Design and Evaluation of a Texture Rendering Method for Electrostatic Tactile Display

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ABSTRACT

Experiencing a sense of touching the displayed objects is the common goal of researchers and users. In this paper, a new texture rendering method for electrostatic tactile display is proposed, through which lateral force to the moving finger is calculated and generated by electrostatic attraction force based on the recorded data such as acceleration signals and friction properties of actual materials. The electrostatic attraction force is adjusted according to the exploring speeds of user's finger. User studies of adjective and similarity ratings on roughness and stickiness of virtual

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KEYWORDS

Texture Rendering; Electrostatic Force; Tactile Display; Evaluation

materials are designed, and the results demonstrate that the sense of touching the rendered materials is similar to that of the real materials, which proves that the proposed texture rendering method can be applied to display tactile information in an electrostatic tactile display.

1 INTRODUCTION

Tactile perception is composed of multidimensional perceptions of roughness, warmness, hardness and friction [6]. Creating realistic tactile perception provides more information which are needed in several virtual reality applications including online shopping and museum exhibition. With the help of such technology as ultrasonic vibration and electrostatic force generation, tactile feedback can be presented directly on bare fingers. To achieve more accurate and truer tactile perceptions of actual materials, haptic data of objects to be touched should be obtained first. Compared with the researches on texture rendering of force or vibration feedback devices [1, 3, 7], fewer researches focused on the texture rendering method of an electrostatic tactile display based on haptic data. Current texture rendering methods for electrostatic devices usually control the excitation voltages by modulating the waveforms, frequencies and amplitudes of periodic signals [2, 8]. Ilkhani et al. used the acceleration signals captured from real materials as the excitation signals directly, so all information of the texture surface contained in acceleration signals can be presented [4]. Jiao et al. displayed the friction information of fabrics on an electrostatic device by modulating the periodic voltage signals according to the recorded friction coefficients [5].

To present realistic tactile perceptions on an electrostatic tactile display, a new texture rendering method for electrostatic tactile display is proposed in this paper, in which the acceleration signals are firstly modeled and interpolated according to the recorded acceleration data and the scanning speed of the finger across the surface, then virtual textures displayed with the stimulus are calculated using both the interpolated vibration signals and the friction properties of materials. Finally, user studies of adjective and similarity ratings are designed to demonstrate the performance of the rendering method. There are two main contributions in this paper:

1) It is the first study that the tactile textures are rendered depending on the recorded acceleration signals and the friction properties. More comprehensive and accurate tactile information including the surface roughness and stickiness can be displayed.

2) A portable and low cost electrostatic tactile display system is developed, and a free user interface is designed. With the help of the proposed system the tactile sensations of different material surfaces can be presented on user's finger in real time.

2 TEXTURE RENDERING ON ELECTROSTATIC TACTILE DISPLAY

2.1 Electrostatic Tactile Feedback Device

Such advantages are provided by the electrostatic tactile display as silent working and portable structure. In our study, a custom-designed electrostatic tactile display with a 3M MicroTouch screen as shown in Fig. 1 is adopted [9]. An infrared touch frame is attached on the touch screen to

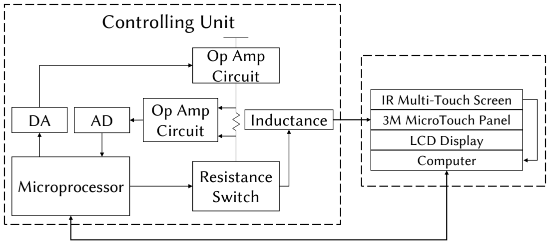

Figure 1: The structure of the electrostatic tactile display.

track the position of the finger. A high-speed microprocessor (PIC 33) is used as the main controller to generate a variety of signals. The simulation pulses are magnified by an OP amp circuit and then passed through a resistor which is controlled by the microprocessor. The pulse signals are regulated by an inductance to prevent sharp increase of current.

According to the working principle of the electrostatic tactile display, the tactile excitation voltage V satisfies the following relationship:

$$f_e = \frac{\varepsilon_0 A V^2}{2(\frac{T_i}{\varepsilon_i} + \frac{T_{sc}}{\varepsilon_{sc}})(T_i + T_{SC})} = kV^2 \qquad (1)$$

where ε_0 is the permittivity of vacuum, ε_i is the relative permittivity of the insulator, A is the finger contact area, T_i and T_{SC} are the thicknesses of the insulator and the stratum corneum, k denotes a constant coefficient.

Thus, the expected tangential force f_t on the moving finger produced by the electrostatic force f_e should be modulated by changing the input voltage V:

$$f_t = \mu f_e = \mu k V^2 \qquad (2)$$

where μ is the friction coefficient. By modulating electrostatic force, the lateral force on the finger will be changed at the same time.

