Suction Pressure Tactile Display Using Dual Temporal Stimulation Modes

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Abstract: In our former papers, we have proposed "Multi Primitive Tactile Stimulation" method for realizing a whole-palm-covering tactile display. Preparing two different kinds of tactile stimuli (primitives) within a unit area, we have realized various tactile sensations from a sharp-pin to a smooth surface by combination of them. In this paper, we propose another method for preparing multiple degree-of-freedom (DOF) tactile stimulations. That is temporal primitives. It is expected that we can activate two kinds of superficial mechanoreceptors selectively if we control the temporal pressure patterns of the stimuli precisely, using the difference of the frequency characteristics among the tactile mechanoreceptor types. We realized stable temporal stimuli by "Suction Pressure Stimulation" which was also proposed in the previous papers, and confirmed that we could realize multi DOF stimuli by the temporal primitives.

Keywords: *Tactile Display, Haptic Interface, Virtual Reality.*

1. Introduction

In our former papers, we have proposed "Multi Primitive Tactile Stimulation (MPTS)" method for realizing a whole-palm-covering tactile display. In MPTS, we assumed that preparing appropriate multi DOF (degree-of-freedom) stimulators can dramatically reduce the stimulator density for displaying various realistic tactile feeling. [1]. This idea is similar to the RGB color display for the visual system. MPTS is based on the hypothesis that any tactile feelings can be produced by combination of basic skin-deformation patterns as Yellow is produced by combination of Red and Green. We named the basic deformation patterns required within a unit area "primitives" [2]. Since the TPDT at the palm is about 10mm, the maximum array spacing of the primitives is expected to be heightened up to a comparable value to 10 mm for covering the tactile feeling on the palm.

In the previous papers, we focused attention on the human excellent ability to discriminate perceived sharpness of the objects whose tips are smaller than TPDT. For example, we never misidentify the tip of the pencil with the bottom end of it at any part of the skin. Therefore we assumed that the simplest set of primitives is a pair of a stress pattern for a sharp pin and one for a dull plane surface. Our first prototype was based on these two primitives using "Suction Pressure Stimulation."

Suction pressure stimulation is based on a discovery of a tactile illusion that human can not discriminate suction form compression when the skin is pulled by negative air pressure through a small aperture. In the first prototype, two kinds of suction holes were empirically used for realizing two primitives [3]. The smaller hole (diameter is about 2mm) with solid edge is for sharp-pin sensation, while the larger hole (diameter is about 4mm) with soft edge is for plane surface. We confirmed that combination of them could make medium sensation between pin and dull surface.

The previous experiments partly supported the multi-primitive theory, however, the results was still lacked the reproducibility to fully convince the theory. Most serious problem of the former method is alignment of the stimulators. In the former papers, two primitives were applied on the different points on the skin surface within a stimulation unit. As a result, contact conditions between skin and stimulators were sometimes unstable, which resulted in a lack of reproducibility. In MPTS method, the ratio of two primitives should be precisely controlled.

In this paper, we propose a new set of primitives which also uses the suction pressure. The difference from the former one is that single suction hole provides the multiple primitives. We changed the temporal profiles of pressure patterns so that identical hole can provide multi DOF stimuli. Using these primitives, we can expect that MPTS is realized stably, and that physical structure of the device is simpler than the former one. We show fundamental study of temporal primitives using single suction hole and discuss the feasibility of the proposed method.

This study is based on a casual discovery that the temporal profile of the suction pressure strongly influenced the perceived curvature in the research of the MPTS. Since some researches [4],[5] suggest that the human uses the ratio between SA-I and RA-I signal intensities for sensing surface sharpness, it is expectable that controlling the stimulation-intensity ratio between SA-I and RA-I using their temporal characteristic changes the perceived sharpness, which means that two independent spatial primitives are unnecessary for realistic tactile display.

2. Temporal Primitives

In this paper, we propose a new set of primitives. That is temporal primitives. Fig. 1 shows the schematic diagram of the suction pressure tactile display using temporal primitives. Each hole is driven by two independent mechanisms. One is an air pressure regulator working at time constant of *T*. Tentatively we assume *T* is as long as 50 ms. We call this stimulus S-primitive. The other one is an electromagnetic valve that induces high-frequency (~40Hz) pressure alternation. We call this stimulus R-primitive. The intensity of latter one is also controlled at a time constant *T*. Each mechanisms is intended to selectively stimulate SA-I receptors and RA-I receptors respectively [6].

