Sensing Ability of Anthropomorphic Fingertip with Multi-Modal Sensors

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Abstract. This paper presents a unique design for tactile sensing: embedding as many receptors as possible randomly in soft material so as to provide different kinds of sensing modalities. Based on this design principle, an anthropomorphic fingertip has been developed. The fingertip consists of two silicon rubber layers of different hardness containing two kinds of receptors, strain gauges and PVDF (polyvinylidene fluoride) films distributed randomly as receptors. The experimental results are shown to demonstrate its sensing ability such as object discrimination.

1 Introduction

There are many studies aiming to realize human-like dexterous manipulation by robot hands. However, the realized dexterity is not sufficient so far. One of the reasons is that the existing robot hands do not have enough sensing modalities. Among such modalities, tactile sensing plays a great role to gather information about the object and contact conditions. Several kinds of tactile sensors are proposed (we can find a comprehensive survey until 1999 [1]). Especially, sensors with distributed receptors are effective to observe detailed contact conditions for adaptive manipulation. Several attempts have been made to make such sensors using pressure-conductive rubber [2], an optical transduction method with a position sensitive detector [3], capacitor arrays [4, 5, 6], a LC network [7], ultrasonic sensors [8], force sensing resistor [9], conductive fabric[10], and conductive gel [11].

The receptors of these sensors are regularly placed on a relatively hard surface. The regularity and hardness help the designer to build a sensing model to translate raw sensor signals obtained by the receptors to physically meaningful information such as a contact position, pressure, and a slip by considering the body/environment/task constraints. Owing to the model, that is, to the designer's knowledge, manipulation can be realized even with a few receptors. For example, the position of the manipulated object is easily calculated from configurations of the fingers with rigid fingertips. Regularly placed receptors lead to an easier sensing model. However, realized manipulation tends to be brittle against disturbance and modeling errors since it is based on very accurate estimation of kinematic and dynamic parameters.

If the receptors are placed on/in a soft surface, it becomes difficult to build such a model since the designer has to take the statics/dynamics of the surface material into account. On the other hand, however, the softness of the surface material provides useful information about the dynamical characteristics such as a slip and friction coefficient [12, 13, 14, 15]. Moreover, the sensing model based on the human designer's bias may exclude some useful information that is naturally included in the sensing signals.

Letting the robot develop the sensing model by itself through experience will be one solution to the problem of utilization as many sensing modalities as possible that the sensor naturally has, and to the problem of building a sensing model for adaptive and robust manipulation. If the robot can acquire the model by itself, the receptors do not need to be regularly placed nor need the fingertip to be rigid anymore. Receptors broadly distributed in the finger may enrich the information on the object. From a manufacturing point of view, it is easier to build a fingertip with randomly distributed receptors packed into very limited volume.

There have been very few studies designing a tactile sensor with randomly distributed receptors in soft material. To the best of our knowledge, only Shinoda and his colleagues proposed randomly distributed receptors in soft material [16, 17]. However, they only showed the characteristics of one receptor, and have not mentioned to characteristics of several distributed receptors.

In this paper, we propose a unique design for tactile sensing: to embed as many receptors as possible randomly in soft material so as to provide different kinds of sensing modalities. Based on this design principle, we have developed an anthropomorphic fingertip. The term "anthropomorphic" has two meanings. One is that this fingertip basically learns the sensing model through interaction with environment like the human fingertip. The other is that the structure of the fingertip is similar to that of a human consisting of a bone, skin, and randomly distributed receptors. The work described in this paper deals with more number and more kinds of receptors, and therefore more number of objects are discriminated than the our previous work [18].

The remainder of this paper is organized as follows. First, the design of the anthropomorphic fingertip is introduced. The fingertip consists of two silicon rubber layers of different hardness containing two kinds of receptors: strain gauges and PVDF (polyvinylidene fluoride) films randomly distributed as receptors. Then, several experimental results are shown to demonstrate its sensing ability.

