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A Cutaneous Feeling Display Using Suction Pressure

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Abstract: In this paper, we propose a novel tactile display by controlling suction pressure. The method is based on our discovery of an illusion that pulling a skin through a hole creates a sensation as if a stick is pushing the skin. Based on this property of perception and multi-primitive stimulation method, we confirmed that we can produce tactile sensation from concentrated pressure to smooth surface by a sparse array of suction holes. We show the principle of the tactile display and experimental results that support the principle.

Keywords: tactile display, haptic interface, air pressure, suction pressure

1. Introduction

Although many tactile displays using pin arrays[1)], a device using surface acoustic wave[2)], electrical stimulation[3)] and radiation pressure of ultrasound[4)] were proposed, they have not been feasible for producing various touch feelings on a large area of skin.

In this paper we propose a new stimulation method that is applicable to a large area of skin like a palm.

The method is based on our discovery of an illusion that we feel as if a stick is pushed on the skin when we lower the air pressure in a dimple of a plate on which we put the hand. Using this property of perception that our skins are insensitive to the positive and negative of pressure, our device displays various tactile sensations by controlling suction pressure distribution on the skin.

Another key concept is a multi-primitive stimulation. By arraying stimulators that generate two kinds of pressure patterns (tactile primitives), we expect the device displays sensations varying from fine textures to smooth objects.

In traditional tactile displays using pin arrays, applying large force on a skin causes large displacement near the contact point, which makes contact between skin and stimulators unstable. In this method, however, since skin surface is constrained on a plate, we can precisely control each stimulation point independently. In addition, because this method is based on air pressure control, the stimulators are easily integrated using remote valves.

In section 2, we illustrate the concept and principle of our large area tactile display. In section 3 and 4, we demonstrate psychophysical experiments and their results.

2. Methods

2.1 Suction Pressure Stimulation

This research is based on a discovery of the following illusion. Fig.1 illustrates a cross-section of a skin put on a rigid plate with a hole. When we lower the air pressure of the hole, we feel as if something like a stick pushes up the skin surface.

When we asked 10 subjects “what do you feel this stimulation is like?” with a suction hole of 6 mm in diameter contacting with the palm, they answered they felt as if the skins were pushed by a muddler. In the answers of 8 of the 10 subjects, they considered suction pressure stimulation as a contact with sticklike object such as a muddler.

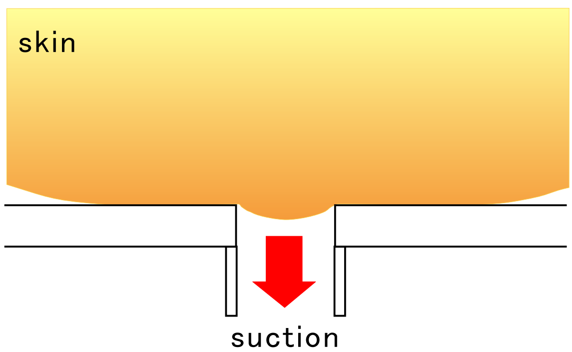

Fig. 1: Schematic illustration of suction pressure stimulation. Drawing air causes a sensation as if something is pushing up.

This illusion suggests that our skin is insensitive to the positive and negative of the stress in the skin. This is supported by a prevailing belief that our mechanoreceptor detects not stress or strain directly but strain energy.

We examined the strain energy distribution in the skin using Finite Element Method (FEM). The graphics in Fig.2 (a) and (b) shows the strain energy in a

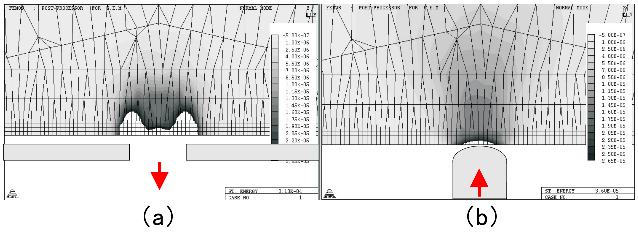

Fig. 2: Distribution of strain energy by suction pressure (a) and positive pressure caused by sticklike object (b). The distributions at skin surface are different from each other.

