AR Simulations in VR: The Case for Environmental Awareness

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Abstract

Augmented reality (AR) simulations in virtual reality (VR) provide fully controlled conditions, fewer hardware limitations than on AR devices, and convenient and safe access to diverse settings. However, for VR to be a fully realistic simulator for optical see-through (OST) AR, it must replicate the effects of environmental context on virtual content appearance and system performance. Here we examine one example of this, the perceived transparency of virtual content under varying environment illuminance, and conduct a user study (N=8) to identify the discrepancy between AR and a standard VR simulation. Our results show that for virtual content designed to be transparent, perceived transparency in AR is greatly reduced at low levels of illuminance, but remains consistently high across all illuminance levels tested in VR. This illustrates the impact of environment properties on the efficacy of AR simulations in VR, and motivates the development of context-aware simulations that more closely replicate AR experiences.

Index Terms: Human-centered computing—Mixed / augmented reality—Virtual reality;

1 Introduction

Augmented reality (AR) simulations in virtual reality (VR) have been proposed and evaluated in multiple influential works (e.g., [3–5]), which identify several advantages in both research and app development over AR implementations. Firstly, the properties of fully virtual environments are readily controlled, facilitating the isolation of independent variables in systematic and repeatable experiments. Secondly, VR allows researchers to bypass the current hardware limitations of AR devices, such as the user's field of view (e.g., [6]), to study a wider range of conditions. Finally, VR can provide convenient and safe access to types of environments for which physical access may be impractical, or dangerous for study participants. However, despite modern game engines (e.g., Unity, Unreal) facilitating the development of highly realistic virtual environments, building an AR simulation in VR remains challenging due to differences in AR and VR hardware, interaction methods, and levels of environmental dependency [4].

In particular, the environmental context of an experience has several effects specific to optical see-through (OST) AR, as illustrated in Figure 1. Previous works have demonstrated the impact of ambient light (e.g., [1]), as well as background textures and colors (e.g., [2]) on the appearance of virtual content on AR headsets with OST displays (e.g., the Microsoft HoloLens, Magic Leap), an effect which is not present in VR. Unlike in VR, virtual content stability in AR, determined by pose tracking performance, is highly dependent on the visibility of textures in the surrounding real environment, while environment lighting is also known to affect the performance of video oculography-based eye tracking employed on modern AR headsets. Semantic understanding algorithms may rely on various input modalities, e.g., RGB images, audio, and thermal images; the quality of these input data, and the resulting algorithm performance are also determined by environment properties.

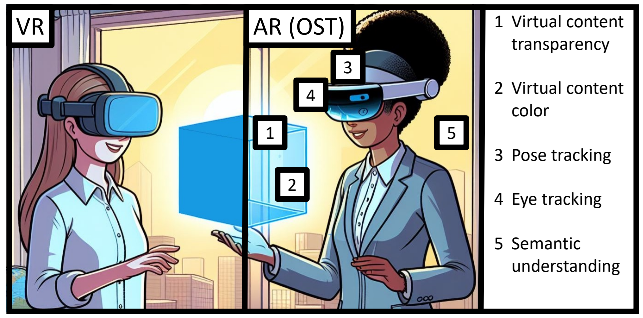

Figure 1: Environment properties such as ambient light and visual texture have minimal effect on VR displays and system performance, but in OST AR they impact virtual content appearance as well as core system functionality.

Due to greater accessibility and portability, OST AR headsets are increasingly being deployed in diverse settings. We must establish the capability of AR simulations in VR to accurately replicate AR across a wide range of environmental conditions. While some works have examined how properties of a VR experience (e.g., visual realism [4]) affect its validity as a simulation tool for AR, to the best of our knowledge none have systematically varied environment properties, a major source of potential discrepancies. In this paper, we address this with *the first study to examine the consistency of AR and VR experiences under varying environmental conditions*. Specifically, we measure the perceived transparency of virtual content in a Sudoku app at different illuminance levels, both on an AR headset and in a simulation in VR. Our results highlight how a standard VR implementation does not replicate the impact of ambient light on virtual content appearance with an AR OST display, and motivates greater context-awareness for AR simulations in VR.

2 Effect of Environment Illuminance on Virtual Content Transparency in AR vs VR

To identify the gap between AR and baseline simulations in VR for perceived virtual content transparency, we conducted an IRB-approved user study with our custom-developed Sudoku helper app, which overlays transparent blue and green virtual hints onto a Sudoku puzzle board. These hints utilized the Sudoku rules to suggest valid positions for digits. Hint transparency is necessary for users to interpret underlying digits and fill in digits accordingly. The app was implemented in both AR (Figure 2a) and VR (Figure 2b), with the option to change environment illuminance added in VR.

2.1 AR and VR App Implementation

Both the AR and VR apps were developed using Unity 2022.3.6f1. The VR app was built to closely match the AR experience by using similar game objects and materials to those present in the real study environment. The same materials were used for virtual hints in AR and VR. The VR app handled the reflection of light on the virtual puzzle board and whiteboards, but not on the hints, to provide a baseline implementation of virtual object transparency in VR.

