A Study on Tactile Resolution of Human Skin

Yoshiharu Tojo[1], Naoya Asamura[1], and Hiroyuki Shinoda[2]

1 Tokyo University of Agriculture & Technology 2-24-16 Koganei, Tokyo 184-8588 Japan
2 The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656 Japan

Abstract: In a previous paper, we proposed a hypothesis on human tactile resolution that is ``if we control appropriate two degree-of-freedom stimuli with intervals of a half of TPDT, we can produce any touch sensation that can be generated by normal stress distributions." However, since the apparatus was insufficient, the hypothesis was not examined clearly. The main reason of the insufficiency was that the stimulator was based on displacement control. Then if a subject's hand moved slightly on the apparatus, unexpected and not negligible stimulus arose. In this paper, we fabricated a new tactile stimulator based on pressure control. And we obtained experimental results that support the hypothesis.

Keywords: virtual reality, haptic interface, tactile display, spatial resolution, two-point-discrimination, teletaction

1. Introduction

Recently, needs for tactile displays are growing. However no tactile display that can present various cutaneous feeling with reality exists at present. One of the main questions before realizing such a display is the tactile spatial resolution of human skin. Evaluating the resolution is not very simple because of a paradoxical feature of the human tactile perception. For example, human skins are very sensitive to differences of small surface structures [1,2]. This suggests a very high spatial resolution of our skin perception. On the other hand, our two-point-discrimination-threshold (TPDT) that is the minimum distance with which we can distinguish a two-point contact as two, is not very short as it is 2-3 mm at fingertip and 7-10 mm at palm [3]. These suggest a human skin has poor spatial resolution.

In a previous paper, we proposed a hypothesis [4] that is ``if we control appropriate two degree-of-freedom stimuli with intervals of a half of TPDT, we can produce any touch sensation that can be generated by normal stress distributions." However, since the apparatus was insufficient, the hypothesis was not examined clearly. The main reason of the insufficiency was that the stimulator was based on displacement control. Then if a subject's hand moved slightly on the apparatus, unexpected and not negligible stimulus arose.

In this paper, we fabricated a tactile display based on pressure control. And we report psychophysical experiments using the apparatus to examine the hypothesis.

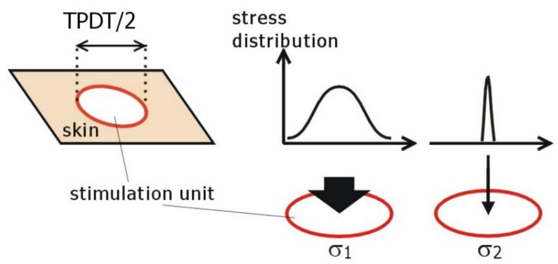


Fig. 1: The 2 DOF stress bases (a concentrated stress distribution and a smooth one) that are required for realistic tactile display.

2. A hypothesis on human tactile resolution

The hypothesis that we proposed in the previous paper [4] is as follows.

Hypothesis
If we control two degree-of-freedom (2 DOF) stress distribution σ_1 and σ_2 which are shown in a **Fig. 1** with intervals of a half of TPDT, we can produce any touch sensation that can be generated by normal stress distributions.

Since we can perceive the stimuli given with separation larger than TPDT as two independent stimuli, it will be necessary that we should give the tactile stimuli with interval of TPDT independently. This assumption says that preparing 2 DOF stimuli for one stimulation point is a sufficient condition for displaying any tactile feeling caused by normal stress distribution. The 2 DOF stimulation basis σ_1 and σ_2 are illustrated in Fig. 1. One is a smooth and uniform stress distribution and the other one is a concentrated one. It is obvious that a realistic tactile display requires these two stimuli because the human can distinguish between them easily. To examine if it is sufficient, we confirm if the combination of σ_1 and σ_2 can produce an intermediate concentration of stress that is generated by an object with an intermediate curvature. If it is true, it strongly supports the hypothesis because any object surfaces are composed of multiple surfaces with various curvatures.

3. Stimulation based on pressure control

Fig. 2 shows our new apparatus to control pressure on a skin. The stimulator has a double piston structure. Air supply from two independent syringes drives the S1 and S2. The top surface of S1 with mass of 1.7 g applies uniform normal stress σ_1 while the pin S2 of 0.4 g applies concentrated normal stress σ_2 to the skin surface. These syringes 1 and 2 are controlled by PC through rotation of ultrasonic motors.