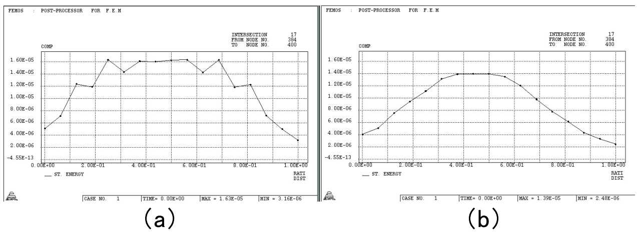

Fig. 3: Distribution of strain energy near the receptors. Suction pressure (a) and positive pressure caused by sticklike object (b). The distributions are similar to each other.

skin under air suction (a) and stick pushing (b). Physical parameters of Young's modulus, Poisson's ratio, and depths of the mechanoreceptors followed a previous study by Maeno[5]. Stress distributions look quite different between the two cases.

On the other hand, the strain energy distribution at the receptor level plotted in Fig. 3 (a) and (b) shows significant coincidence. This explains the insensitiveness of our skin to the difference between the two stimulations.

A tactile display using the suction pressure in stead of pushing pins or sticks will possess the following advantages. First, the skin surface is constrained on a plate even when we apply an intense stimulation. Then stimulation at a point does not interfere with neighbor stimulators. The second advantage is that use of air pressure enables us to integrate stimulators easily with remote valves.

2.2 Multi Primitive Tactile Stimulation

Another key concept of the device is "Multi Primitive Tactile Stimulation (MPTS)." In our system, we array stimulators that apply two kinds of stress patterns (tactile primitives). One of the two primitives is a concentrated stress distribution given by a small hole. The other one is a smooth stress distribution given by a large hole. See Fig.4. The two primitives are arrayed with intervals comparable to the two-point-discrimination-threshold (TPDT) [6]. We expect the combination of the two primitives produces various tactile feeling from fine textures to smooth surfaces.

In our previous study[8], perceived curvature of a virtual object created by combination of the two tactile primitives is tested. And we obtained experimental results that the perceived curvature changed continuously with the ratio of the intensities of the two primitives.

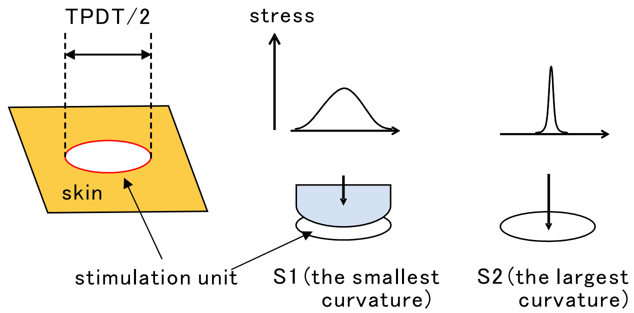

Fig. 4: Illustration of two tactile primitives[7]. A smooth pressure distribution S1 and concentrated one S2.

This method MPTS requires dramatically smaller density of stimulators than that would be required in single-primitive stimulation. Regarding a palm, the TPDT is about 10 mm[9]. Our experiment told that the maximum stimulator interval in MPTS for a palm was 5 mm. The density is feasible for fabrication.

3. Experiment

3.1 Overview

In the previous work[8], we confirmed perception of various curvatures is controllable by the two tactile primitives S1 (smooth) and S2 (concentrated) using suction pressure inside a circle with the diameter of TPDT. One concern is whether multiple S1 primitives can create a sensation of a smooth surface larger than TPDT or not. In this paper, we examine this problem.

The S1 arrays used in this experiment consist of suction dimples with their intervals of 5 mm. The pressure in the dimple was controlled through a hole 2.5 mm in diameter. The edge of the dimple formed with elastic material was rounded to prevent stress concentration at the edge. Fig.5 illustrates the shape of stimulation unit. The arrays are formed on a round-shaped surface to fit a palm curve.

