Diminished Haptics: Towards Digital Transformation of Real World Textures

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Abstract. In this study, we develop and implement a method for transforming real-world textures. By applying a squeeze film effect to real-world textures, we make haptic textures reduced. This method could transform real-world textures, e.g., from paper-like to metal-like, from wood-like to paper-like, and so on. The textures provided by this system are inherently high resolution because real-world textures are used instead of synthesized data. We implemented a system using a 28-kHz transducer. Evaluations were conducted using a three-axis accelerometer.

Keywords. Diminished haptics, Real-world texture, Texture transformation, Ultrasonic

1 Introduction

The representation of texture is a major concern during fabrication and manufacture in many industries. Thus, the manner of fabricating everyday objects and the digital expression of their textures have become a popular research area [1]. It is not easy to change the texture of objects in the real world although it is easy in the digital world (i.e. just setting texture parameters). Recently, computer graphics are getting to be used in the real world. For example, digital fabrication technologies are employed widely from laboratories to consumer uses. The fabricated (3D-milled, 3D-printed, etc.) objects represent their specific textures. There are some methods to modify their textures after fabrication. For design and other industrial applications, it would be useful if the

Figure 1: (Left) System overview (right) real material surfaces.

fabricated objects are malleable [2] like computer graphics in the digital world. In the human computer-interaction and graphics communities, the following concepts have been proposed: Programmable matter [3], radical atoms [4], etc. In the present study, we aim to transform the textures of real-world objects.

Two steps are required to transform real-world textures. The first step is to reduce the original texture and the second is to rewrite the texture. There are many different types of haptic textures in the real world and it is necessary to reduce them as preprocessing. It is then possible to rewrite the textures. In the present study, we focus on the first step and we introduce a technique named "Diminished Haptics" (Figure 1). This technique reduces the degrees of real-world haptic textures using ultrasonic vibration based on a squeeze film effect [12].

This paper is structured as follows. First, a brief overview and background were provided in the introduction. Then, related work and the principle are shown. Finally, the equipment used for the implementation and the results of experiments related to haptic textures are presented. This technology will facilitate new relationships between people and textures in the real world.

2 Related Work

There have been several related studies on haptic texture representation. One approach is wearable devices to provide additional vibration to users' fingers [11]. The other is haptic displays add haptic feedback on their smooth surfaces. The technologies employed in the latter approach include ultrasonic vibrations [5][6] and electrostatic forces [7]. These technologies have been applied to trackpads [8], pointing devices [9], and augmented reality (AR) systems [10]. The ultrasonic technology utilizes a squeeze film effect to reduce the friction of a flat surface and reproduces the texture by modulating the ultrasonic vibration (as shown in Figure 2, top). The electrostatic technology also adds textures to smooth surfaces.

In the present study, we aim to achieve the opposite effect, i.e., we reduce the texture of a real material using a squeeze film effect. We focus on the transformation of real textures and we employ a real material as the surface of haptic display (Figure 2,

