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Measurement and Analysis of Finger Surface Behavior on One-dimensional Textured Surface *

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***Abstract*— Relationship between skin displacement and subjective sensation is indispensable for the design of tactile feeling display. Previous works on the observation of the skin displacement mainly used flat glass plate and a camera. However, the flat glass is not a representative tactile texture that we daily touch. We have developed a system that can observe interaction between textured surface and finger skin by using technique known as index matching. In this paper, we report preliminary result of skin deformation when a number of participants traced several one-dimensional textured surfaces on this measurement system.**

I. Introduction

Tactile displays that present realistic sensations have been intensively studied in the fields of virtual reality, teleoperation, and remote palpation. To realize a realistic tactile sensation, the relationship between skin displacement and associated sensation must be clarified.

Measurement of skin displacement has been intensively performed, especially for the purpose of developing new tactile displays. In most cases, an optical measurement using a glass plate and a camera was attempted. Levesque et al.[1] measured the finger surface behavior on flat, bump, and hole surfaces. Soneda et al. [2] measured the contact surface area using a glass prism. Several studies measured the relationship between the grip status and skin moisture using a similar optical measurement setup. Other than the optical measurement, fingertip vibrations have been measured on a rough surface. Martinot et al. [3] used an acceleration sensor to detect fingertip vibration when the fingertip stroked a rough surface. Romano et al. [4] obtained contact acceleration data for numerous textures. Sato et al. [5] proposed a method of measuring the finger surface displacement using a displacement at the finger side.

As described above, numerous measurements on skin deformation have been conducted, but little has been done so far to directly measure finger surface displacement on a texture surface that we touch on a daily basis.

We have proposed a measurement system that can record skin surface displacements when the finger traces the texture surface with high resolution and high speed [6] (Fig.1). Usually, it is extremely difficult to record the finger skin movement through a transparent textured surface because from under the textured plate, it becomes like frosted glass due to the different of refractive index between air and transparent material. Therefore, we have used a method known as “index matching”. The transparent textured plate is submerged in transparent liquid having the same refractive index, making the object optically invisible. In our case, the textured plate is submerged in silicone oil so that the texture does not hinder optical observation of the skin of the contacting finger. The textured surface is traced with a finger and recorded with a high-speed camera. The finger is stamped with 1 mm interval markers beforehand, and the recorded video is analyzed with OpenCV computer vision library to trace movement of each marker.

In this paper, we report preliminary result of skin deformation when a number of participants traced several one-dimensional textured surfaces on this measurement system.

II. Experiments

In order to examine relationship between deformation of the skin and tactile sensation, preliminary measurements of the skin surface displacement, and subjective tactile evaluation of the textured surface were performed simultaneously.

A. *Experiment condition*

Measurements were performed on six textures. Five of these were hairline textures made by laser cutter, and the other one was flat. The pitch width of the texture surface was 0.3, 0.4, 0.5, 0.6, and 0.7 mm. Fig 1 shows example of the textured surface.

The six types of plates were randomly submerged in the oil, and the participants were asked to trace the plate with their entire index fingerpads, and to be in close contact with the plate. After taking video of each texture, a questionnaire for subjective evaluation were performed to see subjective roughness. They were asked to answer with visual analog scale (0: Rough, 100: Smooth). We recruited six participants, one female and five male, aged 22-25.

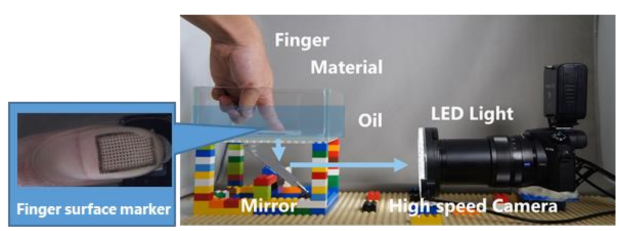

Figure 1. Measurement system[6]