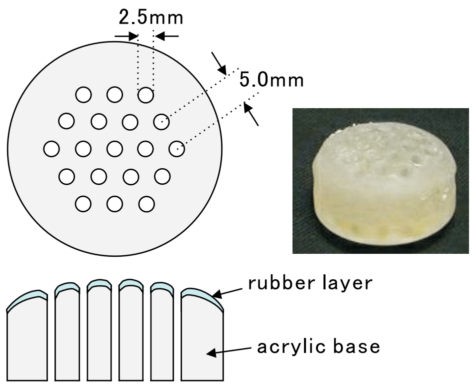

Fig. 5: A shape of stimulation unit and its picture.

3.2 Spatial and temporal patterns of suction

We provided three kinds of stimulations, A-mode: giving suction pressure by the single central hole, B-mode: central hole and surrounding 6 holes were used, and C-mode: all holes were active.

To produce a large plane sensation, we drove them with displays to synthesize a realistic contact. (In C-mode, A-mode is activated at first, then secondly the surrounding 6 holes are activated 10 ms after A-mode, and outermost 12 holes are activated 30 ms after the A-mode started.)

Their final pressure was also different. From the central hole, we pulled a skin with the largest intensity and outermost holes with the smallest. The pressure was determined experimentally so that it created the most realistic feeling of a smooth object.

Fig.6 shows these three stimulations. Holes of the same color are driven simultaneously.

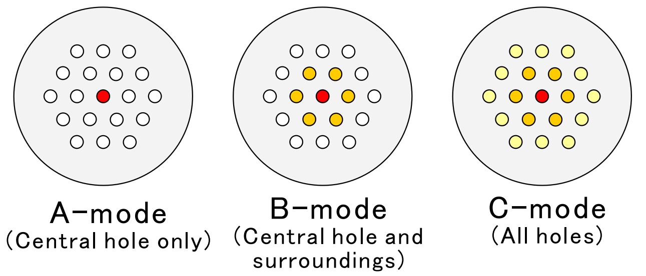

Fig. 6: Three patterns of stimulations. A: Giving suction pressure by the single central hole. B: Central and surrounding 6 holes are used. C: All holes are active.

Fig. 7 is a block diagram of the experimental system. We control three valves in order to provide adequate pressure. Suction pressure was determined by the time during which the valve was open. The tanks inserted between the pump and the valves operate as Low-Pass-Filters of air pressure.

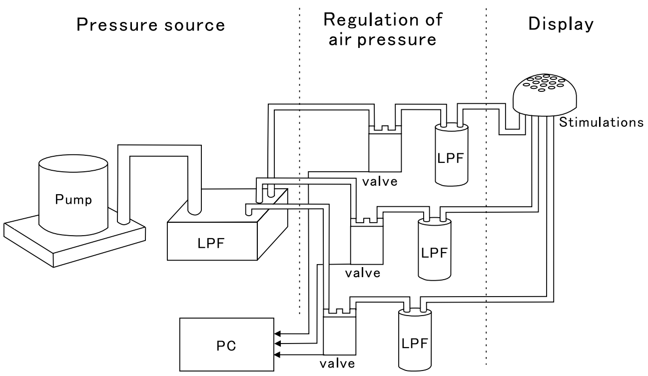

Fig. 7: Block diagram of the system.

3.3 Comparing size of stimulated area with reference objects

We evaluated size of suction pressure stimulations by comparing it with actual objects. We provided suction stimulation to the left hand of a subject and an actual object to the right hand. Then subjects were asked which contact area was larger. The actual reference objects were three cylinders made of acrylic whose diameters were 5 mm, 10 mm, and 20 mm, respectively. 8 subjects (7 males and 1 female) compared 5 times for each stimulation (A, B and C) without visual and auditory information.

3.4 Comparing smoothness of suction pressure stimulations with actual objects

We evaluated smoothness of the virtual smooth surface produced by C-mode. Two reference objects, a smooth surface with curvature radius 10 mm (See Fig.8(a)) and an uneven surface with small balls with the radius 2.5 mm (See Fig.8(b)) are compared with the C-mode stimulation. The subjects answered which stimulation felt smoother between the C-mode stimulation and that of a reference object. 8 subjects (7 males and 1 female) compared 5 times for each stimulation without visual and auditory information.

