Enhancing Fabric Image Realism on Touch Panels Through Low-Frequency Tactile Friction Stimuli

Ami Chihara
Tokyo Metropolitan University
Hino, Japan

Shogo Okamoto
Tokyo Metropolitan University
Hino, Japan

Ai Kurita
Tokyo Metropolitan University
Hino, Japan

***Abstract*—Surface texture displays are LCD panels with tactile feedback functions. Previous studies have shown that low-frequency variations in surface friction presented by such displays can enhance the perceived softness of fabric images. This study investigates whether these frictional stimuli can also enhance the realism of fabric images shown on the display. Additionally, we explore the optimal conditions for improving this perceived realism.**

An experiment involving 15 participants revealed that fabrics were perceived as most realistic when spatial friction variations with a wavelength of approximately 8–12 mm were applied, and the finger sliding speed ranged from 90 to 140 mm/s. These optimal conditions were consistent across four different fabric types. The results suggest that surface texture displays can enhance the realism of fabric images through haptic interaction.

***Index Terms*—surface texture display, electrostatic friction, softness, tactile interface**

I. Introduction

Touch panels are among the most widely adopted human–computer interfaces, enabling users to interact with digital content intuitively by directly touching the screen. Recent research and development have focused on providing tactile sensations of textures, such as fabrics [1]–[4]. These studies have established methods for presenting surface textures. In contrast, since the perception of softness through touch primarily arises from the deformation of the fingertip and the object [5], conveying the softness of fabrics via rigid touch panels remains a significant challenge.

In recent years, tactile stimulation methods utilizing low-frequency mechanical vibrations and frictional modulation have gained attention as effective means of inducing softness perception [6]–[9]. Combining visual information with low-frequency tactile stimuli has shown promise for evoking the sensation of fabric softness in users [8]. Such tactile feedback is expected to enhance the realism of virtual textures, which is a key evaluation criterion for tactile texture displays [10]–[12].

The aim of this study is to evaluate how different tactile stimulus presentation conditions, delivered by a surface texture display, affect users' perception of realism when viewing fabric videos. Specifically, we seek to identify the optimal conditions for frictional stimulation (spatial period of friction variation and finger sliding speed) that maximize perceived realism for various fabric materials. Additionally, we examine whether these optimal conditions depend on the type of fabric.

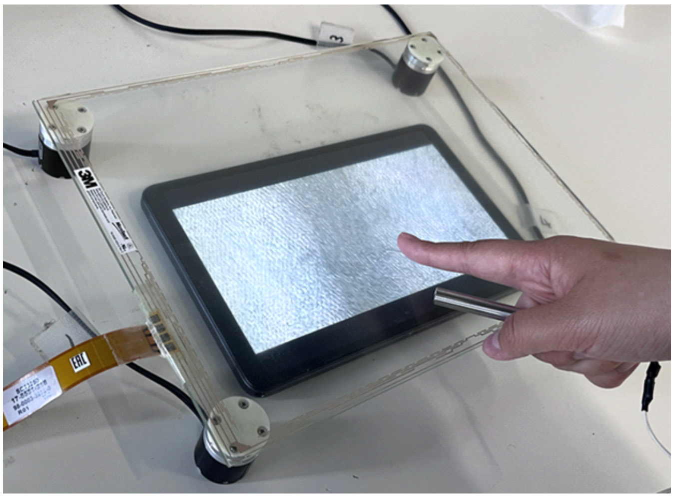

Fig. 1. Electrostatic tactile texture display. The glass surface panel presents variable friction, while an LCD display beneath shows animated fabrics. The same apparatus was used in [8], [13].

The findings of this study are expected to inform the optimization of stimulus presentation in haptic interfaces and contribute to the advancement of user interaction with surface texture displays.

II. Methods

A. Apparatus: Electrostatic Tactile Texture Display

The electrostatic tactile display used in this study, as shown in Fig. 1, consists primarily of a touch panel composed of a conductive layer and an insulating coating [8]. When a voltage is applied to the conductive layer, an electric field is generated between the finger and the conductive surface, resulting in an adhesion force caused by Coulomb interaction between the charges on the skin and the panel. This adhesion produces frictional resistance when the finger slides across the panel surface. By modulating the electric field, the surface friction of the panel can be dynamically controlled. The touch panel is made of transparent glass, allowing users to view a video of fabric textures displayed on a tablet (Headwolf FPad 3, Shenzhen Daohui Industrial Co., Ltd., Shenzhen, China; 1920 × 1200 pixels, 8.4 inches) placed beneath the panel.

The voltage signal applied to the touch panel was amplitude-modulated at 2 kHz and amplified using a conditioner (PD-

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206-150B, Piezo Driver, NF Corporation, Yokohama, Japan). Finger position on the panel was estimated using a force sensor, and the voltage signal was controlled at a sampling rate of 2 kHz via a data acquisition board (PEX-61216, Interface Corporation, Hiroshima, Japan).