The diameters of the stimulator S1 and S2 are 5 mm and 0.5 mm, respectively. The skin part examined in this research is the thenar whose TPDT is about 10 mm.

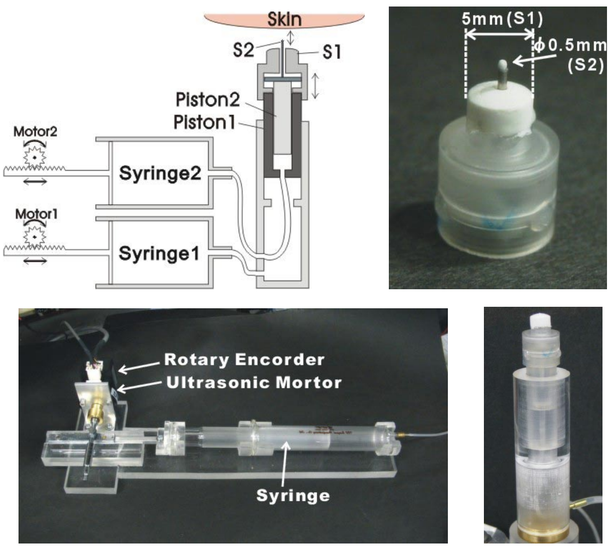


Fig.2: Tactile display based on pressure control.

We confirmed that this apparatus could control the pressure regardless of the position of the skin surface through the following experiments. We measured pressures by S1 and S2 applied to the surface located at various heights z = 0, 1, and 2 mm, respectively. As Fig. 3 shows, the measured pressure for a certain syringe motion was almost independent of the height z. This results show our apparatus can control the pressure on the skin. And the pressure is insensitive to the movement of the subject's hand.

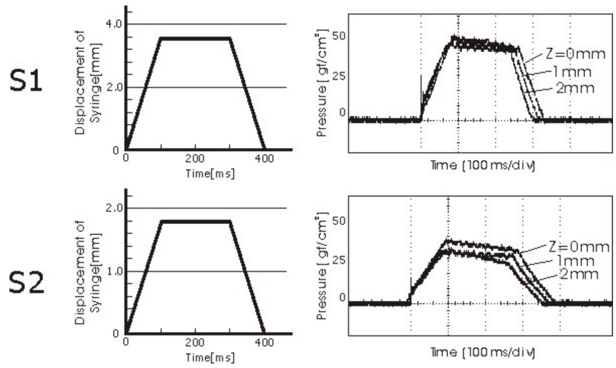


Fig.3: Displacement of the syringe (left) and the measured pressure on an object surface located at various height z = 0, 1, and 2 mm (right).

4. Experiments

As described in section 3, the top of S2 is made of a sphere of 0.5 mm in diameter. In this section, we examine experimentally if combination of S1 and S2 stimulation can generate feeling of contact with a sphere of an intermediate curvature between S1 and S2. If it is possible, the hypothesis in this research is strongly supported as described in section 2.

＜Curvature discrimination experiment＞

Before the main experiment, we evaluated human capability of discerning curvature that is given within a circle of TPDT on the thenar. **Fig.4** shows the objects used in this discrimination test. We applied two stimuli to a subject successively, a standard stimulus and a comparison stimulus. Immediately after that, the subject answered which curvature was larger. We prepared two standard stimuli. The First standard stimulus was contact with a sphere with the radius of 5 mm, while the second one with the radius of 1mm. We applied these stimulus pairs at 4 times randomly to six subjects with eye-masks and headphones. All stimuli were applied to the skin for about 500 ms by the same signal pattern.

The left figure in **Fig. 5** shows that when the standard stimulus was a sphere with 5 mm radius, only a 1 mm-radius sphere and a 1.5 mm-radius sphere were significantly distinguishable from the standard sphere. From the right figure in Fig. 5, when the standard stimulus was 1 mm- radius sphere, only a 0.25 mm-radius sphere was clearly distinguishable. These results suggest that the human can distinguish few steps (possibly three steps) of object curvature from flat surface to sharp tip, which touches the thenar within the TPDT circle. Therefore, we thought that for verifying the hypothesis, it is only necessary to check whether a feeling of sphere with a curvature of 1mm radius can be produced by combination of S1 and S2 (with the radius of 0.25 mm).

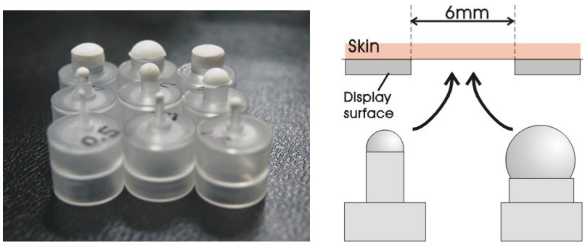


Fig.4 : Curvature discrimination experiment.