(a) (b)

Fig. 8: Two reference objects. A smooth surface with the curvature radius of 10 mm (a) and an uneven surface with 19 steel balls with the radius of 2.5 mm (b).

4. Results

4.1 Comparison of size

Fig.9 shows result of the comparison of perceived size between suction pressure stimulations and actual reference objects. Horizontal axis indicates evaluated diameter of the contact area of virtual surface. The number shows the order of the contact area. The number 1, for example, means that the contact area felt smaller than a circle of 5 mm in diameter. Vertical axis exhibits the number of the answer.

A-mode was evaluated as smallest one and its size was estimated less than 5mm diameter where the central hole had 2.5mm diameter. B-mode and C-mode were also evaluated as the appropriate size. This result suggests that the stimulations produced varying perceptions from a stick with less than 5mm diameter to larger surfaces up to 20 mm diameter.

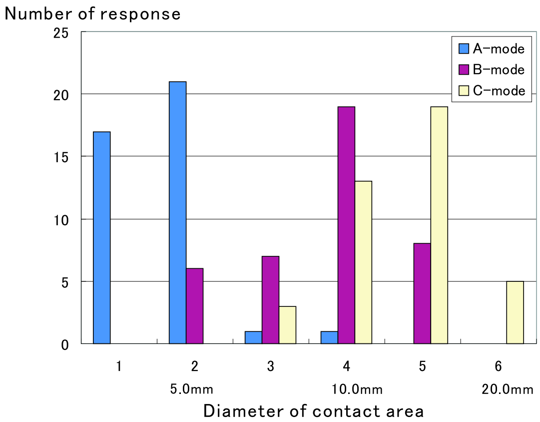

Fig. 9: The result of size comparison.

4.2 Smoothness comparison

The result is shown in Fig.10. The "number of response" of class (a) was the number of the answer that the C-mode stimulus felt as smooth as the smooth reference object. The class (c) means that the C-mode stimulus was similar to the uneven reference object. The class (b) means the stimulus was smoother than class (c) but more uneven than class (a). The number of class (d) is the number of the answer that the C-mode stimulus felt rougher than the uneven reference object. This result shows the perceived smoothness of C-mode stimulation was a little rougher than that of the actual smooth surface.

When we examine this result, however, we have to consider one fact that the comparison between virtual surface and actual surface was not very easy as we had expected. In an additional experiment we asked the subjects which was smoother between the two reference objects. Then only 4 subjects of 8 could identify the smoothness correctly, while the other 4 subjects were not able to distinguish the two correctly. They answered these two stimulations were identically smooth.

Therefore the result of Fig.10 is that of the 4 subjects who were sensitive to the difference of roughness. For another 4 subjects, the C-mode stimulation was identical to the smooth reference object.

5. Summary

In this paper, we proposed a new method of tactile display using suction pressure. The key of the display is a perception property that our skin can not distinguish the positive and negative of the stress, and a concept of multi-primitive stimulation.

We fabricated the display system using suction pressure which produced a sensation varying from a thin stick contact to a smooth surface contact.

However, regarding the display of smooth surface contact by distributed suction pressure, we have to report that the half of the subjects felt weak unevenness.

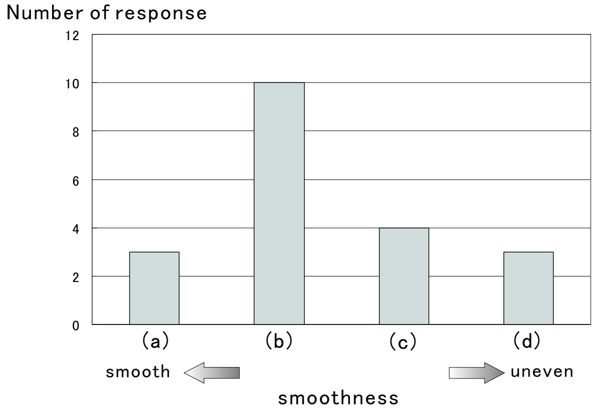

Fig. 10: The result of size comparison. (a): As smooth as the actual reference object. (b): Between the smooth reference and the uneven reference. (c): As uneven as the uneven reference. (d): Rougher than the uneven reference.

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