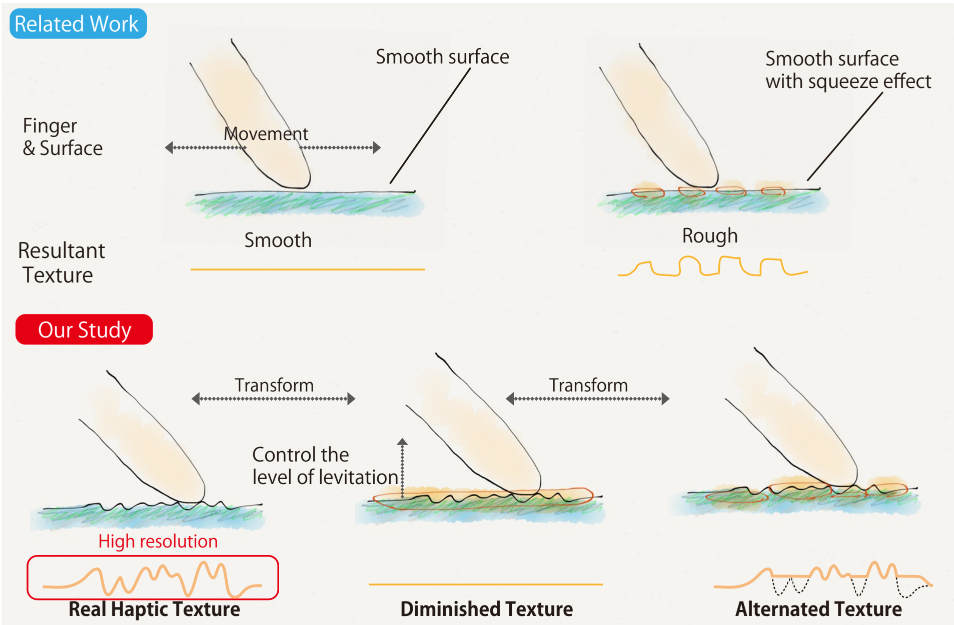


Figure 2: Basic idea (top) conventional studies (bottom) our approach

bottom). We consider that the reduction process has an important role as a preprocessing step in the transformation of real-world textures. Our approach is also applicable to other purposes such as increasing textures and expanding conventional technologies by reducing the original haptic textures.

3 Design & Implementation

Our approach aims to transform the haptic textures of real materials. In particular, our method transforms real textures by utilizing ultrasonic vibration. We employ ultrasonic vibration to reduce and erase the haptic textures of real-world objects based on the squeeze film effect. Using our system, the texture obtained is inherently high resolution and the altered textures are felt without lateral movement of fingers because real material has its own texture (Figure 1, right). These features are different from those obtained using previous methods [5] [6] [7] [8]. Figure 3 shows a diagram of our system, which has four components: The host computer, the resonance controller, the ultrasonic transducer, and real material textures. Users can touch the real material with their bare fingers. The height of levitation by the squeeze film effect is controlled to transform the textures. The process operates as follows. The computer sends a start signal to the controller, which adjusts the resonance frequency. Next, the controller generates the input signal to the transducer. The amplitude of the input signal determines the levitation height of the finger relative to the material surface based on the squeeze effect. We paste papers of various real textures (Figure 1, right) onto a metallic plate that is acoustically

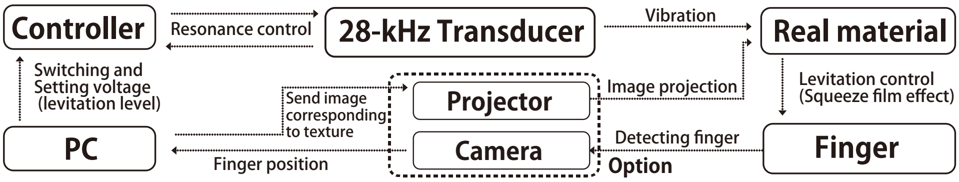


Figure 3: System components; computer, controller, 28-kHz

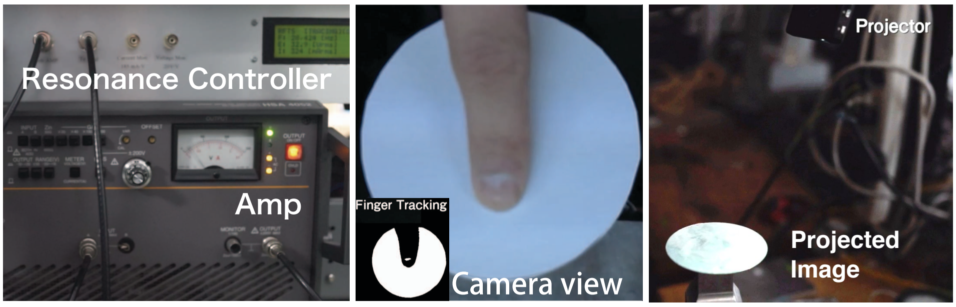


Figure 4: (Left) finger tracking, (right) image projection.

coupled to the 28-kHz transducer. Resonance control (adjusting the frequency of the input signal) is necessary for this use because the resonance of transducer changes when user touches the transducer.