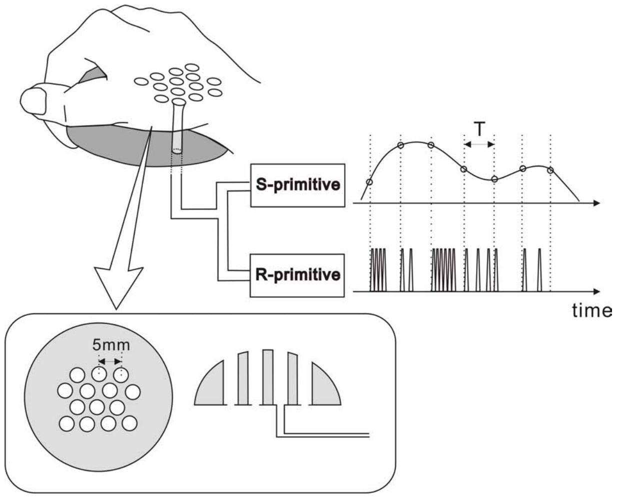

Fig. 1 Schematic diagram of the temporal primitives

3. Experiments

In order to know the fundamental property of the temporal primitives, we fabricated prototype suction pressure tactile display system. Fig. 2 shows the block diagram of the experimental settings and Fig. 3 shows the photo of the prototype system. In the following experiment, only one hole was activated to evaluate the tactile feeling space of the single suction hole with dual temporal stimulation modes.

The valve can switch the connection of the suction hole. “On” state is that the hole is connected to the bottle. “Off” means the suction hole is opened to the atmosphere and the connection to the hole is closed. The absolute pressure of the bottle is controlled by the air pressure regulator.

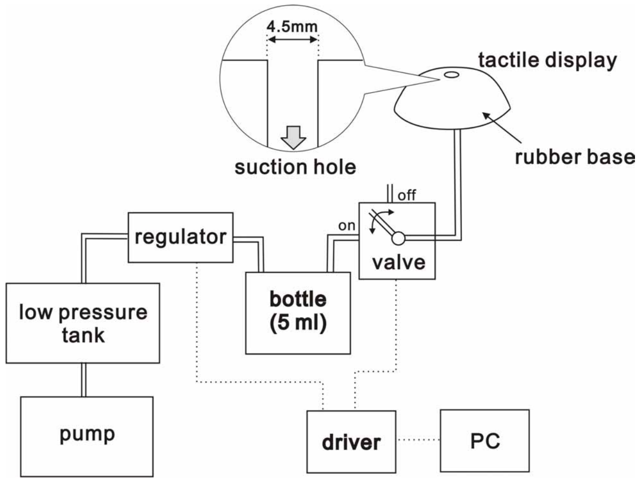

Fig. 2 Block diagram of the experimental settings.

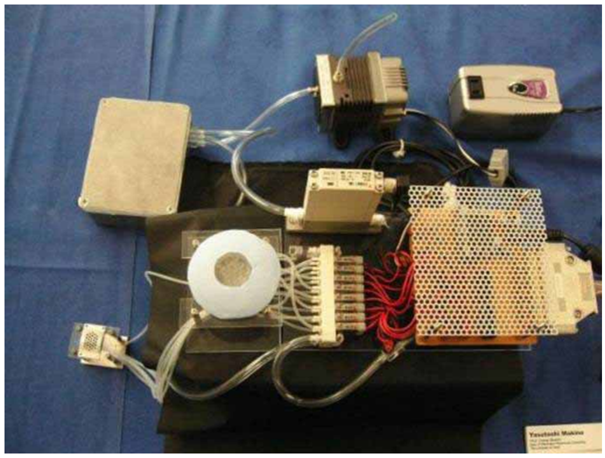

Fig. 3 Prototype system for suction pressure stimulation

Using these apparatus, we prepared three stimuli.

Stimulus (1) --- S-primitive

Only the regulator is driven. The valve is always “on”. The air pressure changed with a large time constant so as to stimulate SA-I receptors selectively.

Stimulus (2) --- S-Primitive + R-Primitive

The regulator lowers the air pressure. At the same time, the valve is switched twice at 40 Hz. Then the valve is constantly “on” and the hole pressure is lowered with a large time constant. This stimulus is intended to simulate combination of the two temporal primitives.

Stimulus (3) --- R-primitive

In the beginning, the valve is “off”, and then the regulator is activated for lowering the pressure of the bottle. After that the valve is switched only twice at 40 Hz and returned to “off.”

