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Pulling Illusion Induced by Asymmetric Vibration with Visual Motion Cues

Keigo Hattori*
Ritsumeikan University

Satoshi Hashiguchi
Ritsumeikan Global Innovation Research Organization

Takeshi Tanabe
National Institute of Advanced Industrial Science and Technology (AIST)

Tomohiro Amemiya
The University of Tokyo

Fumihisa Shibata
Ritsumeikan University

Asako Kimura
Ritsumeikan University

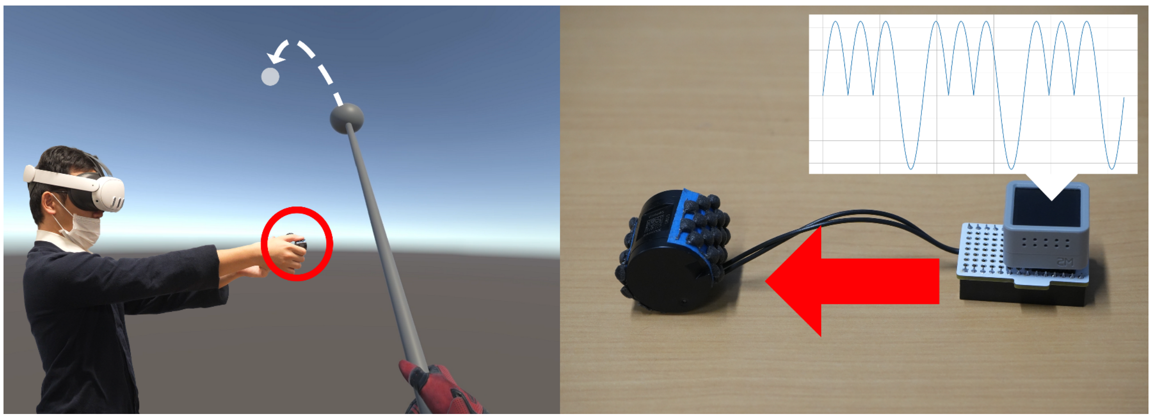

Figure 1: Overview of the VR demo that allows users to experience the pulling illusion induced by asymmetric vibration combined with visual motion cues.

ABSTRACT

In this demo paper, we present a VR system that combines vibrotactile feedback with visual motion cues to demonstrate the illusory pulling sensation induced by asymmetric vibration. The demo allows users to experience illusory pulling sensation without applying physical external forces, using a lightweight and ungrounded setup. The system features a simplified visual scene in which object motion provides an interpretable causal context for vibrotactile stimulation. By synchronizing asymmetric or symmetric vibration with object movement, users can directly experience how visual context relates to the perception of pulling sensations. Our demo illustrates design possibilities for illusory pulling sensations supported by visually interpretable motion cues. Conversely, when these cues conflict with users' expectations, visual causality can weaken the perceived illusion.

Index Terms: Haptics, asymmetric vibration, illusory pulling cues

1 INTRODUCTION

The pulling illusion is a perceptual phenomenon in which users experience pulling sensation without the application of an actual external force. This illusion is typically induced by asymmetric vibrotactile stimulation, where temporal asymmetry in acceleration profiles emphasizes a specific force direction [1, 2]. Because this effect can be generated using only compact vibration actuators and does not require grounding or large mechanical structures, the illusory pulling sensation has attracted attention as a practical force feedback technique for handheld controllers and wearable devices.

*e-mail: hattori@rm2c.ise.ritsumei.ac.jp

Based on these characteristics, asymmetric-vibration-based pulling illusions have been explored in various applications for lightweight haptic interfaces. Prior studies have demonstrated their effectiveness in intuitive guidance tasks, such as walking navigation or directional instruction, by conveying motion cues through perceived pulling sensation [1, 5]. Beyond guidance, the illusion has also been applied to experiential content. For example, previous work has shown that asymmetric vibration can express qualities such as the pulling force of a fish, its perceived size, and even a sense of liveliness in a fishing experience [6]. However, in many of these studies, the pulling illusion is primarily treated as a standalone expressive modality, and its interaction with other sensory cues—particularly visual stimuli—has not been systematically examined.

It is well known that force perception is not determined solely by tactile input, but is shaped through multisensory integration involving visual information. Manipulations of visual deformation or motion can evoke sensations of resistance, inertia, or weight without physically applying force [7, 3]. These findings suggest that visual context plays a critical role in how force-related sensations are interpreted. In this context, a small number of studies have begun to combine visual feedback with the pulling illusion. For instance, Kawagishi et al. demonstrated that combining asymmetric vibration with pseudo-haptics based on control–display ratio manipulation can enhance perceived propulsion and resistance [4]. While this work highlights the importance of visual feedback, it focuses on active user input and altered response mappings, leaving open the question of how visually interpretable object motion itself shapes the illusory pulling sensation.

