Turning Heads: Combining Kinesthetic and Vibrotactile Head-Mounted Feedback for Improved Navigation in XR

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Figure 1: Left: Our head-mounted prototype attached to the Apple Vision Pro. Right: Screenshot of our orientation task with a visual indicator showing which target should be selected.

Abstract

A proper understanding of orientation is essential in head-mounted mixed reality applications. However, conveying information about orientation and guiding the user to the correct location can be a challenging task. Visual cues, such as arrows, clutter the user's view and can overload the user's visual sense. Auditory cues have to compete with environmental noises and can be inappropriate. We present a prototype for a haptic interface mounted on top of a head-mounted mixed reality device, combining kinesthetic and vibrotactile feedback to provide precise orientation and guidance.

CCS Concepts

• **Human-centered computing → Haptic devices**; *Mixed / augmented reality*; *Virtual reality*.

Keywords

Extended Reality, HMD, Haptic Feedback, Multimodal

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1 Introduction

Head-mounted extended reality (XR) devices such as the Apple Vision Pro or the Meta Quest offer immersive experiences on consumer-level devices. They can provide a 360-degree virtual world around the user. Some devices enable users to explore this virtual world while remaining stationary (e.g., by using teleportation with a controller), whereas others require users to move around in the real world and translate their physical movements into the virtual world. In both cases, it is essential for the user to have an adequate understanding of their orientation in the virtual space. To guide the user, existing solutions rely on either spatial audio or, more commonly, visual cues, such as arrows in the user's peripheral view. However, visual and auditory senses are already very saturated from the HMD itself. Adding additional visual clutter can overstimulate the user and actually reduce performance, leading to more mistakes [2]. On the other hand, auditory cues have to compete with environmental noises and may be inappropriate in certain situations.

However, haptic cues are processed independently from visual and auditory ones [10], which makes them a viable alternative for orientation and guidance. Few consumer devices utilize haptics, though. For instance, PlayStation VR offers handheld controllers with haptic feedback, and there are some niche products, such as haptic gloves or vests that are predominantly designed for gaming and immersion. While these devices allow the user to *feel* the virtual world, their location on the human body makes them less suited for orientation. The head, as the natural anchor point for HMDs, is a well-suited location because the mapping of haptic feedback is more intuitive [8].

We present a prototype for a haptic interface that is mounted on top of the HMD that combines kinesthetic and vibrotactile feedback. Our corresponding XR app offers users the opportunity to compare visual, auditory, and haptic cues in the context of orientation and guidance in XR.

2 Related Work

Orientation and guidance are essential when moving around a virtual world with a head-mounted display. Many systems use visual cues to guide the user, which offers a high bandwidth to process information [12]. However, when the visual sense is already saturated from the HMD, visual cues for orientation and guidance have to compete with other visual information [10]. More visual clutter can reduce performance [5], which has also been shown in AR [2].

Using other senses to convey orientation cues can make them easier to process [10]. Audio offers less bandwidth than visual [12] and has to compete with environmental noise. Furthermore, the localisation of audio sources is less precise, with only angles of 20% achieving more than 80% accuracy [4]. For smaller angles (5%), accuracy drops to ~30%.

Haptics offer the lowest resolution [12]. However, they enable feedback in situations where other types of feedback are not possible or more difficult to implement. For instance, Spelmezan et al. [11] implemented vibration-based feedback across the entire body to successfully convey instructions during physical activities. Similarly, a haptic surgical tool handle was successfully used as an augmented reality guidance system during surgery [13].

Further research focuses on haptic feedback applied to the user's head. Kerdegari et al. [8] developed a tactile language specific to navigation commands targeting the user's head. They evaluated multiple dimensions, such as continuous vs. discrete and recurring vs. one-time commands. Users preferred continuous recurring commands, which also led to less route deviation and higher walking speeds. Their findings indicate that head-mounted haptic signals are a promising method for conveying navigational cues.

HapticHead [7] uses vibrotactile feedback around the user's head to guide the user towards objects. They evaluated their haptic system against visual and auditory feedback, with haptic and visual feedback considered useful by the participants. Similarly, ProximityHat [1] used pressure actuators around the user's head to convey navigation information. In a user study, participants who were blindfolded were mostly able to interpret haptic signals. Only a few struggled, possibly due to latency issues, emphasising the importance of low-latency feedback.

GyroVR [3] uses head-mounted flywheels to create a feeling of resistance when users move their head to simulate inertia. This slightly improved immersion, but its potential for navigation tasks was unexplored. Odin's Helmet [6] uses propellers to move the user's head with haptic feedback. The authors suggest that it could be used for redirected walking tasks.

3 Interactivity: The HeadTurner

Our *HeadTurner* prototype offers visitors the opportunity to experience and compare three different modalities for orientation and guidance in mixed reality:

(1) In *visual mode*, arrows indicate to the user where to look or move.
(2) In *audio mode*, we use spatial audio to guide the user.
(3) In *haptic mode*, a combination of kinesthetic and vibrotactile haptic feedback works together to guide the user. Kinesthetic feedback is used for the general direction, whereas vibrotactile feedback is used for more precise changes and to convey distance information.

