

Experiencing Weight Illusion in AR Extended Displays: A Portable Community Demo

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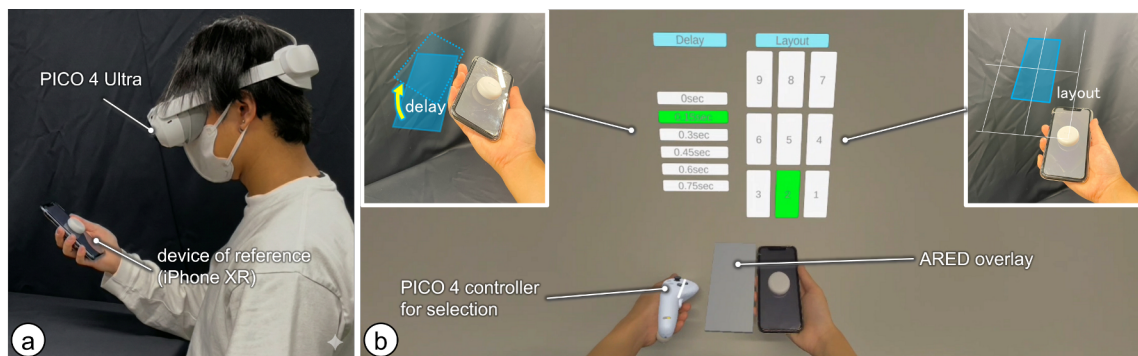


Figure 1: Overview of the demonstration system and interaction design. (a) Experimental setup showing a user wearing the PICO 4 Ultra HMD and holding the handheld device (iPhone XR) with a PICO Motion Tracker attached. (b) View observed through the HMD during the demonstration. An AR extended display (ARED) is overlaid near the handheld device, and a control panel is presented in front of the user. The left-side buttons adjust the visual delay, while the right-side buttons change the spatial layout of the ARED. The inset illustrations depict the conceptual effects of the design parameters: visual delay causes the ARED to lag behind the device motion, and layout changes modify the relative position and distance between the device and the virtual display.

ABSTRACT

Augmented reality (AR) design parameters, such as spatial layout and visual delay, are typically optimized for system performance, yet they can also influence human perception. Prior research has shown that visual manipulation alone can alter perceived weight through pseudo-haptic effects, even in the absence of physical feedback. In particular, the perceived weight of AR extended displays (AREDS) has been reported to vary depending on their spatial arrangement relative to a handheld device and the visual delay applied to them. In this demonstration, we present an interactive AR system that enables participants to directly experience how these design parameters affect perceived weight. By transforming a laboratory-level experimental setup into a demonstration-oriented system, participants can freely adjust the layout and visual delay of AREDS in real time and experience corresponding changes in weight perception. This demonstration highlights how subtle system-level design choices in AREDS can shape perceptual experiences and provides an accessible platform for exploring pseudo-weight illusions beyond controlled experimental settings.

Index Terms: Augmented reality, pseudo-haptics, weight perception

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1 INTRODUCTION

Augmented reality (AR) systems enable virtual content to be spatially aligned with physical objects and the human body, allowing users to interact with digital information as if it were part of the real world. While such systems are often discussed in terms of usability and task efficiency, AR also provides a unique opportunity to investigate how visual information alters human perception beyond explicit interaction outcomes. Human perception of physical properties, such as weight, is known to emerge from the integration of multiple sensory modalities. Prior work on pseudo-haptics has demonstrated that force or weight sensations can be induced solely through visual manipulation, even in the absence of physical feedback devices [4]. This phenomenon is commonly explained by statistically optimal integration of visual and haptic cues, where changes in the reliability or consistency of visual information alter perceived physical attributes [2].

A representative example of such perceptual effects is the size-weight illusion, in which objects with identical mass are perceived as having different weights depending on their visual appearance. This illusion has been extensively studied in immersive virtual reality, where conflicts between visual and haptic information systematically bias weight perception [1], and similar effects have more recently been reported in augmented reality, demonstrating that AR-specific visual manipulations can also change perceived weight [7]. In addition to static visual properties, temporal factors play an important role in weight perception. Visual delays between a user's physical action and the corresponding visual response have been shown to affect force scaling and perceived object weight during object lifting tasks [6]. These findings indicate that weight perception is sensitive not only to what is shown, but also to when visual information is presented relative to motor actions.