2.2 Texture Rendering Algorithm

When a bare finger moves across a real material surface, forces are generated on the finger because of the sensing of the tactile information including the friction, texture distribution and compliance of the surface, so how to display authentic tactile information of the material surface is crucial for texture rendering.

Data-driven modeling to be applied to haptic textures rendering can improve the accuracy of the tactile reproduction, which has been explored in recent years. To generate the data-driven tactile feedback for the moving finger, the haptic data from the Penn Haptic Texture Toolkit [3] is used to calculate the corresponding input voltage to generate the electrostatic attraction forces of the tactile display. The lateral force feedback for the finger which is generated by the texture surface can be seen as the sum of the texture force $f_{texture}$ and the friction force $f_{friction}$. The direction of the lateral force is perpendicular to the surface and in the opposite direction of the moving velocity of the finger. The lateral force f_t is:

$$f_t = f_{friction} + f_{texture} \qquad (3)$$

Based on equation (2) and (3), the input voltage V of the tactile display can be calculated according to the rendered texture and the speed of moving finger:

$$V = \sqrt{\frac{1}{\mu k} f_t} = \sqrt{a(f_{friction} + f_{texture})} \qquad (4)$$

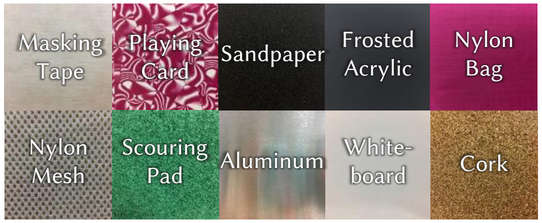

Figure 2: Ten materials selected according to the HaTT database.

Figure 3: Experimental set-up.

The acceleration signals are actually the vibration caused by the texture distribution of the surface, thus the texture force of the surface can be estimated as the result of the acceleration scaled with the effective mass of user's hand, which is set as 0.05kg [3]. After the recorded acceleration signals are segmented using the Auto-PARM algorithm and modeled using AR models, signals to calculate the texture force will be interpolated with users' current scanning force and speed. Besides, by using the Coulomb friction model, the friction force depends on the friction parameters of materials and the normal force of user's hand. A constant normal force(1.6N) according to the measured result in [10] is used.

The input voltage V of the tactile display can be calculated based on Equation (4). Similar to Ilkhani's rendering method [4], frequency content of the recorded signals is used to generate the excitation signals in our approach. To prevent the excitation from exceeding users' tactile threshold, the input voltage V is modulated proportionally using the staircase method.

3 EXPERIMENTS

Two user studies were designed to evaluate the performance of texture rendering:

Adjective ratings of the textures, in which participants were asked to sense the roughness and stickiness of virtual and real materials respectively without visual and audio cue, and then rated the roughness and stickiness of each surface in a 7-point Likert scale (from smooth to rough and slippery to sticky).

Similarity ratings of the textures, in which participants were presented a pair of real and virtual textures that can be touched freely, and then rated the similarity between the two textures with a 7-point Likert scale (from the lowest similarity to the highest similarity).

Ten materials (masking tape, playing card, sandpaper220, frosted acrylic, nylon bag, nylon mesh, scouring pad, aluminum, whiteboard, and cork) were chosen from 100 texture samples in the HaTT [3] (see Fig. 2) to present different roughness and frictions.

Fourteen people (six males, eight females) participated the experiments. The ages of participants ranged from 17 to 30 years old (average age = 21 years). Two participants were left-handed, and the others were right-handed. Before the experimental trials, all the participants were trained to familiarize with the experiments and the device. Participants were asked to dry their fingers to avoid sweating. During the experiments, the participants sat on a chair in front of the electrostatic tactile display with a curtain hanging in front of the participant to block their view. Participants were asked to wear an earplug and active noise-canceling headphone to damp surrounding disturbances. The temperature of the room in our experiment was 23.5℃-25.5℃, and humidity was 38%-45%. The experimental setup is shown in Fig. 3.

Periodic signals on the electrostatic device with manually modulated waveforms were always adopted in previous works. To measure whether the proposed method could get relatively good texture rendering results, textures rendered with standard square wave signals with constant amplitude of the input voltage was created and compared. The frequencies of the signals were chosen according to Bau's study [2], which changed from 30Hz to 300Hz.

