Enhancing Vibrotactile Signal Propagation using Sub-Surface 3D-Printed Waveguides

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ABSTRACT

The mediation of haptic feedback largely depends on physical properties of the surface of interaction and its internal structure. Most mobile devices today are assembled using a wide range of components with varied physical properties that can limit the propagation of tactile signals. For that reason, it is important to understand how common materials used in assembling mobile devices relay vibration signals and develop techniques of effectively mediating haptic feedback uniformly throughout the entire device. This research compares three off-the-shelf waveguide materials and one custom-designed 3D-printed ABS structure for creating feedback signals on flat interaction surfaces. Preliminary results indicate that by altering the internal structure of the interaction surface we can reduce attenuation and integration of the applied signal and improving the overall haptic experience.

Author Keywords

Haptic Mediation; global device actuation.

CSS Concepts

• **Human-centered computing~Human computer interaction (HCI)**; *Haptic devices*; User studies.

INTRODUCTION

Calibrated vibration signals have been used to convey tactile information in various devices [2, 3, 11, 12, 17, 18]. In global device actuation, the generated signal is intended to propagate uniformly across the entire device. However, due to the nature and assembly of current interaction devices, signal attenuation and integration can greatly affect this propagation [7, 8]. Therefore, applied signals may appear considerably altered when sampled farther away from the actuation source. To reduce this signal distortion, it is possible to utilize haptic waveguides that can mediate the source signals more efficiently [1, 9, 13, 15]. Depending on the material properties as well as the structural design of the waveguide, applied signals may be enhanced to create more reliable and consistent global device actuation. In this research we discuss a technique to create Embedded Haptic Waveguides (EHWs) within a 3D-printed surface and compare its efficiency with common materials used in mobile devices (Gorilla glass, Plexiglas and aluminum.) The goal of this research is to improve global device actuation [4, 5, 9, 10] by reducing signal attenuation and integration on the interaction surface.

3D-Printed Embedded Haptic Waveguides

A waveguide is a medium where the wave propagation is bounded in two directions of space and free in the third [6, 9, 10]. With current advances in 3D printing it is possible to create calibrated wave guides using specific materials. We know that there is a close correlation between the material properties (ρ, Y) of the waveguide and the resonance frequency of the system [14, 16]. In most cases these properties remain fixed throughout the entire surface. However, within a 3D-printed structure it is possible to vary these properties by altering fill rate and combining composite materials together (i.e. ABS). Moreover, in our testing we found that it is also possible to create multiple waveguides within the 3D-printed object by designing 1.5mm wide chambers or shaft-like indentations inside the object itself (Fig. 1) with a ratio of solid waveguide to empty space of 1:1. The solid material acts as the waveguide while the empty space provides an insulation around the waveguide reducing the unwanted propagation of the applied signals. This technique reduces unnecessary energy dissipation and guides the applied signals from the actuation source to the point of contact. Using this process, we were able to develop embedded waveguides specifically designed to relay actuation signals throughout the entire device without signal attenuation.

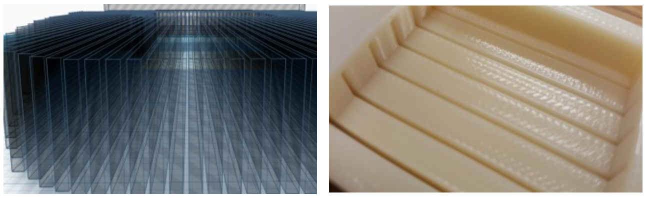

Figure 1. 3D-printed waveguides with embedded shafts (left) and chambers with surface groves (right) to enhance mediation of vibration signals.

EXPERIMENT DESIGN

To measure the efficiency of continuous actuation signal at four frequencies (100, 140, 180, 220Hz) traveling through the four waveguides, we mounted the 3+1 waveguides to the

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touchscreen of a Microsoft Surface 4 device (Fig. 2). We also attached a Tectonics TEAX14C02-8 actuator on top of each waveguide surface and by using a unidirectional piezoelectric sensor (WS-16025YDW) we measured the vertical components of vibration introduced by the actuator at 95mm from the actuator. To gauge any perceived difference on two points of the given surfaces, we asked 22 university students (8 male, 14 female) to feel a 120Hz sinusoidal signal generated by the TEAX14C02-8 actuator (same setup as above) on each surface at two discrete points. Point A was 28mm away from the actuator and point B was 190mm away. The participants were asked to rate the perceived difference between the signals felt at point A and point B on a scale of 0-10, where 0 represented no difference and 10 represented completely different signals, following the method in Zwislocki & Goodman [19] (Fig. 2).