In further applications, we also employ a projector, a camera, and other equipment. These are optional components which are connected to the computer for the application purpose (Figure 3). A finger tracking system with a camera is shown in Figure 4 (left). A camera (640 × 480 pixels) is set above the material's surface. Because the finger moves only two-dimensionally, tracking with a binary image is enough to detect the finger position. Thanks to this finger-tracking, multiple textures can be provided on the same material by altering the ultrasonic vibration according to the finger position. In addition, a projector is set above the material's surface, which projects an image onto the surface to transform the visual appearance of the material. By utilizing ultrasonic vibration and projection, our system can transform the real material in terms of haptic and visual characteristics.

4 Evaluation

In this section, we describe the experimental evaluation of our approach. Our evaluation involved a quantitative evaluation based on a three-axis accelerometer and interviews with subjects. First, we describe the experimental design and we provide an overview of the results, which are followed by a description of the quantitative evaluation and interviews.

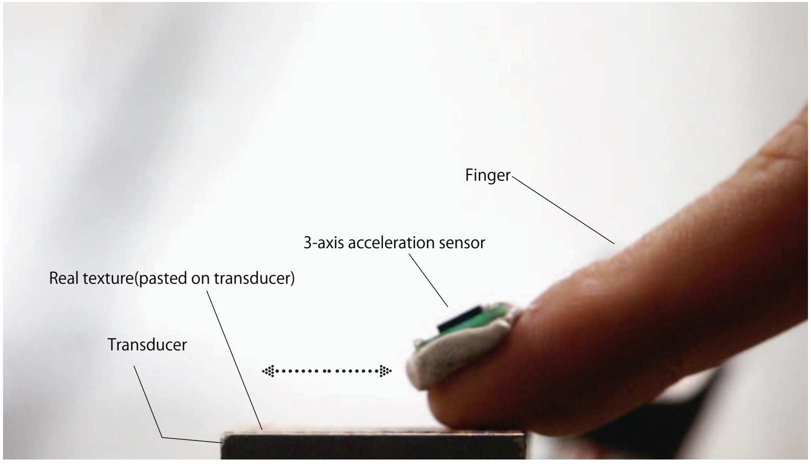


Figure 5: Experiment overview: 3-axis accelerometer attached to the nail and finger trace the texture on the transducer.

4.1 Experimental Design and Results Overview

To evaluate the reduction of the haptic texture, we focused on the high-frequency components of the finger vibration when a finger was traced on the surface. Using a three-axis accelerometer (KXR94-2050) attached to a fingernail, we measured the degree of haptic texture reduction (as shown in Figure 5). Graphs were obtained for the accelerometer in two states: transducer active (levitated) and inactive (not levitated), where the shapes of the graphs contained waves that exhibited changes in the high frequency components. When the transducer was inactive, the friction was not altered and the high frequency components of the graphs were evident. When the transducer was active, the friction was decreased and the high frequency components of the graphs were reduced.

In this experiment, the area of the touch surface was 2 cm^2 and the finger movement was regulated to 4 cm/s. The accelerometer could measure $\pm 2 \times g$ and the output data were captured using an oscilloscope.