Fig. 4 shows the observed pressure patterns at the skin surface. Fig. 4 (a) shows the overall profiles of three stimuli. Fig. 4 (b) is zoomed graphics at the rising edge of the stimuli. The maximum pressure of the stimuli was determined beforehand so that subjects felt no painful sensations. The threshold of the pain was investigated in a pilot experiment. The threshold of the pain was about 2 times larger than the final pressure of S-primitive. The suction hole had its edge as shown in Fig. 2 and its diameter was about 4.5 mm which was smaller than TPDT at the palm.

The experiments were conducted as follows.

1) The subjects sat on a chair in a comfortable posture. White noise sound was given to the subjects so as to eliminate auditory cues.
2) Each subject was required to put the left palm on the tactile display with elbow rest.
3) One of the stimuli among three was given to the left palm in random order.
4) The subjects were asked to compare the virtual stimulus with real reference objects using right hand and to choose the most similar one among them.
5) Subjects were allowed to feel the stimulus as many times as they wanted.
6) Three stimuli were given five times each to one subject in total.

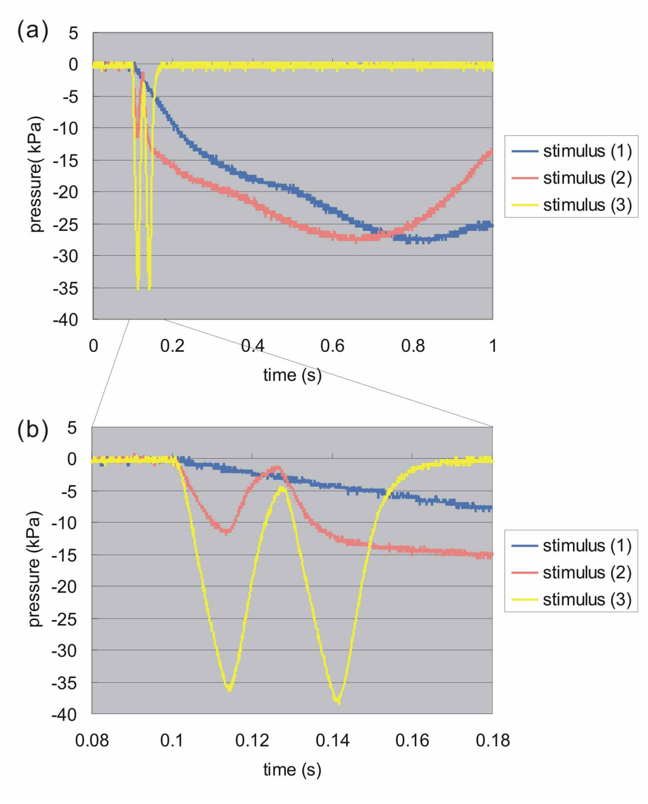

Fig. 4 Three pressure patterns used in the experiment. (a) shows the overall profiles of the stimuli. (b) is zoomed graphics at the rising edge for 0.1s. The stimulus (1) is S-primitive and the stimulus (3) is R-primitive. The combinations of two primitives are shown as the stimulus (2).

We prepared seven reference objects (described in Fig. 5). The reference No. l, 2, and 3 were hemispherical objects. Their curvature radii were 2.5mm, 2.0 mm and 1.5mm, respectively. Reference No. 6 and 7 were cylindrical objects. We prepared truncated hemispherical references as No. 4 and 5 because the subjects in the pilot experiment reported that they perceived the shape of such objects for stimulus (2). These references were chosen intentionally so that the subjects could find a similar reference to the virtual stimuli. The radii of the cut hemisphere were 1.5 mm and 2.0mm (given with a lowercase letter r in Fig. 5). And the radii of the cross-sectional surface were about 1.0mm and 1.5 mm (given with capital R).

The difference of the reference No. 5 from No. 2, No. 6 or No.7 was clearly discriminable from the evidence of the edge though it might seem very similar. The subjects were 6 males and l female who knew nothing about the purpose of the experiment.

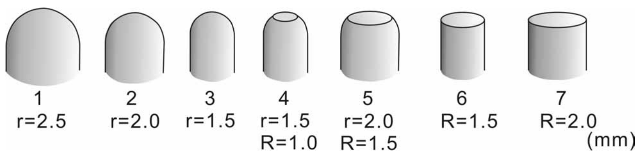

Fig. 5 Seven references used in the experiment. Reference No. 1,2,3: hemispherical objects. No. 4, 5: truncated cone-like reference. No. 6, 7: cylindrical objects. In the picture, "r" indicates the curvature radius and "R" represents the radius of the top circle.