2 Anthropomorphic fingertip

2.1 Design of the fingertip

Figure 1 shows a cross sectional view of the developed anthropomorphic fingertip. The fingertip has two layers made of two kinds of silicon rubber imitating the human finger: a dermis (inner) layer and an epidermis (outer) one. The rubber used for the outer layer is harder than that for the inner layer. A rod is inserted at the center of the fingertip to play the role of a bone. Many strain gauges and PVDF films are embedded in both silicon layers as receptors.

Since the fingertip has anisotropic structure, the same kind of receptors embedded in the different positions may sense different modalities. 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 strain gauge embedded near the rod 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 gauge is. 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. Thus, we suppose that the developed finger has different kinds of sensing modalities.

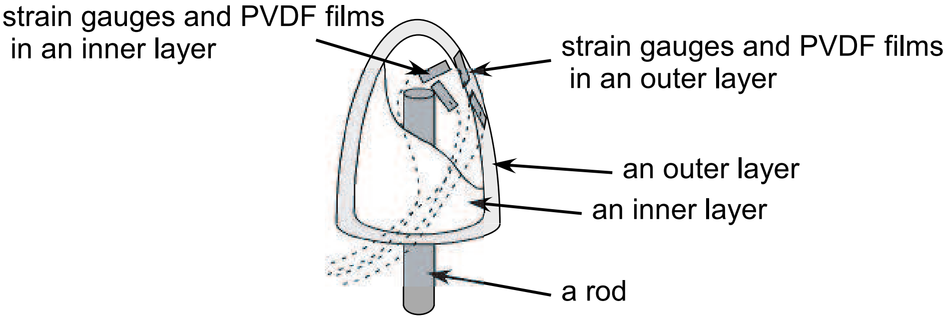

Figure 1: A cross sectional view of the developed anthropomorphic fingertip: The fingertip has two layers made of two kinds of silicon rubber basically imitating the human finger with its dermis and epidermis layers.

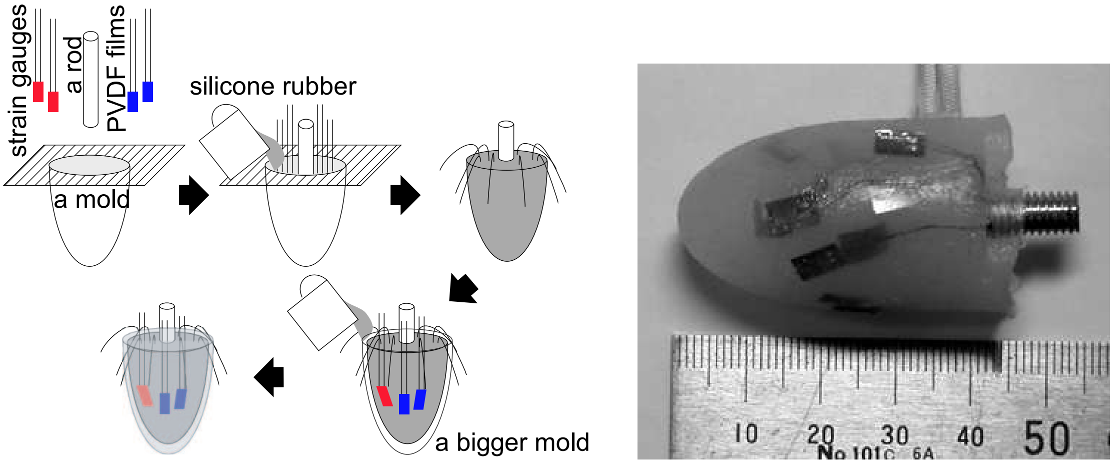

Figure 2: A procedure to make the anthropomorphic fingertip (left) and a photo of the completed fingertip (right)

2.2 *Production of the fingertip*

Figure 2 (left) shows a production process of the fingertip. First, the liquid silicon rubber is poured into the mold, and the strain gauges and the PVDF films are put into it. A rod 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 liquid silicon rubber is poured, the mold is put into the vacuum, and is baked in the oven again.

