Mid-Air Haptic Textures from Graphics

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Abstract—In this paper we present a method for instilling the haptic dimension of texture to virtual and holographic objects using mid-air ultrasonic technology. We first extract a set of features from imported images. Textural qualities such as micro and macro roughness are then computed and fed to a haptic mapping function, together with information about the dynamic motion of the user’s hands during holographic touch. Finally, mid-air haptic textures are synthesized and projected onto the user’s bare hands.

I. INTRODUCTION

The digitization of textured graphics has in recent years made huge strides and has enabled a wealth of applications. It is possible for example to search online databases via content-based image retrieval algorithms using graphics-only input features (rather than metadata and keywords). Graphics algorithms can then be fed with the search results and tasked with auto-generating massive photorealistic renders of virtual worlds. Physics engines that couple user interaction within these 3D worlds can then be used to synthesize textured audio, therefore creating an immersive multi-modal experience, minus the haptics. When we search blindly through our pockets however, haptic information such as an object’s compliance, the microgeometry of its surface and its friction properties is what allows us to quickly assess what is in there. Haptic technology has therefore been the focus of many research efforts in an attempt to render and communicate high fidelity textured tactile sensations. Wearable gloves, hand-held tools and vibrating electrostatic touchscreens are just a few examples of available hardware contraptions capable of conducting texture information to the human haptic sensory system.

In this paper, we add to this list by demonstrating an initial first step towards leveraging modulated focused ultrasound to generate mid-air haptic textures given an image or graphic input. Specifically, our novel contributions are: i) the introduction of a haptic mapping function \( f \), ii) its use to translate texture information from an input image or graphic into a haptic texture sensation in mid-air, thus iii) allowing for surface-free, tool-free, and wearable-free dynamic textured touch interactions with AR/VR content.

II. BACKGROUND

The ability for haptic technology to reproduce texture information has several enabling applications, inter alia, the touch of realistic virtual copies of valuable or historical items, robotic teleoperation for medical or industrial purposes, educational and training simulations in AR/VR, and forms a key part of Human Fashion Interaction (HFI); textural haptic information about products and fashion items are known to increase online purchase intention [1]. There are many different methods of delivering haptics:

Hand-held: Notable efforts include the Penn Haptic Texture Toolkit [2], a publicly available repository of 100s of haptic texture and friction models, the recorded data from which the models were made, images of the textures, and even includes the code and methods necessary to render them on a Phantom Omni (or similar). Wearables: There is an abundance of haptic gloves that are actuated via servos, pneumatics, voice coils, piezoelectric or other vibrotactile actuators. Surface Haptics: There are three means of texture reproduction on touchscreens: moving overlays, ultrasonically vibrating surfaces, and electrostatic surfaces that respectively generate shear forces, reduce or increase the effective surface friction. Ultrasound Mid-Air Haptics: Electrical signals drive a set of ultrasonic speakers (or transducers) such that ultrasound waves interfere constructively at one or more focus points in space such that a tactile sensation is felt when touched by the bare hand of a user [3]. This touchless technology was first demonstrated in Japan [4] and commercialized by Ultrahaptics in the UK. When a user touches a virtual object, the contact points between her hand and the object are recorded and one or more ultrasonic focus points can be made to 'jump' from point to point (in some order and speed) such that an object surface is felt; a tactile hologram.

It has been hypothesized that varying the order, speed or waveform of the modulated ultrasound will simulate perceivable differences in textured effects e.g., a faster hand traversal speed may be associated with a smoother surface, and a square modulated wave with a rougher one [5]. Here, not only do we demonstrate this to be true, but we also automate the capture, conversion, and haptic rendering process, therefore creating a one-to-one mapping between a graphical object’s texture and the projected mid-air haptic.