In this work, we present a VR demo that explores the interaction between asymmetric-vibration-induced pulling illusions and visual motion cues that explicitly convey object movement and causality. Rather than relying on active manipulation, the demo emphasizes passive visual motion derived from object behavior, allowing users to directly experience how visual context affects the interpretation

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of an illusory pulling sensation.

Through an interactive demonstration, users can experience how the perceived magnitude and direction of illusory pulling sensation change when asymmetric vibration is paired with visually interpretable motion cues. By making the source and direction of illusory pulling sensation intuitively understandable through visual representation, the demo illustrates how visual causality can support or interfere with the pulling illusion. This work provides insights into the potential design space of multisensory pulling sensations and suggests how visual context may shape the illusory pulling sensation in lightweight and ungrounded VR systems.

2 Implementation

The VR demo system was implemented using Unity and SteamVR. A head-mounted display (Meta Quest 3) was used for visual presentation. Vibrotactile feedback was provided through a compact vibration actuator (hapStak), which was controlled by an external microcontroller (M5Stack AtomMatrix) and synchronized with events in the virtual environment. Participants interacted with the system using a physical button held in their left hand, which triggered both visual events and vibrotactile stimulation.

The original concept of the system was based on a fishing-cast scenario, in which a sinker is thrown forward and the fishing line is pulled out, providing a visually clear causal relationship between object motion and illusory pulling sensation. This scenario was selected because it naturally conveys both the source and direction of illusory pulling sensation through visual motion. However, to focus on the essential interaction between visual motion cues and vibrotactile feedback, the demo scene was simplified.

In the simplified implementation, the fishing rod and sinker were replaced with abstract geometric objects: a cylinder and a sphere, respectively. When the participant pressed the button, the system presented one of two visual conditions:the sphere was given an initial forward velocity and followed a ballistic trajectory, or remained stationary. These visual events were synchronized with vibrotactile stimulation delivered to the participant's hand.

Two types of vibration patterns were implemented: asymmetric vibration, which induces a directional pulling sensation, and symmetric vibration, which does not convey directional pulling sensation. The vibration waveform parameters were designed based on prior work on asymmetric vibrotactile stimulation. By combining the visual motion conditions with the vibration types, the system enabled controlled exploration of how visual cues influence the illusory pulling sensation.

This implementation allowed users to experience illusory pulling sensations in a minimal and interpretable environment, while maintaining precise control over the relationship between visual motion and vibration. As a result, the system is well suited for demonstrating how visual context modulates both directional and non-directional vibrotactile sensations in VR.

3 Observations

Based on observations during the demo, some participants reported that visual stimuli influenced their perception of vibrotactile feedback under both asymmetric and symmetric vibration conditions. When the sphere moved forward, participants tended to report a stronger sensation of being pulled compared to conditions in which the sphere did not move, regardless of the vibration type. Some participants also commented that it felt as if their center of gravity was shifting forward. These observations suggest that visual motion cues may contribute to illusory pulling sensation even when the vibration itself does not encode directional information.In addition, some participants reported a stronger pulling sensation at the moment when the sphere detached from the tip of the cylinder.

However, additional observations during the demo suggested a qualitative difference related to the consistency between visual causality and direction of pulling sensation. Specifically, some participants reported a sense of discomfort or incongruity when a forward pulling sensation was presented while the sphere moved away from the user. In such cases, the illusory pulling sensation tended to weaken, even though the asymmetric vibration remained unchanged.

4 Conclusion

We presented a VR demo system that explores the interaction between vibrotactile feedback and visual motion cues, focusing on the illusory pulling sensation induced by asymmetric vibration. By employing a simplified and abstract visual scene, the demo allows users to directly experience how visual context influences the interpretation of vibrotactile sensations without relying on physically applied forces.

The demonstration suggests that visual motion cues do not merely enhance illusory pulling sensations but can also weaken them when the perceived visual causality becomes inconsistent with the expected physical interaction. In cases where object motion conflicted with the direction of pulling sensation, the illusory pulling sensation tended to weaken, indicating that users reinterpreted the sensation based on visual feedback. These observations highlight that illusory pulling sensations in VR are conditioned by the coherence of visual causality, rather than by vibrotactile stimulation alone. Visual information therefore plays a dual role, capable of both supporting and weakening the interpretation of vibrotactile cues depending on their consistency with users' expectations.

This work contributes a design-oriented perspective on illusory pulling sensations and provides a foundation for future exploration of visually grounded haptic interactions. In future work, we plan to extend the demo to additional scenarios involving propulsion and resistance, and to conduct more systematic evaluations to further clarify the relationship between visual causality and illusory pulling sensations.

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