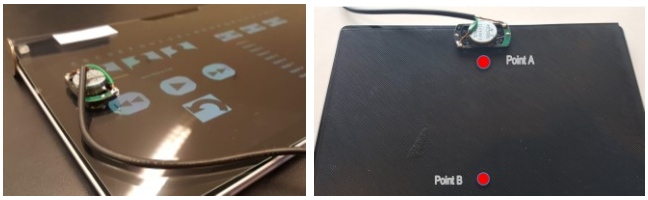

Figure 2. Setup for technical evaluation and user study.

RESULTS

Results from both sets of measurement show that the current version of the custom-designed 3D-printed waveguide was more efficient at relaying haptic signals among the four surfaces. Wave propagation measurements recorded at the four frequencies (100, 140, 180 and 220Hz) showed that the 3D-printed waveguide was better at maintaining signal integrity while reducing attenuation and signal decay (Fig. 3 and 4).

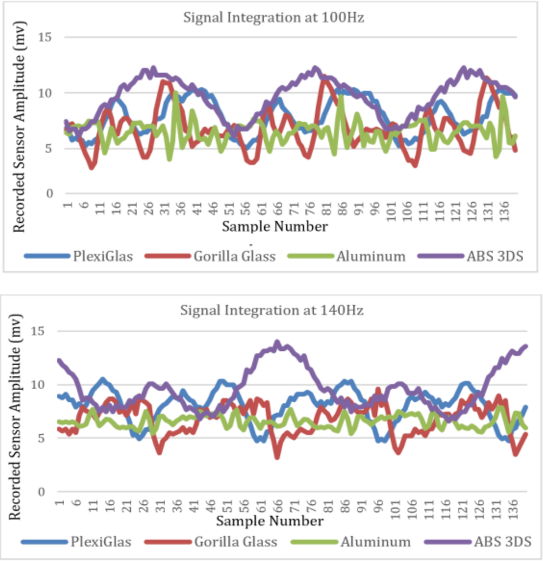

Figure 3. 100Hz (top) and 140Hz (bottom) signals recorded at 95mm from the source actuator to illustrate distortion / attenuation in the 4 surfaces.

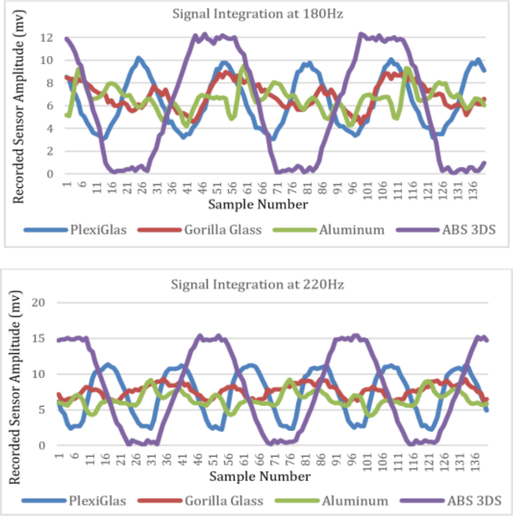

Figure 4. 180Hz (top) and 220Hz (bottom) signals recorded at 95mm from the source actuator to illustrate distortion / attenuation in the 4 surfaces

Results for the measured frequencies also showed little signal attenuation and parasitic vibrations for the 3D-printed waveguides across the board. However, we can see that both the aluminum and Gorilla glass surfaces attenuated the applied signal, mostly altering the waveform by integrating the applied signals [20]. We also observed signal degradation and integration in the Plexiglas waveguide, however it was not as severe as the aluminum and Gorilla glass surfaces. Similarly, results from the user study (Fig 5) indicated that the participants rated the actuation signal received at points A and B, as more similar and far more consistency on the 3D-printed waveguide, as compared to the other waveguide surfaces.

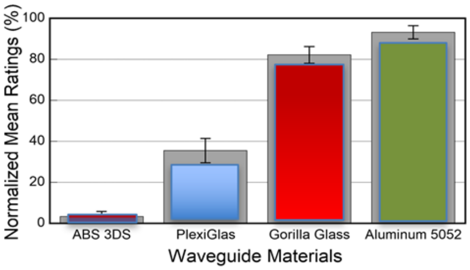

Figure 5. Comparison of mean ratings of perceived differences

CONCLUSION

This research focused on evaluating three off-the-self waveguide materials and one custom designed 3D-printed structure for creating controlled global device actuation. Results show that the custom designed 3D-printed waveguide was able to relay the actuation signals with least attenuation and distortion with very little signal integration compared to the other three surfaces. This is visible at all the measured frequencies (100Hz, 140Hz, 180Hz, 200Hz and 220Hz). These results indicate that custom waveguide can be useful in improving the reliability and efficiency of vibrotactile feedback for surface-based interactions.

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