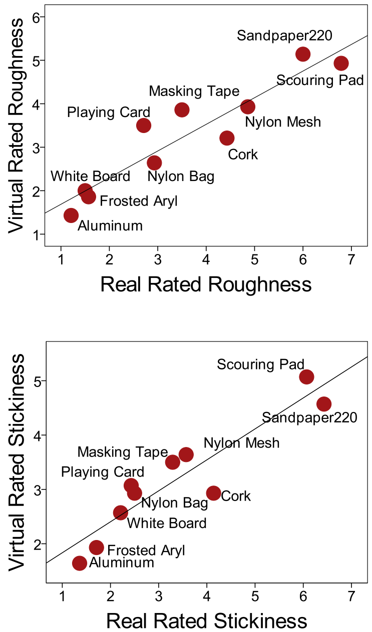

Figure 4: Relationship between the averaged rated adjectives for real and virtual materials.

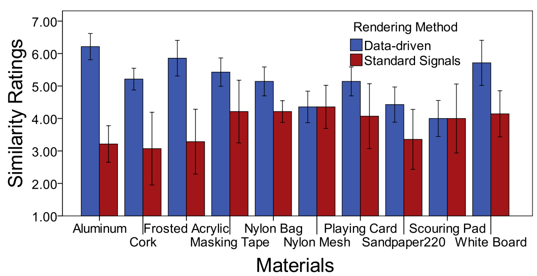

Figure 5: Comparison of the rated similarity between different rendering methods.

4 RESULTS AND DISCUSSION

After the experiments, participants were asked to comment the rendered textures on tactile display and the comfort degree during the use of the device. Common comments state that the differences between rendered textures can be perceived clearly, while the physical properties of the touch screen (lack of hardness and warmness) influence the tactile perception. Few participants felt the finger would be numb and uncomfortable when they touched the surfaces for a long time. The overall mean of comfort degree of the electrostatic tactile system is 5.87 (SD:0.67), which is evaluated using a 7-point Likert scale (from uncomfortable to very comfortable).

The relationship between the averaged ratings of adjectives is shown in Fig. 4, which proves that the rating results of the rendered textures are similar to that of the actual materials. The significant correlation between the real and virtual rated adjectives proves that the perception of the roughness ($r = 0.935, p = 7.3 \times 10^{-5}$) and stickiness ($r = 0.926, p = 1.22 \times 10^{-4}$) of the real materials can be rendered on the tactile device.

The distribution of similarity ratings for each material is shown in Fig. 5. The rated similarity between the rendered textures and real textures ($AVG: 5.15, SD: 1.07$) is higher than that of the standard signals rendering method ($AVG: 3.95, SD: 1.52$). There is a significant effect of rendering method on the rated similarity ($F(1{,}260) = 85.795, p < 0.05$). We also studied the correlations between the similarity ratings and the real rated adjectives. The rated roughness is highly inversely correlated with the similarity ratings($r = -0.936, p = 6.9 \times 10^{-5}$), and the rated stickiness is significantly inversely correlated with the similarity ratings($r = -0.851, p = 2 \times 10^{-3}$).

The capability of textures simulation on electrostatic tactile display is correlated with materials. It can be seen from Fig. 4 and Fig. 5 that the materials with higher roughness are rated lower similarity, which is consistent with the negative correlation relationship between the similarity and the roughness/stickiness of the real materials. It can be inferred that the amplitude of input voltage to render textures is limited in a safe range, thus strong tactile sensations of the textures with larger roughness and friction would be hard to obtain on the device. Besides, the physical properties of the touch screen also reduced the simulation dimensions of virtual materials; for instance, the low rated similarity for scouring pad might owe to the failure in fully displaying the complex textures, greater friction force and the deformation property of the real materials. Thus, better performance of data-driven texture rendering on electrostatic tactile display could be achieved for the smoother and harder materials such as the aluminum, frosted acrylic and the white board, which were rated higher similarity. Except the limitations of the touch screen, a constant normal force we used to calculate the excitation signals may also lead to the dissimilarity of the tactile feedback between virtual and real materials, for human's actual tactile sensation clearly changes with different forces they use to touch the object surface. Although there are some limits on rendering rough and deformable materials on the touch screen, the relative roughness and stickiness perception of different materials still can be provided, and the tactile characteristics of the real materials are reflected partly.

5 CONCLUSIONS AND FUTURE WORK

In this paper, a new texture rendering method on electrostatic tactile display is proposed. The virtual textures are created by interpolating the acceleration signals and calculating electrostatic attraction force. Experimental results verify that the rendering method on electrostatic tactile display can create similar tactile perceptions of actual materials successfully. The reproduced tactile information can be used in the application of virtual reality which can improve the realism of scenes and the immersion of users.

There are some limitations which are needed to be studied in the future. Different haptic data recording methods may influence the capability and the performance of the texture rendering. We will work on recording haptic data for bare finger touching and image data of actual materials under complex environments and address the issue of automatic tactile rendering based on the content of the displayed images.

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