Active Haptic Feedback for a Virtual Wrist-Anchored User Interface

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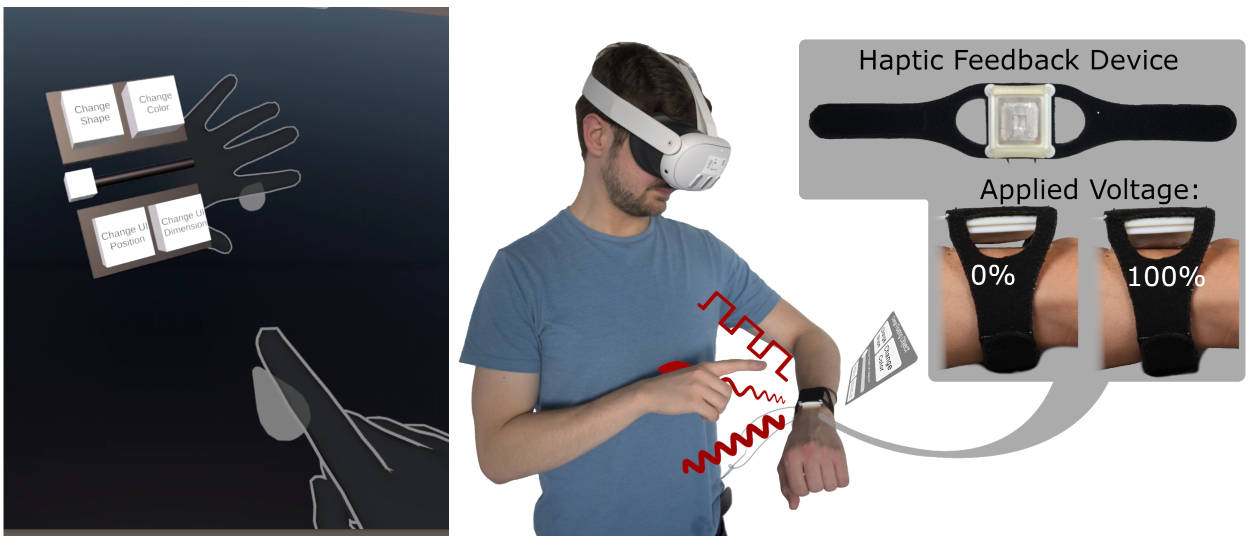

Figure 1: Left: The wrist-anchored interface in VR. Center: A user interacting with the interface while wearing the cutaneous electrohydraulic (CUTE) device on their wrist. Right: The CUTE device in its minimum and maximum actuation states.

ABSTRACT

The presented system combines a virtual wrist-anchored user interface (UI) with a new low-profile, wrist-worn device that provides salient and expressive haptic feedback such as contact, pressure and broad-bandwidth vibration. This active feedback is used to add tactile cues to interactions with virtual mid-air UI elements that track the user's wrist; we demonstrate a simple menu-interaction task to showcase the utility of haptics for interactions with virtual buttons and sliders. Moving forward, we intend to use this platform to develop haptic guidelines for body-anchored interfaces and test multiple haptic devices across the body to create engaging interactions.

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CCS CONCEPTS

• **Human-centered computing → Haptic devices**; *Gestural input*.

KEYWORDS

human computer interaction, haptic interfaces, virtual reality, body anchored interfaces

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1 INTRODUCTION

The miniaturization of motion sensors, advances in machine vision, and improved strategies for estimating body pose from sparse sensor data have made it possible to track the human body with reasonable accuracy using cost-effective wearable sensors and cameras. In turn, users can now directly interact with virtual content using their hands, and digital content can move with their body parts. These two advances have led to the emergence of *body-anchored user interfaces*, which utilize the human body and the surrounding space as a display for virtual content, and the body's configuration as an input method, allowing for intuitive interactions such as direct poking and gesturing [12].

Body-anchored UIs differ from classical UIs in that they follow some point of the body and are hence always within reach, can easily be located due to proprioception, and can easily be brought into and out of view by adjusting the corresponding limb [6]. A common place for body-anchored interfaces is the forearm due to its reachability, high degree of control, and the already established practice of wearing watches to display information [2, 8, 9, 12, 16].

However, being virtual in nature, body-anchored interfaces typically lack the haptic feedback inherent to interactions with physical objects. As a result, these interfaces demand higher visual attention when interacting since the user lacks feedback about critical stages of the interaction, such as making and breaking contact with the surface, the click of a button engaging, or the vibration of a slider moving. This phenomenon has also been observed in stationary virtual interfaces where the addition of haptic feedback has been shown to improve user performance [4, 5].