B. Tactile Stimuli

The low-frequency frictional stimuli used in this study were generated by applying a sinusoidal voltage to the display, modulated according to the finger's position as it slid across the surface. The applied voltage followed a sine function determined by the wavelength, resulting in a spatially periodic variation in surface friction.

The spatial period of the frictional modulation was defined by the wavelength λ (mm). In this study, both the wavelength λ and the finger sliding speed v (mm/s) were optimized as in Section II-D. The gain parameter of the applied voltage was individually adjusted for each participant prior to the experiment. The maximum amplitude of the amplified voltage was 36 V (72 $\mathrm{V_{pp}}$).

C. Displayed Cloth Videos

Participants were shown videos of fabric in which a single drape moved from left to right across the screen. The speed of drape's movement was adjusted by changing the playback speed. Separate videos were prepared for each of the four fabric types: towel, leather, cotton, and suede. The same videos were also used in [8].

D. Procedure

For each of the four types of cloth, nine different stimulus presentation conditions were tested. These conditions were determined using a central composite design and included the following pairs of λ (mm) and v (mm/s): (5, 150), (7.9, 79.8), (7.9, 220), (15, 50), (15, 150), (15, 250), (22.1, 79.8), (22.1, 220), and (25, 150).

Participants watched a video of undulating fabric displayed on a tablet while sliding their finger across the touch panel in synch with a moving drape for 20 s. After each trial, they rated the perceived realism on a 10-point scale, where 0 indicated the lowest and 9 the highest level of realism.

E. Participants

Fifteen university students, all naive to the study's hypothesis, participated in the experiment.

F. Data Analysis

First, to investigate differences in the realism scores among the nine conditions defined by combinations of wavelength and finger velocity, a repeated-measures analysis of variance (ANOVA) was conducted for each fabric type. Next, the realism scores were modeled as a second-order polynomial function of finger velocity (v) and wavelength (λ), and the response surface methodology was used to estimate the optimal presentation conditions for each fabric type and each participant. Finally, to examine whether the optimal parameters varied by material, a multivariate analysis of variance (MANOVA) was performed for each pair of fabric types, using λ (wavelength) and v (velocity) as dependent variables and material as the independent variable, with Bonferroni correction applied for six comparisons.

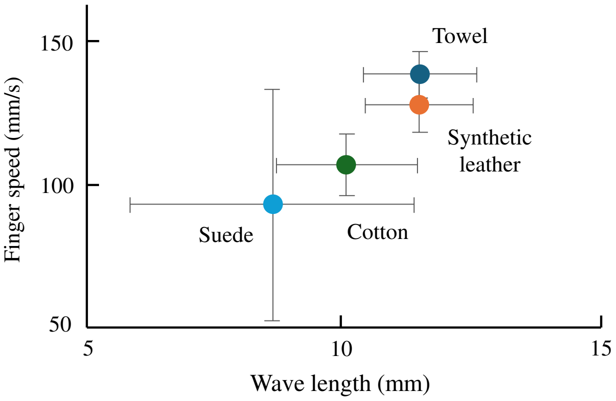

Fig. 2. Mean optimal conditions across participants. Error bars represent the standard error of the mean.

III. RESULTS

The repeated-measures ANOVAs revealed significant differences in realism scores among the nine presentation conditions for towel ($p = 3.0 \times 10^{-2}$, $F(8, 112) = 2.2$) and cotton ($p = 4.0 \times 10^{-2}$, $F(8, 112) = 2.1$). The realism were reported higher for some conditions. In contrast, no significant differences were observed for leather ($p = 7.9 \times 10^{-2}$, $F(8, 112) = 1.8$) or suede ($p = 9.3 \times 10^{-1}$, $F(8, 112) = 3.7 \times 10^{-1}$).

Fig. 2 shows the mean and standard error of the optimal conditions estimated using response surface methodology for each fabric type. According to the MANOVAs, there were no significant differences among these mean values, indicating that the effective conditions for enhancing perceived realism did not differ across the fabric types tested in this study.

IV. DISCUSSION

The reality of the towel and the cotton cloth differed significantly depending on the stimulus conditions. Further, the stimulus condition that maximized the reality was independent of the fabric type. This indicates that the optimum conditions for tactile presentation are approximately the same for different fabric images and do not need to be adjusted for individual materials. In other words, the reality of various fabric images can be enhanced with a simple implementation. However, this may not be the case for fabrics that differ significantly from the four fabric images used in the experiment.

A limitation of this method is that, in the absence of visual information, it is unlikely that participants could identify the material using only the tactile stimuli. The tactile feedback serves to supplement and enhance the realism of the displayed fabric but is not sufficient on its own.

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