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2.2 User Study Design

Apparatus: For the AR device, we used a Magic Leap 2, with the display at full brightness and global dimming at the lowest level. For the VR device, we used an Oculus Quest 3, with contrast at the lowest level. Illuminance in AR was measured using a URCERI MT-912 light meter. All surveys were administered using Qualtrics.

Participants and environment: We recruited 8 participants (aged 20–29, 6 males, 2 females, 5 wearing glasses) from our university. The study was performed after sunset at two fixed time periods in a lab environment to ensure a fully controlled illuminance among experiments. Two whiteboards were placed in front of the user in both the real AR environment and the VR space. A Sudoku puzzle was attached to one whiteboard and its height adjusted to align with the participant's eyes. Environment illuminance was controlled with a wall dimmer switch and measured with a light meter placed on the Sudoku board for the real AR environment; the average illuminance values for the five levels tested were 20 lux (very dark, little ambient light), 90 lux, 158 lux, 237 lux, and 305 lux (bright, maximum ambient light). Illuminance in the VR environment was adjusted using UI buttons, with main Unity scene light intensities of 0.2, 0.4, 0.6, 0.8, and 1.0. Matching AR and VR illuminance is difficult due to the lack of comparable measuring techniques, so we empirically set these values to approximate a similar experience for the users.

Procedure: After signing a consent form, participants completed a pre-experiment survey in which they were asked about their previous AR and VR experience. During the study, each participant completed a total of 10 trials; 5 different illuminance levels in both AR and VR. The order of the AR and VR trials and different illuminance levels were randomized. After each trial, participants used a 5-point Likert scale to rate the transparency of virtual hints, and how significantly virtual hints interfered with the view of digits. After all 10 trials, participants completed a post-experiment survey on their overall experience with both apps.

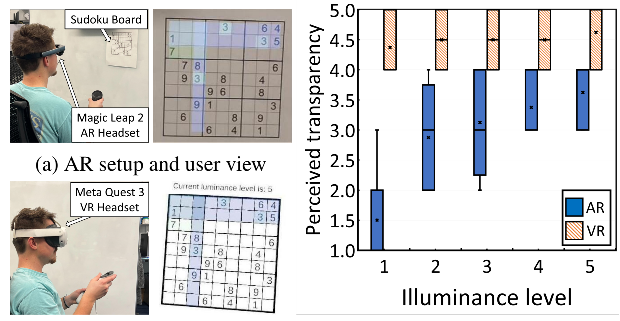
2.3 User Study Results

Hint transparency: The difference in the perceived transparency of transparent virtual hints at different illuminance levels in AR and VR is shown in Figure 2c, with numerical values assigned to each Likert scale response: 1=*fully opaque*, 2=*fairly opaque*, 3=*partially opaque, partially transparent*, 4=*fairly transparent*, 5=*fully transparent*. In AR, the mean perceived transparency was 3.6 at the highest illuminance level, but 1.5 at the lowest illuminance level, and in the post-study survey, all participants "agreed" or "strongly agreed" that perceived transparency increased as illuminance levels increased in AR. In contrast, there was little change in perceived transparency in VR across different illuminance levels, with virtual hints consistently rated as "fairly" or "fully transparent" by all participants. Notably, AR was generally perceived to be less transparent than VR at all illuminance levels. The baseline implementation of materials in VR did not replicate the transparency perceived by users in AR under varying illuminance.

Digit visibility: The extent to which the virtual hints interfered with the view of digits on the puzzle board under different illuminance levels followed a similar trend as perceived hint transparency. At the lowest illuminance level in AR, all participants reported that the hints interfered "Quite a lot, makes it very difficult to see" or "A lot, can't see digit". In VR however, only 2 participants found the hints to "slightly" interfere with their view of the digits at the lowest illuminance level and reported no interference at all in the remaining trials. These results further demonstrate discrepancies in perception in VR and AR under different environmental conditions.

3 Discussion and Future Work

The results of our study highlight the discrepancy in perceived transparency of virtual content in AR and VR under varying environment illuminance. The perceived transparency of virtual content



(a) AR setup and user view

(b) VR setup and user view

(c) Transparency perception results

Figure 2: User study setup and participant view in (a) AR and (b) VR, and (c) perceived transparency of virtual blue and green hints at five environment illuminance levels (1=lowest, 5=highest).

in AR ranged from fully opaque at the lowest illuminance level to "fairly transparent" at the highest illuminance level, while in VR, transparent virtual content was consistently perceived as "fairly" or "fully transparent" across all illuminance levels studied. This demonstrates that the baseline implementation of VR virtual object material transparency is not consistent with the illuminance-dependent transparency in OST AR, and motivates the use of virtual materials with adaptive transparency (i.e., those for which alpha values change according to current illuminance) when simulating AR in VR.

In our future work, we will develop these illuminance-adaptive materials and evaluate them in AR simulations in VR. Similarly, we will explore how color shifts in OST AR can be replicated in VR, and how realistic environment-informed virtual content stability artifacts such as jitter and drift can be simulated. These efforts will enable the development of more accurate AR simulations in VR, enhance the community's ability to more accurately study AR experiences in non-ideal environmental conditions, and support the development of AR applications more robust to those conditions.

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