Many researchers have sought to address the lack of haptic feedback in body-anchored interfaces by letting users make contact with their own skin [2, 3, 8, 12, 16], but this approach allows only the sensation of contact with a soft body and is constrained to actions on the skin surface. Meanwhile, interactions with physical buttons, knobs and sliders produce rich tactile sensations with various stiffness, friction, and changing contact, which a passive haptic surface like the skin cannot replicate. Presenting these sensations therefore requires active haptic rendering. Indeed, prior work has shown that a small capacitive sensor attached to the skin can be transformed into a wide range of buttons by adding a small vibrotactile actuator to the index finger, illustrating the potential of augmenting UI elements with active haptic feedback [15].

Active haptic feedback has been combined with body-anchored interfaces to provide users with the sensations of cold, warmth, tingling, or numbness by applying different chemicals to the skin [10]. Lu et al. note, however, that the slow action of the chemical interface, measured in minutes, is more suited to render environmental and other slow-changing effects. Instead, our work focuses on providing the immediate tactile experience involved in UI interactions.

To showcase the benefits of active haptic feedback in body-anchored interfaces, we combined a virtual wrist-anchored interface and a novel wrist-worn cutaneous electrohydraulic (CUTE) device that is capable of making and breaking contact with the skin (2.4 mm stroke) and applying forces with independent magnitude and frequency from 0 Hz to 200 Hz [14]. Each CUTE device is driven by a stack of expanding hydraulically amplified self-healing electrostatic (HASEL) [1] actuator pouches. We chose to render our feedback at the wrist because this location has been identified as an effective place to provide haptic feedback [11, 13], allows for larger devices and is less encumbering.

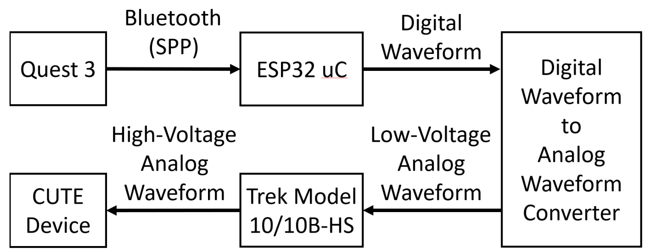

Figure 2: Signal chain of the system.

2 IMPLEMENTATION

The signal chain of our demo is depicted in Figure 2. To participate in the demo, a user only has to don the Meta Quest 3 headset and the CUTE device.

Users can interact with the body-anchored interface with just their hands. However, we have found that the vision-based tracking used by the Meta Quest 3 becomes unreliable when the two hands are near one another. Thus, our system also allows participants to hold the Meta Quest 3 controller in their left hand to improve tracking.

When interacting with one of the virtual UI button or sliders, the Meta Quest 3 sends encoded impulses and sinusoids to the ESP32 via Bluetooth. These encoded signals are then converted into a low-voltage analog signal which drives a Trek 10/10B-HS high-voltage (HV) source that ultimately generates the HV signal required to actuate the CUTE device.

Given the high voltages needed to drive the actuator, the system ensures safety by insulating the HV electrodes with non-conductive materials, containing all interconnects in 3D-printed enclosures, current-limiting the HV source, and utilizing a monitoring circuit that rapidly disables the HV source in case of an unexpected discharge.

3 INTERACTIONS

Our demo showcases the utility of haptic feedback for body-anchored interfaces with a small virtual menu, consisting of four buttons and a slider.

- Using two buttons and the slider, participants can adjust the shape, color, and height of a virtual object as well as the color of a real LED driven by the ESP32, demonstrating how body-anchored interfaces can be used to control objects in the virtual and real worlds.
- With the other two buttons, participants can move the virtual user interface between four different locations around the forearm and toggle between a flat and a three-dimensional UI.

While pushing the buttons and moving the sliders of the menu cause effects in the virtual world, this interactivity primarily aims to entice participants to engage with the different UI elements and experience the haptic feedback. We use the CUTE device to provide participants with four haptic sensations that commonly occur when interacting with a physical user interface:

- Contact: When a participant makes contact with a virtual interface element, the haptic device makes contact with the skin, mimicking the transient waveforms that occur when we first touch real objects [7].
- Pressure: When a participant pushes into any of the 3D buttons, the system renders proportional pressure to the wrist, similar to how physical buttons resist the fingertip when actuating.
- Button click: When a virtual button is pushed to its actuation point, the haptic device renders a quick impulse akin to the click of a button.
- Vibration: When moving the virtual slider, the user feels a vibration from the haptic device.

4 CONCLUSION AND FUTURE WORK

This demo gives attendees the chance to experience a body-anchored interface supported with versatile tactile sensations produced by a cutting-edge wrist-wearable device. Through the device's wide-band actuation, attendees can experience first-hand how expressive wrist-based haptic feedback can enhance the user interaction across a variety of virtual interactions. Combining body-worn haptics with body-anchored interfaces opens up a rich design space with countless visual/haptic mappings, paving the way for further studies.

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