities, and may have more abilities to sense, for example, strain gauges embedded in different positions are supposed to sense different quantities, local strain and global force. We have to investigate what qualitative differences the fingertip can sense.

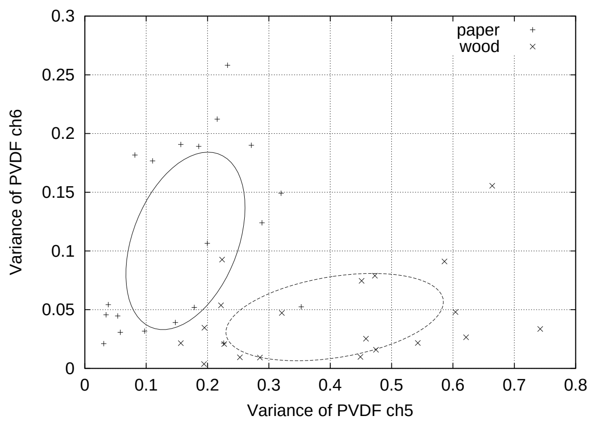

Figure 8: *A scatter diagram of the variance of the PVDF film channels 5 and 6 which are embedded in the epidermis and the cutis, respectively.*

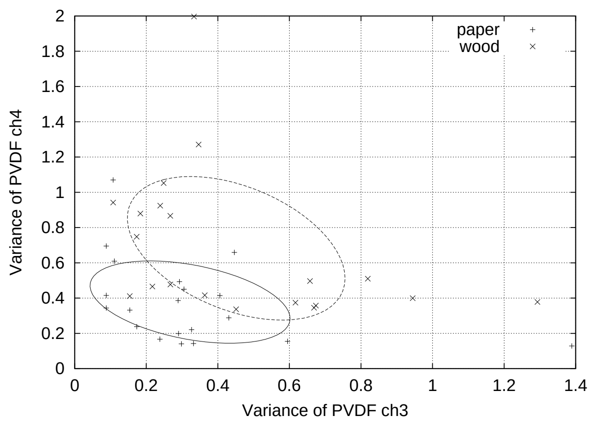

Figure 9: *A scatter diagram of the variance of the PVDF film channels 3 and 4 which are both embedded in the epidermis.*

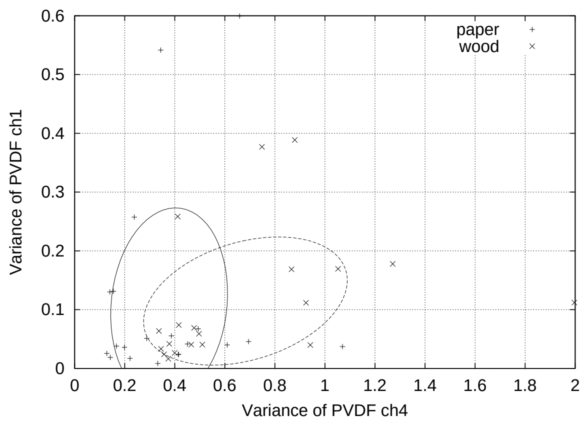

Figure 10: *A scatter diagram of the variance of the PVDF film channels 4 and 1 which are embedded in the epidermis and the cutis, respectively.*

Acknowledgments

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