Measurement and analysis of spatial-temporal skin deformation on an electrostatic tactile display

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Abstract. Electrostatic tactile displays are expected to be widely used on touch panels. To clarify the range of tactile sensation produced by such displays, we measured the skin deformation directly with a high-speed camera when the finger traced on the electrostatic display, which applied 20 Hz or 40 Hz sinusoidal or rectangular waves. Motion analysis revealed that the skin deformed synchronously for each waveform regardless of location. In addition, while skin deformation from the sinusoidal wave was observed to be sinusoidal with the same frequency, the response to the rectangular wave was more complicated.

Keywords: measurement, electrostatic tactile display

1 Introduction

Many tactile displays have been proposed for smartphones, but they are characterized by restrictions such as limited electric power, size of the device, and the necessity to not obscure the visual display. Among them, the displays using an electrostatic friction force can reproduce the feeling of various textures with a simple and thin three-layer mechanism composed of transparent glass, a conductive layer, and an insulating layer.

A number of studies have been performed to quantify the range of tactile sensations that can be produced by electrostatic touch displays [1][2]. While physical observation of the electrostatic touch display was mainly focused on the vibration and frictional force of the whole fingertip or the substrate, the distribution of the finger skin deformation was, to the best of our knowledge, not measured. Therefore, whether the deformation of the skin on the finger is synchronous as a whole or depends on the location of the skin is not known.

To tackle this issue, we optically observed the spatial distribution of the vibration of the skin while using the electrostatic touch display with high spatial-temporal resolution using an improved version of our previously proposed system [3].

2 Experiment

The measurement apparatus is shown in Fig. 1. The skin surface displacement was measured directly from the bottom using a mirror tilted at an angle of 45 degrees. To measure the distributed skin displacement, 10 × 16 markers 1.0 mm apart were stamped on the fingertip for image processing. The displacement of the markers was measured with a high-speed camera at a resolution of 1920 × 1080 pixel at 1000 fps (SONY, RX 10). This resolution corresponds to 16.6 um/pixel. An LED light was used to raise the brightness of the finger surface and reduce noise in the high-speed photography.

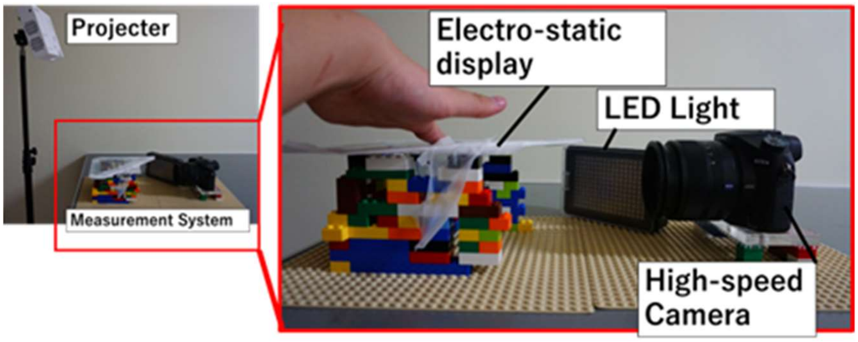

Fig. 1. Measuement system

An indicator projected on the display guided the participants to move their finger at an approximately constant speed of 3 cm/s. Sinusoidal and rectangular waveforms were applied at frequencies of 20 Hz and 40 Hz, giving a total of four test conditions. The amplitude was fixed at 600 V. The pressing force was subjectively controlled by the participants until they felt the largest vibrotactile sensation. We recruited six participants from our lab, five males and one female aged 21-33 years old.

An image processing program using OpenCV (https://opencv.org) computer vision library was used to track the trajectories of the markers. Details of the processing are described in our earlier report [3]. While the markers were placed two-dimensionally on the whole fingertip, we focused on one line of markers on the median line of the finger.

3 Result

The velocity of each marker along the median line measured on one of the participants when the sinusoidal and rectangular waveform was applied is shown in fig. 2 (left). The number of extracted markers was 13 on average and did not vary much among the different test conditions. It was found that the velocity of each marker was synchronous, i.e. no particular phase shift was observed. This trend was observed for all participants.

Fig. 2 (right) shows the skin velocity waveform averaged over all markers and all participants for each of the test conditions. Note that the applied voltage waveform was used to synchronize all data.

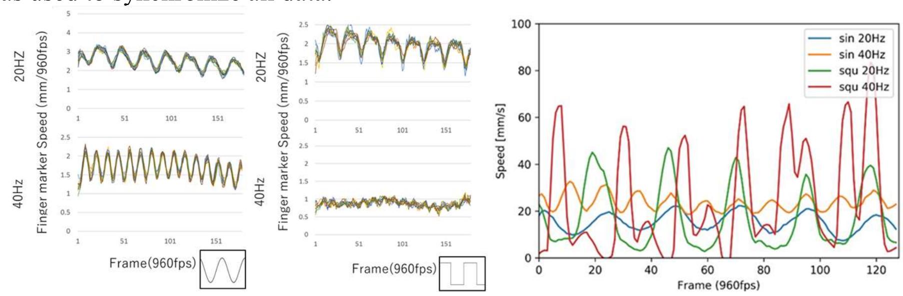

Fig. 2. (left) Velocity of all markers along median line for one participant for sinusoidal and rectangular wave **(right)** Average skin deformation rate under each condition

4 Discussion

From the results shown in Fig. 2, it was found that the markers moved synchronously and a phase shift (time shift) between the markers was not observed. One reason for this is believed to be that the friction coefficient change due to the electrostatic touch display was quite large. Another reason might be that we asked participants to control the pressing force so that they could feel the strongest vibration, which might have resulted in inducing a strong stick-slip condition over the whole fingertip. We also must note that only markers on the median line of the fingertip were analyzed at this time.

It is also clear that the maximum skin velocity for the rectangular wave was larger than that of the sinusoidal wave. This is assumed to be because a strong stick-slip phenomenon occurred due to the instantaneous frictional force change when the rectangular waveform was applied. The sinusoidal input gave a sinusoidal output with the same frequency, which agrees with previous findings [4]. However, the rectangular input gave a complex wave-form output.

In considering what kind of process is involved in producing this output, the velocity change is divided into four phases (Fig. 11): (1) sudden velocity increase, (2) deceleration, (3) constant velocity, and (4) another deceleration.

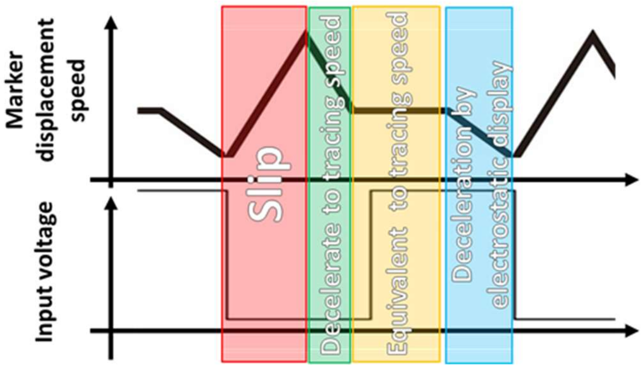

Fig. 3. Correspondence between speed change and input voltage wave- form in rectangular wave

Looking at these phase changes, the relationship between the input waveform and the skin deformation is quite complex. Since the velocity of the skin when inputting a sinusoidal wave was a sinusoidal wave of the same frequency, it was expected that the relationship between the input voltage and the skin deformation would be linear. However, the response of the skin to the rectangular wave would not be explained by the simple linear assumption, which will be the focus of our future work.

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