4. Results

Fig. 6 shows the results of the virtual stimuli by SPS compared to the actual reference objects. The horizontal axis indicates the reference number which coincides with the references given below. The vertical axis indicates the number of the answers. The blue bars show the histogram of the answers when we gave the S-Primitive only (stimulus (1)). It is obvious that the stimulus (1) was evaluated as a hemispherical object. On the other hand, the stimulus (3) (R-Primitive only) was evaluated as cylindrical objects which is shown with yellow bars. Evaluated sizes were comparable to the size of the hole (4.5mm) in both cases. When we activated two primitives simultaneously, the stimulus (2) was mostly perceived as a truncated hemispherical object (No. 5). The answers from the subjects indicated that reference No. 5 was felt like flat surface with edge-like sensation though the edge was felt duller than the actual cylindrical references.

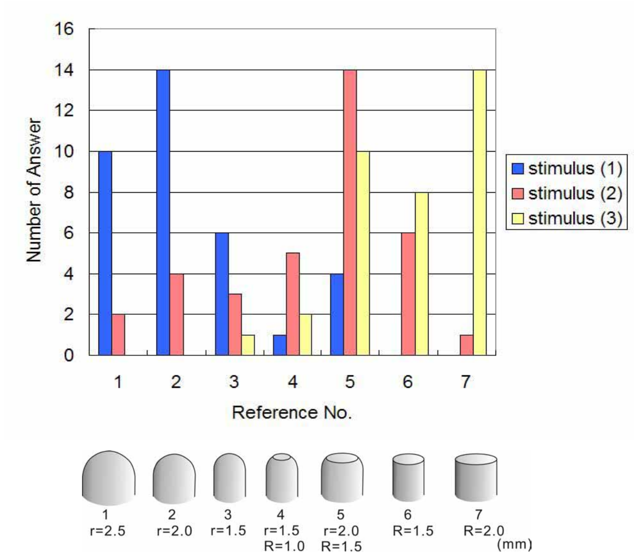

Fig. 6 Results of the comparison between SPS and actual reference objects.

5. Discussions

From the experimental results, it is clear that we can change the perceived spatial features by temporal primitives. Based on the response from the subjects, most different point between S-primitive and R-primitive was existence of edge sensation. Suction pressure with high-frequency makes sharper edge sensation which is perceived as cylinder than slow change of the air pressure. Although the perceived size was sometimes a little smaller than actual hole size (r = 2.25 mm) for the stimulus 2, we could not create a sharp-pin like object by combination of two primitives, unexpectedly. Perceived sizes were almost the same (its radius is about 2.0mm) in three cases. It is our future work to investigate whether we can give sharp-pin like sensation using the same suction hole by another temporal pattern or not.

One merit brought by temporal primitives is that the suction pressure stimulation becomes feasible also to the finger. A difficulty in applying the MPTS to the fingerpad by the former method is alignment of multi DOF stimulators with their intervals of TPDT, which is about 2 mm at the finger. Since the proposed method requires only one suction hole within a unit area, we can array primitive sets with their intervals of finger's TPDT.

We are now investigating the hole size thresholds which gives pushed sensation on the fingerpad. Our pilot experiment says that the minimum diameter of the hole at the finger is around 1mm. Since the smallest size of the suction hole, 1 mm, is smaller than the TPDT, it is expected that we can array the holes with appropriate intervals. An interesting discovery in the threshold study at the fingerpad is that the S-primitive is tend to be felt as sucked or pinched sensations when the size of the hole becomes larger than 2 mm, though R-primitive is certainly perceived as pushing. This result may give important insight to the perception coding of the mechanoreceptors. It also affects the practical configuration of the tactile display. Details may appear in another paper in the future.

6. Summary

In this paper we proposed a new set of primitives to realize a large-area covering realistic tactile display. They stimulate the skin surface with suction pressure (SPS method) as our former paper proposed. The difference from the former device is that a single suction hole provides a pair of primitives. Since the identical hole provides the multiple primitives, we can expect that Multi-Primitive Tactile Stimulation is realized more stably, that the physical structure is simpler than the former method and that it is also feasible to the finger tactile display. The method uses the frequency characteristics of the mechanoreceptor sensitivity. We showed the basic theory and results of fundamental experiments. In the experiments, we showed the spatial feature of the virtual object (edged or round) could be controlled by the temporal profile of the primitives. However we could not create a sharp-pin like object by combination of two primitives, unexpectedly. Finally we discussed the possibility of the proposed method to the finger tactile display.

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