A completed anthropomorphic fingertip is shown in Figure 2 (right). Its diameter and length are 2cm and 5.5cm, respectively. The fingertip has twenty-four receptors; six strain gauges and six PVDF films are embedded in the inner layer, and also the same number of strain gauges and PVDF films are embedded in the outer layer.

3 Experiment

3.1 Experimental equipment

Figure 3 shows the experimental equipment. A robot finger has 3 DOFs and the anthropomorphic fingertip. Sensor signals from the strain gauges and the PVDF films are amplified and fed to a host computer via an A/D convertor. We investigated signal flows from the receptors through two tasks, rubbing and pushing.

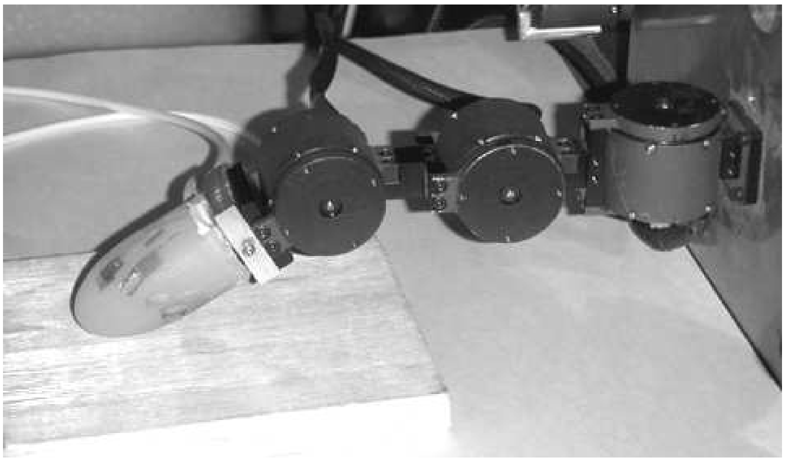

Figure 3: A robot finger equipped with the anthropomorphic fingertip

3.2 Discrimination between objects by rubbing

The sensory data are analyzed when the fingertip rubs cork board, paper, vinyl board, and wood board. The experimental procedure consists of three phases: 1) the fingertip is not touching an object, 2) the fingertip is pushing the object with a constant force, and 3) the fingertip is rubbing the object. The host computer collects sensory data during this procedure. The procedure is done fifty times for each object.

Sensory data observed by PVDF film #5 is shown in Figure 4. Large vibration is observed at first one second when the fingertip touched the object. Next, the fingertip only pushes the object with a constant force until about 2.2 second. Since the fingertip does not move, the sensor signal is relatively small. Then, the fingertip rubs the object until about 5.2 second, and large vibration is observed until the end of the rubbing.

The variances of magnitude of the PVDF films while the fingertip is rubbing the objects are calculated. Figure 5 shows a scatter diagram of these variances on various objects. The horizontal and vertical axes indicate the variance of the outer PVDF film #3 and the inner PVDF film #1, respectively. In the figure, variance of the variance for each object is indicated as an ellipse. The “noise” indicates the variance of the background noise. From this figure, we conclude that the fingertip can sense the textures of the objects by the differences between the PVDF films embedded in the outer and the inner layer.