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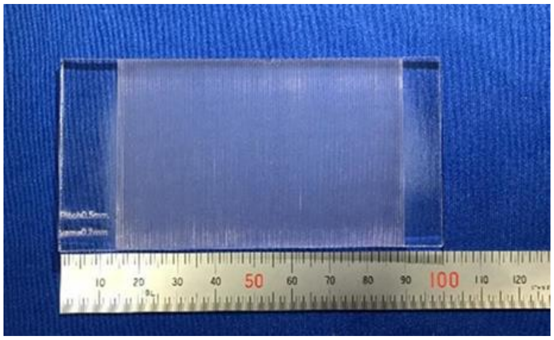

Figure 2. An example of textured surface

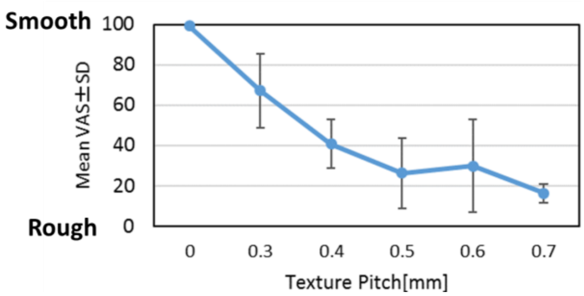

Figure 3. Result of subjective evaluation

B. *Result*

Fig 3 shows the subjective evaluation results for the textured surface. As the graph shows, roughness was sensed subjectively by increasing the width of the unevenness, even if it was submerged in oil.

In the measurement of finger skin deformation, skin vibration was clearly observed on a textured surface of 0.5 mm pitch or more. To clarify the characteristic of this fingertip vibration, we checked marker movement of three points, at the tip side, the center, and the base side, as shown in Fig 4.

III. Discussion

From Fig 4, three things are observed.

First, we observe low frequency component (up to 3 Hz) and high frequency component (around 80 Hz). The former is in the range of slowly adapting mechanoreceptors, and we might interpret it as traction force. The latter is in the range of rapidly adapting mechanoreceptor, and we might interpret it as texture vibration.

Secondly, the two frequency components had almost no phase difference at these three locations. It suggests that to reproduce the roughness sensation of these textured plates with horizontally moving tactile display, such as STRESS2 [7], phase difference at each point might not necessary to reproduce.

Thirdly, the high frequency component at the tip of the finger was larger than that at the root side, although the finger skin was fully contacted with the plate. The reason of this amplitude difference is thought to be due to the finger shape. As the finger has spherical shape at the fingertip and cylindrical shape at the root, vertical force (pressure) gradually becomes smaller at the tip of the finger while

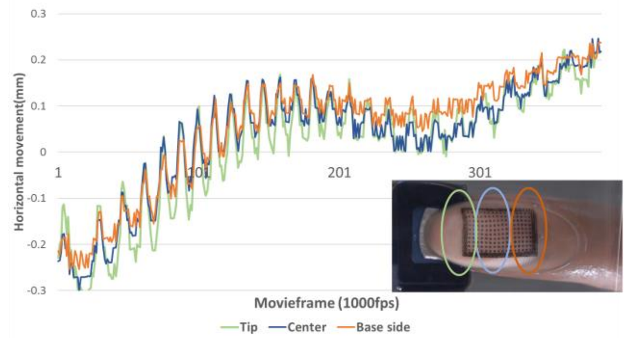

Figure 4. Result of skin defromation at each point

tangential force (traction) is almost constant, fulfilling stick-slip condition at only the fingertip. We presume that this characteristic vibration distribution might partly explain different density of mechanoreceptors, which are dense at the tip of the finger.

IV. Conclusion

In this paper, we report preliminary result of skin deformation when fingers were traced on one-dimensional textured surfaces. Although our method requires submerging finger to oil, relationship between skin deformation and subjective feeling can be observed. Through the experiment, we observed that the skin vibration has spatial variation, but position related phase difference was not observed, at least with the simple hairline textures.

Our future work includes improvement of accuracy of the measurement system, which currently has around 20um noise. Then we will conduct measurements with uneven one-dimensional textures and two-dimensional dot surfaces, and find relationship between subjective tactile feelings and spatial-temporal characteristics of skin deformation.

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