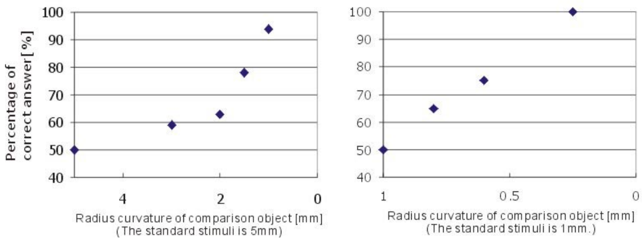


Fig.5 : The results of curvature discrimination experiment. Correct answer ratios that the subjects answered the correct order of the curvature between the standard stimulus and the comparison object.

<Generating synthesized tactile feeling>

A standard stimulus and a comparison stimulus were applied to subjects successively, and they answered whether the pair of the stimuli was composed of "identical" or "different" stimuli. The synthesized stimulus by S1 and S2 is called Virtual stimulus, and the stimulus by the surfaces of spheres with the curvature radius of 1mm, 0.25mm, and 5mm are called R1, R2, and R3, respectively. R1, R2, and R3 were compared with Virtual stimulus, respectively. In addition, we also investigated how correctly subjects could answer when we gave an identical stimulus of R1 twice successively. The four stimulus pairs R1-R1, R-Virtual, R2-Virtual, and R3-Virtual were applied to 7 subjects 10 times in a random order. For Virtual stimulus, a signal pattern (in **Fig. 6**) that generated the most similar feeling to R1 was used. Other experimental conditions followed the curvature discrimination experiment.

Fig. 8 shows the percentage of answer "identical." For R1-Virtual pair, the subjects felt they were identical at the ratio of 60 %. Considering the ratio for R1-R1 pair was 71 %, we can say R1 and Virtual were felt very similar. This result supports the hypothesis because S1-S2 stimulator could a feeling of sphere with an intermediate radius between S1 and S2.

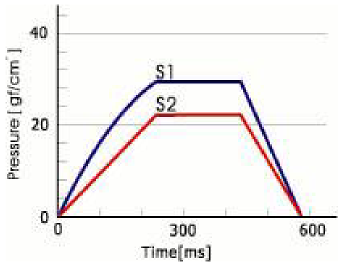
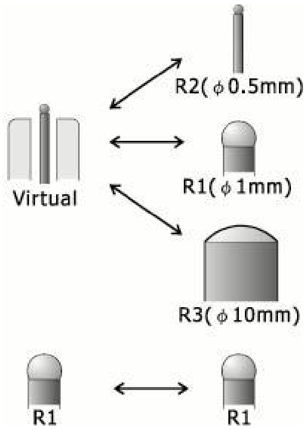


Fig. 6: Signal pattern of S1 and S2 for "Virtual" stimulus.



Standard stimulus Comparison stimulus

Fig.7: Stimulus pairs.

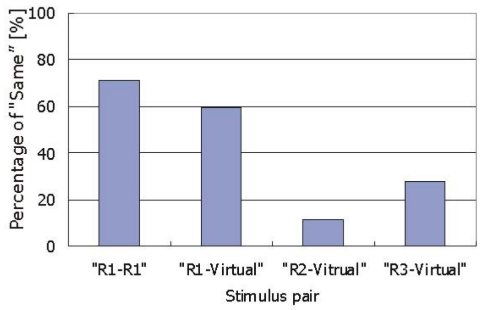


Fig. 8: The result of tactile composition experiment.

References

[1] G. D. Lamb,``Tactile Discrimination of Textured Surfaces," Psychophysical Performance Measurements in Humans," J. Physiol. Vol. 338, pp.551-565, 1983.

[2] J. W. Morley, A. W. Goodwin and I. Darian-Smith, ``Tactile Discrimination of Gratings," Experimental Brain Research, Vol. 49, pp.291-299, 1983.

[3] S. R. Geiger ed. "Handbook of Physiology section 1: The Nervous System," American Physiological Society, 1984.

[4] N. Asamura, T. Shinohara, Y. Tojo, N. Koshida, and H. Shinoda, "Necessary Spatial Resolution for Realistic Tactile Feeling Display," Proc. IEEE Int. Conf. Robotics and Automation, pp. 1851-1856, 2001.