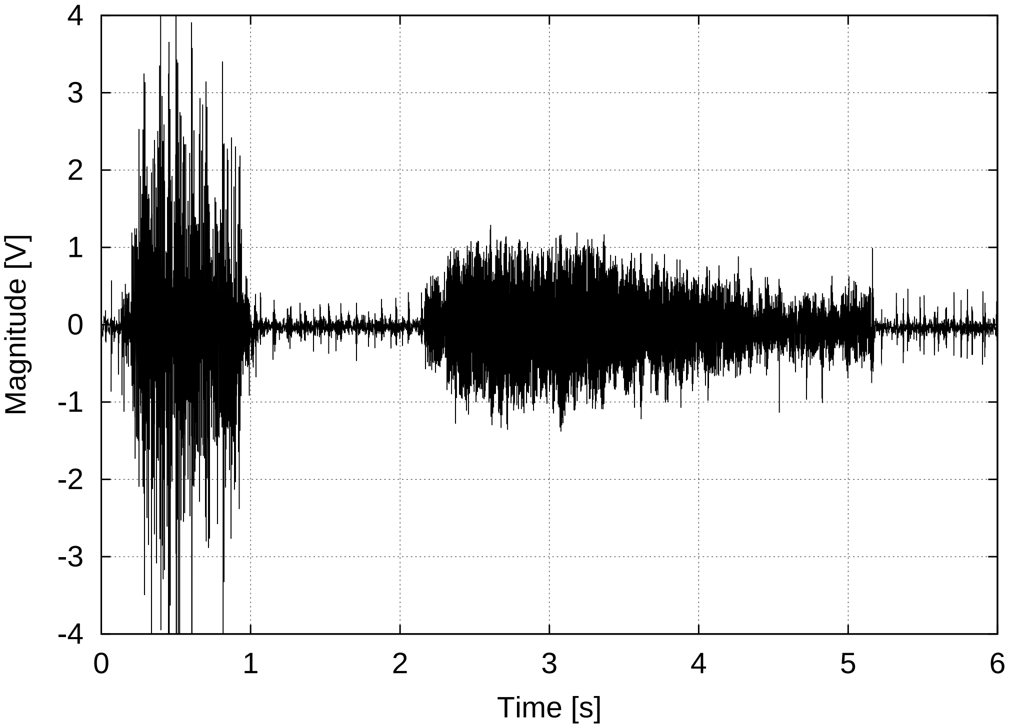

Figure 4: An output example of the PVDF film #5 which is embedded in the outer layer

