Skin Deformation Feedback for Force Sensory Substitution in Teleoperation and Virtual Reality Training

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1. Narrative

Virtual reality (VR) has become a common tool for training in scenarios that are risk intensive, or difficult and expensive to replicate in the real world, such as medical simulation. Professions within the skill-intensive medical field require extensive bimanual interaction with the environment, frequently necessitating skill development through hands-on experience. Despite rapid advancements in the visual component of virtual environments, current VR systems lack the ability to convey realistic haptic (kinesthetic and cutaneous) sensations to replicate the important haptic information that is naturally present in manipulation tasks. In this work, we attempt to create a more realistic haptic experience with wearable multi-degree-of-freedom tactile feedback.

Introduction

A large body of research has focused on grounded, 3 degree-of-freedom (DoF) kinesthetic haptic devices that render virtual environments by outputting a force through a robotic end effector. While these devices create compelling sensations, they are bulky and expensive, and constrained to small, table-top workspaces. Our work expands the genre of haptics for training in VR by developing wearable skin deformation solutions to convey more realistic tactile feedback over a large workspace, and performing user studies to determine how users fundamentally perceive the feedback from these types of devices.

For this work, we developed a wearable skin deformation device that is worn on the tip of the finger. The devices have two separate components, the first of which is a finger grounding interface that straps to the medial phalanx. The interface holds a magnetic tracking sensor from an Ascension 3D Guidance trakSTAR system, which provides tracking information about the position and orientation of the fingers in free space at 200 Hz.

The second component of the devices is the delta mechanism, which attaches to the finger grounding interface and kinematically wraps around the fingertip. The end-effector of this delta mechanism makes contact with the fingertip and then moves normally and laterally to deform the fingertip skin to emulated the tactile forces that are present during manipulation. CAD models of the entire created assembly can be found on https://github.com/sschorr/WearableDevice.

By attaching two of these devices, on a user's index finger and thumb, and combining with immersive virtual scenes rendered by a head mounted virtual reality display, we were able to perform investigations on human perception when receiving wearable skin deformation feedback associated with virtual object interaction.

Results

Several human subject experiments were performed to determine the efficacy of the skin wearable skin deformation feedback devices for providing force information in 3 degrees of freedom. In the first experiment, participants were tasked with locating a stiff region in a virtual tissue phantom. Participants using the skin deformation device were able to locate this stiff region with similar accuracy as reported in prior literature using force feedback. In a follow-on experiment, we showed that not only could participants use variations in normal force stiffness to determine this location, but they could also discriminate between small variations in surface friction. Friction inherently requires perception of both fingertip normal and lateral forces, showing that participants could use the vector direction of the applied skin deformation force effectively.

In addition to exploring static environments, the use of a pair of devices on the index finger and thumb enabled participants to manipulate dynamic virtual objects. In a set of experiments designed to determine participants' naive untrained response to wearable skin deformation feedback, we had participants interact with two virtual cubes resting side by side in a virtual environment. Participants were asked to describe any differences between the two virtual objects. With no externally grounded force feedback method, only feedback from the wearable skin deformation devices, we showed that participants were able to distinguish between virtual object physical properties such as mass, friction, and stiffness with no training.

Furthermore, we investigated combining pseudohaptic principles with skin deformation feedback, using visual stimuli to alter user haptic perception. Our results showed that distortion of the user control to display ratio, the amount of visual object motion based on a given user input, we could cause participants to feel that objects were heavier or lighter than the haptic sensation being rendered. This finding further extends the boundaries of convincing rendering via skin deformation feedback

Significance and impact

The growing prevalence of head-mounted virtual reality displays and more immersive virtual experiences has contributed to creating a large population interested in the next evolution of haptic experiences. These new, untethered virtual reality experiences drive a need for a new type of high fidelity haptic feedback. The traditional externally grounded haptic feedback devices are inherently cost and workspace limiting.

While many have focused on portable haptic solutions for addressing this problem area, most of these feedback methods are focused on relatively low fidelity haptic feedback, such as single actuator vibration which can only display amplitude and frequency information, but neglects the more realistic parts of haptic sensation. Our wearable skin deformation feedback device and rendering solutions can convey a larger range of compelling haptic stimuli, including the physical properties of virtual objects, such as mass, friction, and stiffness.

By performing human subject experiments that determine how users fundamentally perceive physical properties when receiving this type of haptic feedback, we not only create a more compelling haptic experience, but our research also serves as guidance for how to create more effective haptic feedback for training in virtual reality.

Where might this lead?

As virtual reality experiences become more immersive, training in virtual reality will provide the opportunity for better training in situations that are dangerous or expensive to replicate. As device designs become smaller, and the rendering techniques more advanced, users will be able to receive body grounded haptic feedback that is not reduced to single dimension vibration, but rather conveys all of the rich parts of tactile sensations that are present during real-world physical interactions. By more closely matching the real world, these training experiences will be more authentic and more effective than existing training methodologies.

2. How did the fellowship make a difference?

The fellowship was absolutely essential in my ability to pursue my specific interests in bringing this research to fruition. Rather than being forced to mold the project to match an existing grant scope, I was able to investigate the fundamental human perception questions that are most critical for enabling wide reaching future research.

3. Future Plans

I graduated in early June and started working at Intuitive Surgical in Sunnyvale, California as a Systems Analyst. In this role, I get to apply a lot of the things I learned while executing the research described in this document.

4. Publications, Presentations, and Other Outputs.

Schorr, Samuel B., and Allison M. Okamura. "Pseudo-haptic alteration of perceived virtual mass with wearable skin deformation feedback." In preparation for submission to *IEEE Transactions on Haptics.*

Schorr, Samuel B., and Allison M. Okamura. "Fingertip Tactile Devices for Virtual Object Manipulation and Exploration." *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*. ACM, 2017. (BEST PAPER AWARD)

Schorr, Samuel B., and Allison Okamura. "Three-dimensional skin deformation as force substitution: Wearable device design and performance during haptic exploration of virtual environments." *IEEE Transactions on Haptics* (2017).