Building on these insights, prior AR studies have explored how visual augmentation can alter perceived weight without modifying

the physical properties of real objects [3]. In our prior work presented at IEEE VR 2022 [5], we systematically investigated the perceived weight of AR extended displays (AREDS) by manipulating two system parameters: the spatial layout of virtual displays relative to a handheld device and the visual delay applied to the displays. The results showed that increasing the distance between the device and the virtual display induced a lighter impression, whereas introducing visual delay led to a heavier perceived weight.

This work presents a research demonstration that extends our previous study toward a community-oriented experience. Rather than focusing on controlled laboratory evaluation, our goal is to transform an experimental AR system into an interactive demonstration. The demonstration allows a broader community to directly experience how layout and visual delay affect perceived weight.

2 SYSTEM OVERVIEW

The demonstration system consists of a head-mounted display, a tracking device, and a handheld device (Figure 1a). We use a PICO 4 Ultra as the HMD, a PICO Motion Tracker attached to the handheld device, and an Apple iPhone XR as the physical device. Virtual display areas are rendered around the handheld device and updated according to the tracked motion. The application is implemented using the Unity game engine (2022.3.446f1), which integrates tracking input, AR rendering, and virtual control panel within a unified software framework.

Upgrades Compared to the system used in prior ARED pseudo-weight research [5], the hardware performance has been substantially improved. The camera system latency has been reduced from approximately 0.3 s to 0.05 s, and the binocular resolution has increased from 2880×1600 pixels to 4320×2160 pixels. In addition, the tracking device has become significantly lighter, decreasing from 89 g to 15 g. These improvements allow the illusion to be demonstrated with a more practical and accessible AR setup.

3 DEMONSTRATION APPLICATION DESIGN

Two Explorable Parameters The application allows participants to interactively control two system parameters: the spatial layout of the ARED and the visual delay of the display. The spatial layout parameter controls the relative position of the AR extended display with respect to the handheld device. Layouts ($L1$ – $L9$) are defined and arranged on a 3×3 grid around the device, as shown in Figure 1b. The visual delay parameter introduces an additional temporal delay (denoted as *delay* in Figure 1b) between the physical motion of the handheld device and the rendered motion of the ARED. We provide six delay levels: 0, 0.15, 0.30, 0.45, 0.60, and 0.75 s. Combined with nine spatial layouts ($L1$ – $L9$), the system offers 54 combinations.

User Interface A control panel is displayed in front of the participants (Figure 1b). Buttons on the left control the visual delay, while buttons on the right change the display layout. With a single button press, participants can instantly switch to the corresponding condition, enabling them to explore how different design parameters affect perceived weight. The design of the application emphasizes immediacy and ease of exploration. Each button press updates the system state instantly, enabling participants to compare configurations without interruption. This rapid switching is intended to support perceptual comparison across conditions, rather than encouraging prolonged interaction within a single setting. By presenting all layout and delay options through a unified interface, the demonstration encourages participants to actively explore how subtle changes in system parameters influence their perception. This design choice shifts the focus from task performance to perceptual experience, which is central to understanding pseudo-weight effects in AREDS.

Portability and Accessibility Beyond the hardware upgrades, the improved system configuration is particularly important for demonstrating pseudo-weight illusions in a public setting. By reducing visual delay, increasing display resolution, and minimizing the physical load added by the tracking device, the demonstration system allows participants to experience changes in perceived weight with fewer confounding factors. This configuration supports a clearer observation of how visual design parameters alone contribute to pseudo-weight perception by reducing confounds from hardware artifacts. It also facilitates the reproduction of prior findings in a more practical and community-accessible AR setup.

4 DEMONSTRATION SCENARIO

During the demonstration, participants wear the HMD, hold the handheld device in their right hand, and hold a controller in their left hand. With the controller, they select the display layout and visual delay conditions through the control panel. By moving the handheld device while changing these parameters, participants can directly experience how variations in display layout and delay alter the perceived weight of the device.

Although the physical properties of the device remain unchanged, *participants are expected to perceive the device as becoming lighter or heavier* depending on the selected layout and delay, enabling them to intuitively experience the pseudo-weight illusion with different AREDS.

5 CONCLUSION

This work presented a research demonstration that transforms a laboratory-level pseudo-weight system into a community-accessible experience. Our demonstration enables participants to directly experience how design parameters, such as display layout and visual delay, influence perceived weight in AREDS. This makes pseudo-weight perception observable beyond controlled experimental environments. By making pseudo-weight effects accessible through an interactive demonstration, future work can explore how such perceptual manipulations can be integrated into AR interface design, training systems, and experiential applications.

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