햅틱 증강현실을 위한 능동적 진동 제어: 초기 연구
Active Vibration Control for Haptic Augmented Reality: An Initial Study

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Abstract

This paper presents an initial study on the use of active vibration control in haptic augmented reality environment. The study utilizes two vibrotactile actuators, attached to an aluminum tool, to actively control and cancel vibrations in the system. Four different waveforms were tested using one actuator to excite the system and the other to cancel out the response in real-time. Accelerometer data was collected for both scenarios. The results showed a significant reduction in vibration response when both actuators were running simultaneously, demonstrating the potential of vibrotactile actuators to control incoming vibrations. Overall, this study provides a proof of concept for the use of active vibration control in haptic texture rendering in augmented reality, paving the way for more immersive and realistic multi-sensory experiences.

1. Introduction

Augmented reality, through the use of computer vision, allows users to view their real-world environment while simultaneously overlaying virtual objects onto it. This unique technology provides a mixed sensory experience that seamlessly blends the physical and digital worlds to create an immersive experience [1]. Similarly, the field of haptic augmented reality is also exploring new ways to enhance the user experience by simulating a combination of digital haptic stimuli with real-world environments. By leveraging advanced haptic technology, haptic augmented reality can provide users with a multi-sensory experience, bringing together the sense of touch with vision to create a more engaging and realistic experience [2].

Haptic texture rendering is a critical aspect of haptic augmented reality, where users can interact with the surface texture of virtual objects overlaid onto the real world. This interaction can be accomplished using either bare hands or tools, enabling users to perceive the modified texture surface properties of real objects, such as flatness, bumpiness, roughness, and smoothness. While previous attempts have been made to modify surface roughness by attaching a vibrotactile actuator to the finger during surface exploration [3, 4], bare hand interaction fails to provide the necessary control over the vibrations of real-world textures, as capturing surface texture data is challenging. To address this issue, a possible solution is to use a metallic tool to interact with the real-world surface and record haptic information in the form of vibrations.

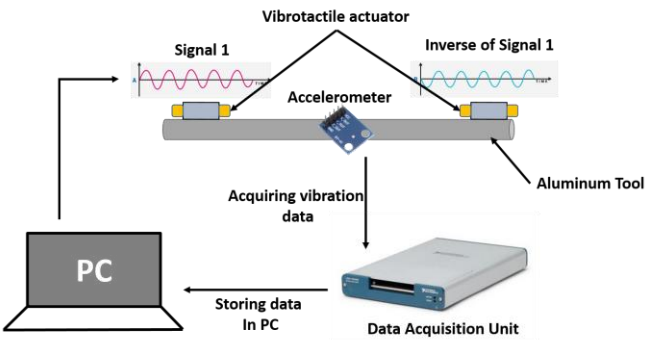

Figure 1. Overall Framework

In this paper, we conducted an initial study for actively controlling and canceling vibrations in a texture rendering system in haptic augmented reality environment, with the aim of improving the fidelity and realism of tactile feedback. Our system draws inspiration from the principles of active noise cancellation in audio technology [5], by observing the input signal (captured with sensor) of surface texture during tool based interaction, we can design an algorithm to get a control of texture vibration to remove unwanted vibration noise in the system or overlying a digital haptic signal to provide users with a more immersive haptic experience.

2. System design

To carry out our study, we developed a framework, as illustrated in Figure 1. The framework comprised two vibrotactile actuators (Haptuator, MM3C-HF from Tactile Labs, resonance frequency = 85 Hz) attached to an aluminum tool. One actuator served as an exciter, providing input vibrations to the system, while the other acted as a real-time canceller, canceling out the response of the first actuator. We used a PC's sound card to render various vibration waveforms on the actuators. Additionally, we placed an accelerometer (ADXL 335) to monitor the vibration response in the aluminum tool, and acquired the accelerometer data using a data acquisition unit (NI DAQ USB-6351).

3. Data collection and processing

We conducted experiments using four different waveforms: sine, square, saw-tooth, and sine sweep. The first three waveforms were rendered at a frequency of 100 Hz, and the system was tested with a sine sweep where the frequency range was set between 20~250 Hz. Actuator 1 received all four waveforms to excite the system, while actuator 2 received the inverse of these waveforms to cancel out the response of actuator 1 in the system. During vibration rendering, the accelerometer's 3-axis data was recorded in the system. We collected data for both scenarios - when a single actuator was active and when both were active.