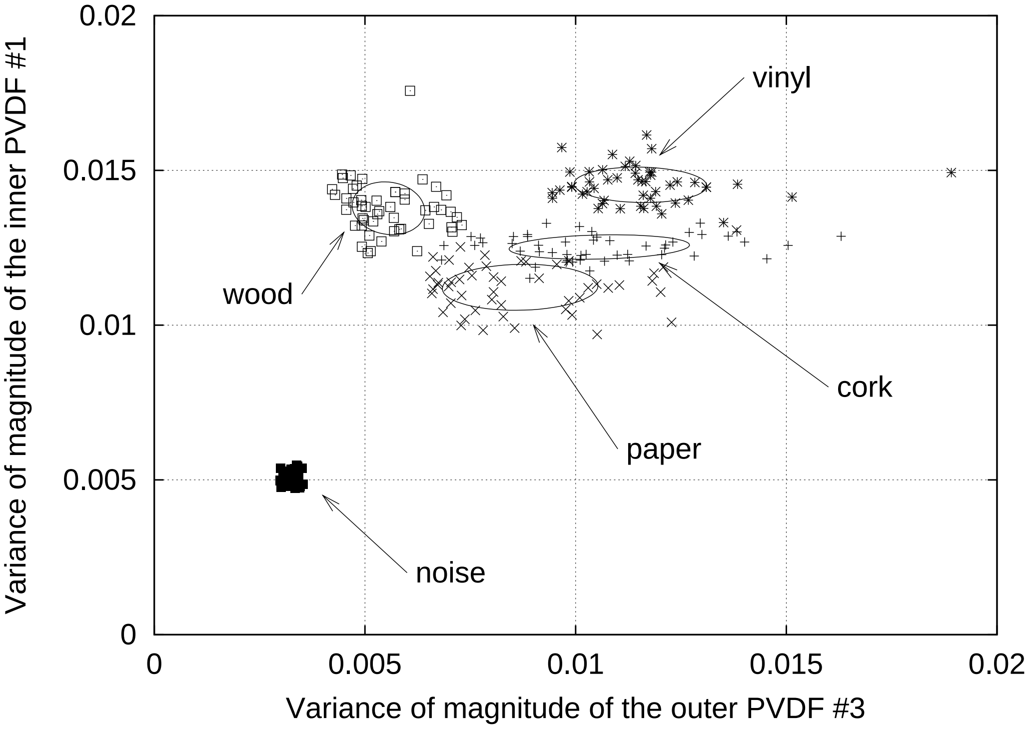

Figure 5: A scatter diagram that indicates variances of magnitude of the PVDF films

3.3 Discrimination between the objects by pushing

The sensory data when the fingertip pushes the objects are analyzed. The strain when the fingertip touches the object is reported to be varied by the friction coefficient of the object [13, 14]. Therefore, the sensory data of the strain gauges seem to be useful to observe the friction coefficient. In the experiments, we analyze differences of the strain when the fingertip touches cork board, paper, vinyl board, and wood board. To analyze differences of the strain, the pushing force should be constant. To make a pushing force constant, we applied a controller to keep the output of one strain gauge constant. The experimental procedure consists of two phases: 1) the fingertip is not touching an object and 2) the fingertip is pushing the object to keep the constant output of one strain gauge in the inner layer. The procedure is done fifty times for each object.

In this experiment, the pushing force is controlled so that the output of the inner strain gauge #4 is constant. Figure 6 shows a time course of the inner strain gauge #4 and the outer one #6. Each curve is an average of all trials. The fingertip does not touch the object until about 0.6 second, then it pushes the object. The inner strain gauge #4 has almost the same value for each object by the control. On the other hand, the outer strain gauge #6 outputs different values for different objects. However, in Figure 7 that shows averages and standard deviations of outputs for four kinds of objects between 4 and 4.01 seconds, standard deviations of paper and cork board overlap with the standard deviation of the other objects. Therefore, the fingertip can discriminate only vinyl and wood board by comparing the outputs of strain gauges that are embedded in the outer and the inner layers.