These three modalities can be compared in two different scenarios:

Orientation. In the *orientation scenario*, the user is stationary in the center with 36 identical virtual balls spaced 10 degrees apart surrounding them. Their goal is to locate and select the correct ball using the sensory cues (visual, audio, or haptic) by looking at it. The time and precision for each selection are measured, resulting in a score that accumulates into a high score at the end of the *orientation scenario.*

Guidance. In the *guidance scenario*, the user moves around the real world to find an invisible virtual treasure chest hidden somewhere. The treasure chest becomes visible once they is close enough to it, sprinkling them with gold and jewellery. They receive sensory cues (visual, audio, or haptic) not only for the orientation, but also for the distance to the target.

3.1 Hardware

The key feature of the interactivity is the haptic interface, which mounts on top of the Apple Vision Pro as shown in Figure 2. It attaches directly to the strap of the Apple Vision Pro and floats above the user's head. It consists of a reaction wheel for kinesthetic feedback on top (Figure 2A) and five vibrotactile actuators (Figure 2B) that rest on a Velcro strap against the user's forehead.

The haptic interface is controlled via an Arduino Nano. The Arduino controls the five vibrotactile actuators directly. They are spaced over ~2.5cm apart so they can be perceived as a continuous sensation [9].

The Arduino also controls a brushless motor that powers the reaction wheel via a drive belt, providing the kinesthetic feedback. The motor is powered by an external battery pack equipped with an emergency off-switch, allowing for immediate power cutoff. To enable changes in direction, we do not use the motor's acceleration for kinesthetic feedback but its deceleration. The motor accelerates slowly in the opposite direction without the user noticing, and uses

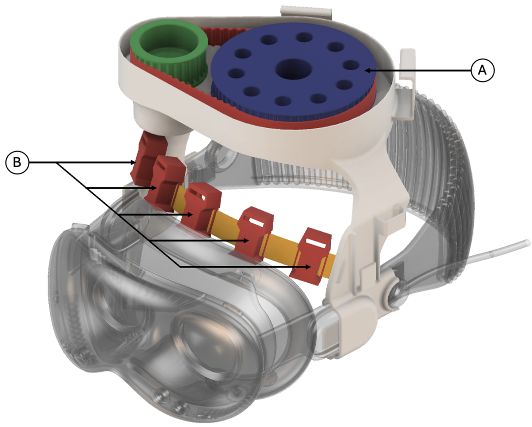

Figure 2: The 3D model of our prototype and the Apple Vision Pro. A: The reaction wheel provides the kinesthetic feedback. B: The five actuators are placed across the user's forehead and provide the vibrotactile feedback.

its brakes for a more rapid deceleration, resulting in the kinesthetic feedback.

3.2 Software

While the Arduino controls the motor and actuators of the haptic interface, the logic is controlled via the Apple Vision Pro app. It tracks the user's location and orientation in 3D space. Based on the chosen modality, it either displays the visual indicators in mixed reality, plays the spatial audio, or communicates the required haptic feedback to the haptic interface.

The app connects to the haptic interface via Bluetooth LE. For a more robust communication, it sends target speeds to the Arduino and lets the Arduino handle the changes in speed. The app also computes the strength and pattern data for the five vibrotactile actuators and sends it to the Arduino. We use linear interpolation for the vibrotactile actuators to create the impression of a continuous stimulus across the user's forehead instead of five distinct vibrations [7]. The vibrotactile feedback is continuous and recurring, following the findings of Kerdegari et al. [8] as the best way to convey haptic feedback for navigational cues.

3.3 Interaction

The goal of our Interactivity is to enable visitors to experience our head-mounted haptic interface, which combines kinesthetic and vibrotactile feedback, for orientation and guidance in the context of XR, and to compare it to common existing solutions, such as visual and auditory cues. Users wear an Apple Vision Pro with our haptic interface attached to it. Our app guides the user through the entire interaction, where they experience both scenarios - orientation and guidance - in all three modalities.

In the *orientation scenario*, visitors can compete for a place on the leaderboard by being both precise and fast with their selection. There is an overall score, as well as individual scores for each modality, to showcase the strengths and weaknesses of each modality.

In the *guidance scenario*, we want to make the experience more engaging for spectators: they can manipulate the location of the treasure chest on a tablet to showcase the adaptability of our prototype even to external changes. To commemorate their successful treasure hunt, we plan to give every visitor a 3D-printed gold coin, containing a QR code to our project.

4 Conclusion

We presented *HeadTurner*, a haptic interface that combines kinesthetic and vibrotactile feedback to give users haptic cues for orientation and guidance in XR. Visitors can experience our haptic interface and compare it to visual and auditory cues in two playful scenarios. In the *orientation scenario*, they remain stationary and have to locate the correct ball following the cues provided to compete for a place on our leaderboard. In the *guidance scenario*, visitors move around the real world to find hidden treasure chests using the cues provided. Our aim is to provide visitors with an entertaining way to experience and compare different guidance methods in XR.

Acknowledgments

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