III. MID-AIR HAPTIC TEXTURES FROM GRAPHICS

The term tactile texture relates to the surface/material properties perceived by our fingers upon static (pressing down) or dynamic (sliding) contact with an object. During tactile exploration, qualities such as friction, roughness, and temperature are perceived. Different tactile dimensions are perceived depending on the type of tactile interaction used. As the hand/finger contacts an object's surface, the central nervous system is informed about the qualities of the contact, which influences our perception towards exploring, grasping, and manipulating our environment [7]. Based on work by Okamoto et al. [8], five fundamental perceptual texture dimensions have been identified: fine roughness (rough/smooth), macro roughness (uneven/relief), hardness (hard/soft), warmth (cold/warm), and friction (sticky/slippery). In this work, we

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explore the presentation of fine and macro roughness features extracted from images of material surfaces, e.g., fabrics, plastics, and woods using ultrasound mid-air haptics. Our algorithm starts by using a displacement map i.e. a greyscale value for each pixel in a 2D image corresponding to height detail. These values are then used to calculate the image micro- and macro- scale roughness. The setup and method summary are shown in Fig. 1.

**Figure 1: Demonstration Setup and Method Schematic.**

*Micro-Scale Roughness* is calculated using the 2D autocorrelation function for a high-resolution textured image, e.g., those found in [6]. This function establishes whether an image contains non-periodic features. For example, the autocorrelation function of a regular texture will contain peaks and valleys with spacings equal to the distance between the texture primitives. The autocorrelation function is most often achieved by taking the discrete Fourier transform (DFT) of the image and multiplying each coefficient with its complex conjugate before taking the inverse DFT. If the inverse DFT is not taken, the function obtained is the power spectral density (PSD) function that in this case measures the energy at each spatial scale. In addition, the PSD function can determine the coarseness of the texture, which we identify as micro-roughness. Fitting a slope to the higher frequency sections of the PSD function gives us the roughness parameter we require. If the function rapidly decays then the image contains a smoother texture with texture information concentrated at lower spatial frequencies, whereas the image contains a rough texture if the function drops off slowly or flatens, indicating texture information at higher spatial frequencies. The micro roughness values (mRVs), which were learnt from the PSD function earlier, are then used to choose the haptic parameters from a look up table (LUT) that we have constructed *a priori* through user testing. The LUT maps the mRV to a ‘draw speed’ and haptic sample points which are projected onto the user’s hands when 1) the hand is located within the bounds of the textured image, and 2) the hand has a lateral velocity above a predefined threshold. *Macro-Scale Roughness* is more closely coupled with the dynamic exploration of the textured surfaced. We achieve this by setting the haptic intensity to be proportional to displacement map value. Hence, the haptic intensity perceived by the user varies dynamically in strength according to the location of the main holographic touch points. The acoustic radiation force of the focused ultrasound (haptic sensation strength) is thus modulated between a minimum value corresponding to the vibrotactile threshold, and the maximum output power of the ultrasonic mid-air haptic device (in this case an Ultrahaptics STRATOS Inspire device). Applying both micro- and macro-scale texture effects simultaneously is what we have called here the haptic mapping function $f$.

### IV. Discussion and Conclusion

We have described a novel procedure for rendering fine and macro roughness features [8] of textured graphics using mid-air ultrasonic haptics [3]. The algorithm links dynamic exploratory touch with spatial variations in image textures and projects these tactile sensations directly onto the user’s hands through an impinging ultrasonic pressure field. Thus, the method avoids possible sensory conflicts due to inconsistency between a haptic texture and its visual representation. Moreover, the method is robust against computer graphic rendering techniques (e.g., normal and bump maps) and can therefore be applied to a vast range of applications. This initial step towards ultrasonic mid-air haptic textures presents new opportunities for the enhancement of immersive AR/VR experiences, as well as the possibility of substituting real fabric textiles with ultrasonic replicas, what is effectively a new human-fashion-interaction (HFI) paradigm where users of VR-dressing rooms and online shops can touch and feel digital products. Going forwards, we plan to subject our setup and methods to rigorous user testing to establish the spectrum and resolution of textures that can be achieved and identified, and to what extent these can be potentially be improved by adding dynamic auditory feedback.

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**References**