4.2 Experimental Tests of Roughness and Levitation

In these experiments, we investigated the reduction of haptic textures based on a quantitative evaluation. We used sandpaper as the surface. We cut sandpaper into pieces that measured 2 cm^2 and pasted them onto the transducer. The sandpaper grades ranged from #600 (smooth) to #240 (rough), i.e., #600, #500, #400, #320, #280, and #240. The diameters of the particles on the sandpaper surfaces are shown in Table. 1. The particles were attached to the surface of the sandpaper and their diameters determined the roughness of the sandpaper. We adjusted the output voltage from 0 V to 40 V (5 V steps). The squeeze film effect began to occur at 10 V. If the output exceeded 40 V, the subjects felt heat on their finger. The graph obtained using the three-axis accelerometer is shown

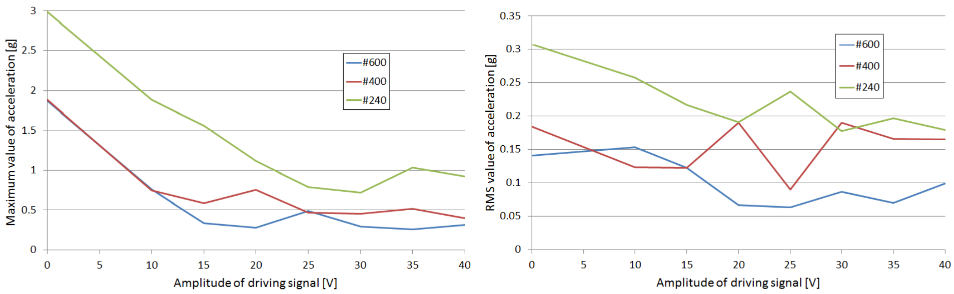
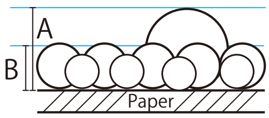


Figure 6: (Left) maximum value of acceleration #600 vs #400 vs #240 (right) RMS value of acceleration #600 vs #400 vs #240

Table 1. Sandpaper number grades, the diameters of the particles, and height of bump



Number of sandpaper	Max particle size (μm)(A)	Average diameter (μm) (B)	Height of bump (μm) (A)-(B)
#600	≦53	20.0±1.5	33±1.5
#500	≦63	25.0±2.0	38±2.0
#400	≦75	30.0±2.0	45±2.0
#320	≦98	40.0±2.5	58±2.5
#280	≦112	48.0±3.0	64±3.0
#240	≦127	57.0±3.0	70±3.0

in Figure 6. The RMS and maximum value of acceleration were reduced with high amplitude.

4.3 Experiments using Real Materials

In these experiments, we investigated the reduction in the haptic textures of several materials: sticky plastic, rough paper, copy paper, metal, bumpy rubber, and double-sided tape. We cut the materials into pieces that measured 2 cm^2 and pasted them onto the transducer (30 V RMS). Each subject traced the textures on the transducer with a finger. The three-axis accelerometer was attached to a fingernail. The examples of the results are shown in Figure 7. It is confirmed that the textures are effectively reduced.

4.4 Human factors

Four subjects stated that: “The texture changed,” “I did not feel the vibration,” “The texture became smooth but it was slightly jagged,” “It is very high resolution,” etc. The ultrasonic vibration was sufficiently high frequency not to be detected by the human sensory system. If the squeeze film was not sufficiently thick to levitate the finger from the material, the subjects felt a jagged sensation from the tops of the geometry of rough materials. All subjects (age; 23, 26, 33,41) recognized the texture transformation.

5 Application

Examples of possible applications of the proposed method are as follows.