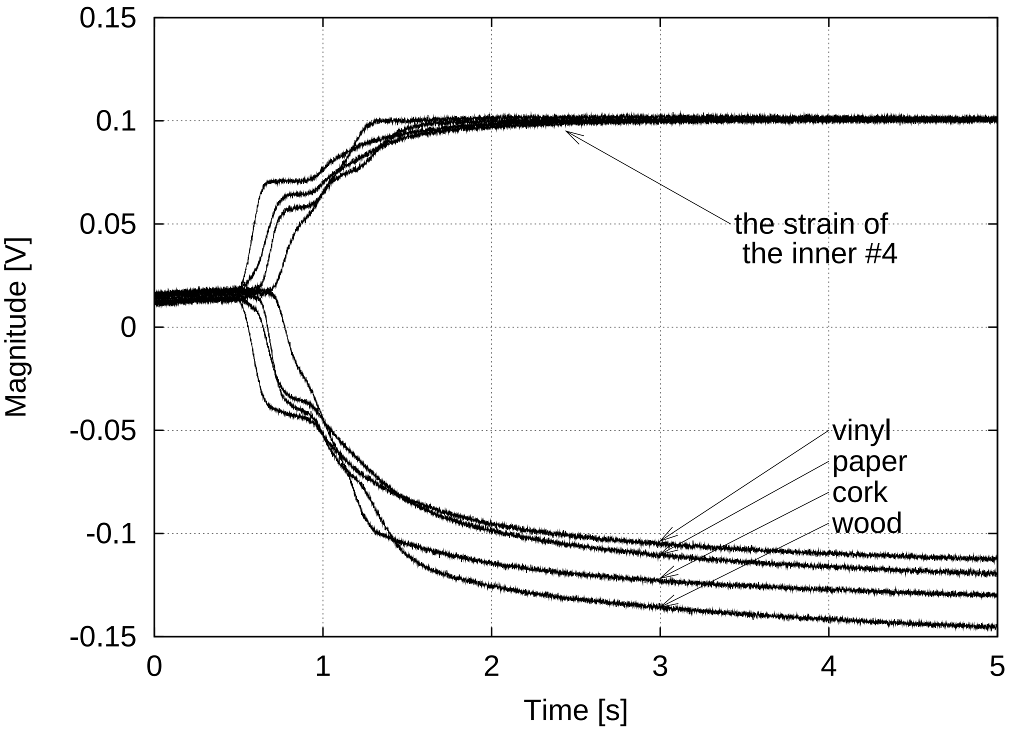

Figure 6: Comparing the outputs of the outer strain gauge #6

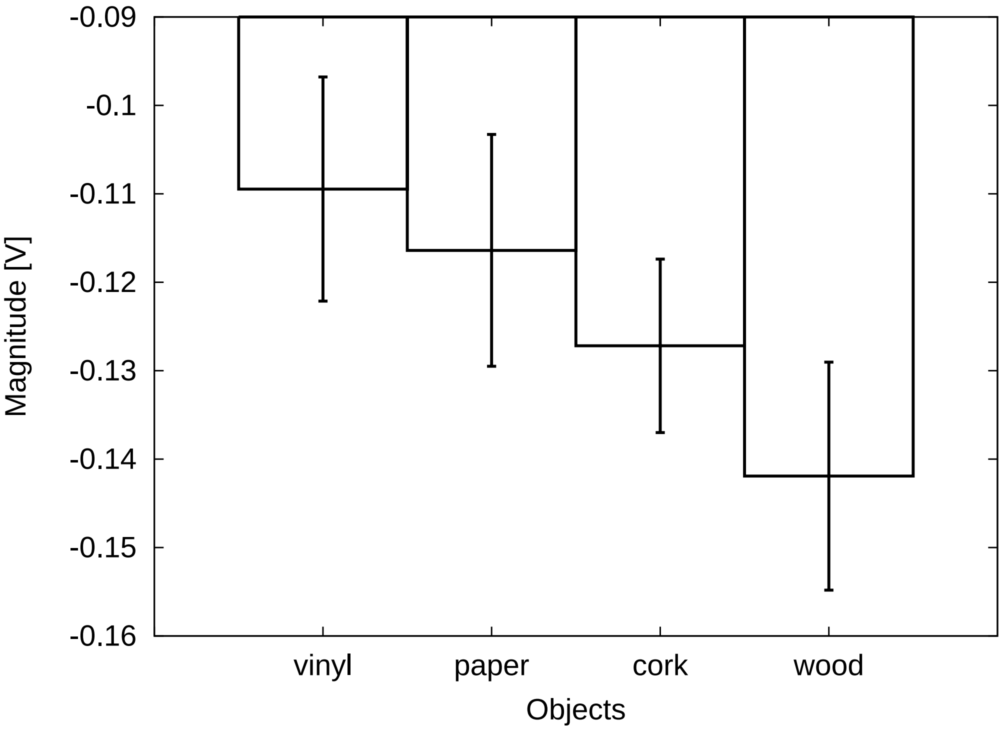

Figure 7: Comparing the outputs of the outer strain gauge #6 with standard deviation

4 Conclusion and future work

In this paper, the unique design for tactile sensing is proposed, and an anthropomorphic fingertip based on the design is developed. The fingertip has two layers of different hardness with two kinds of receptors randomly distributed: strain gauges and PVDF films. Through the preliminary experiments, it is shown that the fingertip can distinguish cork board, paper, vinyl board, and wood board by two PVDF films that are embedded in the different layers. However, the fingertip can distinguish only vinyl and wood board by strain gauges. We expect a kind of learning method enables to discriminate more objects, and that is the future work.

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