The recorded data from the accelerometer was in three dimensions. To better understand and visualize the data, we performed dimensionality reduction on the vibration data. Several dimensionality reduction techniques for high-frequency vibrations in haptic rendering exist, such as sum of components, PCA, and vector magnitude. However, the DFT321 method is currently considered the best approach for this task [6], so we used it in our study.

4. Results and discussion

Figure 2 displays the results of our study, where we observed a significant reduction in vibration response when both actuators were running simultaneously. When holding the aluminum tool, the combined actuator's strength was noticeably weaker than that of a single actuator. These results demonstrate that vibrotactile actuators can effectively control incoming vibrations in a system, as evidenced by both the recorded vibration response and perceptual observations.

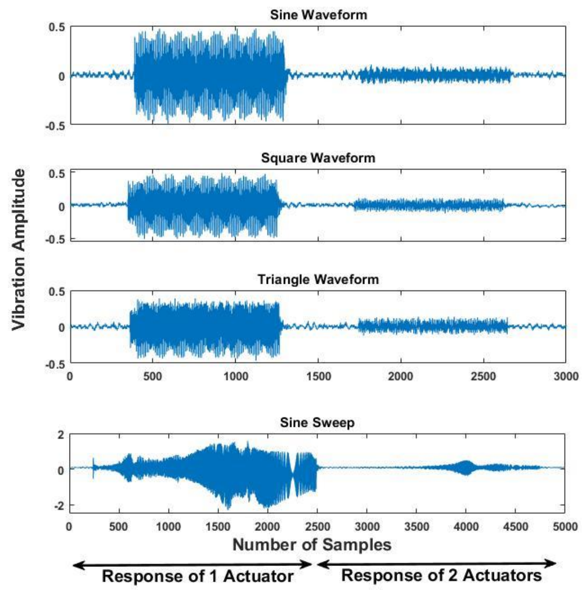

Figure 2: Vibration response comparison.

Our study serves as an initial proof of concept for active vibration control in haptic rendering environments. While we conducted our experiments in an open loop environment, our future goal is to extend the system to a closed loop design. This entails exciting one actuator, recording its response with an accelerometer, and then reconstructing the signal (from 3 dimensions to 1 dimension) to invert and send it to the other actuator. We plan to use the DFT321 method for signal reconstruction, which can preserve both spatial and temporal features of the signal. However, one potential challenge in the system is computational delay due to signal reconstruction. We believe this issue can be resolved by using dedicated hardware for signal processing.

5. Conclusion

Our study presents a proof-of-concept for the use of vibrotactile actuators in active vibration control for haptic rendering. By attaching two vibrotactile actuators to an aluminum tool and using one actuator as an exciter and the other as a canceller, we were able to significantly reduce the vibration response in the tool when both actuators were running simultaneously. The results were validated both through accelerometer data and perceptual tests. Future work includes implementing a closed-loop system and addressing the computational delay that may arise. Overall, our study contributes to the advancement of haptic technology and has potential applications in a variety of fields, including virtual and augmented reality.

6. Acknowledgement

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7. References

[1] Chen, Yunqiang, et al. "An overview of augmented reality technology." Journal of Physics: Conference Series. Vol. 1237. No. 2. IOP Publishing, 2019.

[2] Jeon, Seokhee, and Seungmoon Choi. "Real stiffness augmentation for haptic augmented reality." Presence: Teleoperators and Virtual Environments 20.4 (2011): 337-370.

[3] Yoshimoto, Shunsuke, et al. "Material roughness modulation via electrotactile augmentation." IEEE Transactions on Haptics 8.2 (2015): 199-208.

[4] Asano, Shuhei, Shogo Okamoto, and Yoji Yamada. "Vibrotactile stimulation to increase and decrease texture roughness." IEEE Transactions on Human-Machine Systems 45.3 (2014): 393-398.

[5] Hansen, Colin N. Understanding active noise cancellation. CRC Press, 2002.

[6] Landin, Nils, et al. "Dimensional reduction of high-frequency accelerations for haptic rendering." Haptics: Generating and Perceiving Tangible Sensations: International Conference, EuroHaptics 2010, Amsterdam, July 8-10, 2010. Proceedings. Springer Berlin Heidelberg, 2010.