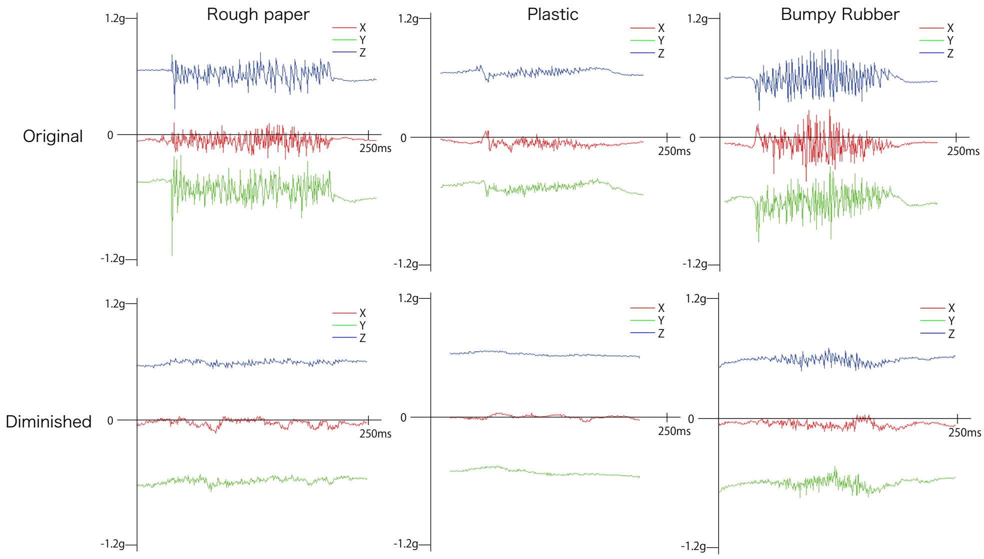


Figure 7: Results (30 V RMS) on several materials (left) rough paper, (center) plastic, (right) bumpy rubber.

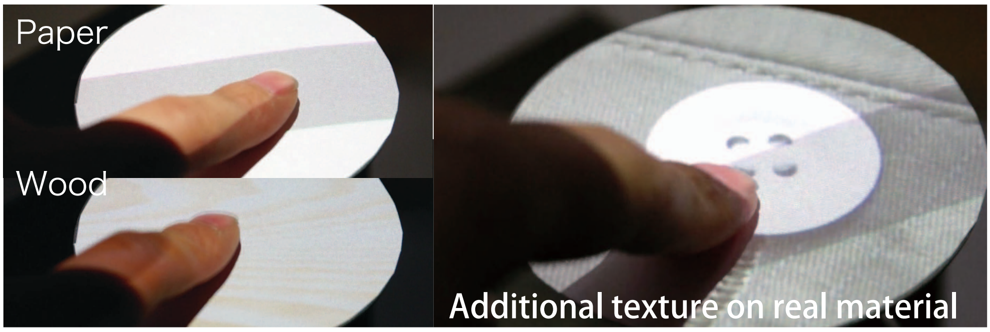


Figure 8: Application: spatiotemporal control with projection

1. Haptic transformation: The proposed method controls the magnitude of the texture using a squeeze film effect. While the texture is eliminated when the squeeze film is sufficiently thick, the texture is reduced when the squeeze film is thinner than the height of the texture peaks.
2. Spatiotemporal Control: The proposed method can provide multiple areas of different textures on the same material (Figure 8) based on levitation control according to the finger position. Switching the squeeze film effect can also provide additional textures on a real material.
3. High resolution haptic texture: Real materials are employed and their textures are reduced in the proposed method, the presented textures are inherently high resolution. Additionally they can be felt from the onset of the touch (without lateral movement).
4. Multimodal display: The proposed method can be combined with projection to provide visual and haptic textures at the same time (Figure 8).

6 Discussion, Conclusion, and Future work

In this study, we developed a method that allows the haptic transformation of real textures. This method reduces the haptic texture of a real material using the squeeze film effect generated by ultrasonic vibration. We discussed several related methods that use ultrasonic haptic systems. Our approach is different from these approaches because it reduces the texture of surfaces. We also implemented and evaluated the proposed method. The textures generated by this method are inherently high resolution. We conducted evaluations using a three-axis accelerometer and we confirmed that our prototype system operated successfully. In future research, we will apply this method to 3D-printed objects by applying ultrasonic vibration at adequate frequency. Resonance analysis is needed because the resonance frequency is different depending on the shape of the object.

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