Creating a Stereoscopic Magic-lens to Improve Depth Perception in Handheld Augmented Reality

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Abstract

Handheld Augmented Reality (AR) is often presented using the magic-lens paradigm where the handheld device is portrayed as if it was transparent. Such a virtual transparency is usually implemented using video captured by a single camera rendered on the device's screen. This removes *binocular-disparity,* which may undermine user's ability to correctly estimate depth when seeing the world through the magic-lens. To confirm such an assumption this paper presents a qualitative user study that compares a magic-lens implemented on a mobile phone and a transparent glass replica. Observational results and questionnaire analysis indicate that binocular-disparity may play a significant role in participants' depth perception. These promising results led to the subsequent implementation of a stereoscopic magic-lens prototype on a commercially available mobile device.

Author Keywords

Virtual transparency; stereoscopic rendering; depth perception; binocular disparity; parallax; handheld; mobile; user study; mobile;

ACM Classification Keywords

H5.1. Information interfaces and presentation (e.g., HCI): Artificial, augmented, and virtual realities.

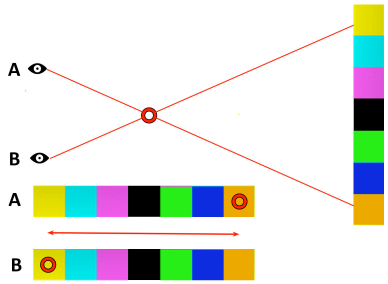


Figure 1. Binocular-disparity (parallax): Left and right eye see a different image.

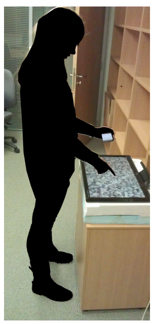


Figure 2. Experiment setup.

Figure 3. Left-transparent glass replica of a magic-lens. Right-phone magic-lens.

Introduction

Handheld Augmented Reality (AR) is normally introduced to users through the magic-lens paradigm [1] where a magic-lens is a transparent interface revealing an enhanced view of the scene lying behind the lens. However, as the majority of handheld devices are not transparent there is a requirement to artificially create such a transparency. Virtual transparency is typically implemented using the back-facing camera on the handheld device with the captured video rendered on the device's screen. Consequently, this introduces a number of perceptual problems caused by the difference between ideal transparency and this virtually transparency [3]. One such problem relates to depth perception which may be caused by the monocular scene capture and subsequent rendering that removes *binocular-disparity*[1] (see Figure 1).

However, beside binocular-disparity, there are other depth cues, such as, motion-parallax [2, 4] and object depth ordering [3]. These have been identified as more important depth cues for 3D scene interpretation [2, 4]. Nevertheless, majority of previous research is limited to experimentation with head-mounted displays, thus the extent to which users' will be affected by the lack of binocular-disparity when interacting within handled AR is yet to be uncovered.

This paper examines the impact of monocular scene capture and rendering on users' depth perception within the context of handheld AR. The research presents a qualitative user study in which participants are asked to complete a selection task using two different magic-lenses, namely: magic-lens implemented on a mobile phone using single camera where binocular-disparity is removed (see Figure 3 right); and a transparent glass replica of a magic-lens where binocular-disparity is present (see Figure 3 left). Results indicate that the lack of binocular-disparity may play a significant role in participants' depth perception, especially when hand interaction within the AR scene is required.

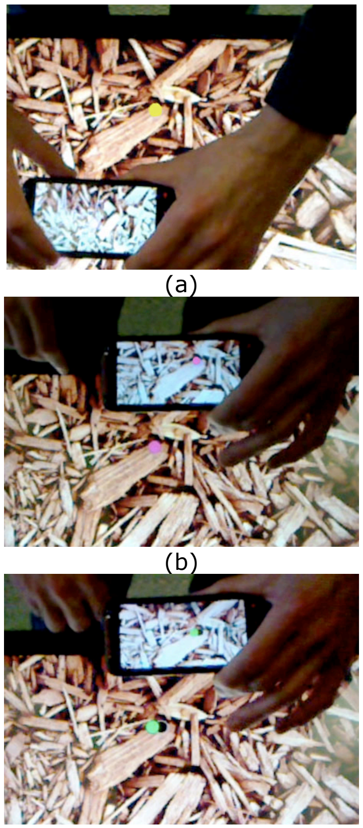
Recent advances in capabilities of commercial mobile devices have seen the emergence of 3D display technology and stereoscopic image capturing capabilities. Such a configuration enables us to consider stereoscopic magic-lens rendering on a commercially available handheld device. However, 3D display technology on handheld devices is mainly restricted to the parallax-barrier approach which limits observer's point-of-view (POV) to small angle and distance variations (see Figure 5). Despite this current limitation, the results from the user study encouraged us to create a prototype. The prototype demonstrates how stereoscopic magic-lens rendering might improve handheld AR.

Methodology

In order to test depth perception, the study focuses on testing user's ability to precisely touch a target laying on the interactive surface while looking through the magic-lens. Even though there are not many handheld AR use-cases where such scenarios are encountered, we consider such task is viable to detect any problems users might encounter when interpreting depth of their hand approaching the target.

Throughout the experiment, participants were asked to complete the task as quickly as possible while achieving

1 Difference in image location of the object by the left and right eye parallax.



(a)

(b)

(c)

Figure 4: (a) Shows target as yellow dot at the initial stage of the task. (b) Once target appears within the magic-lens view it is activated, thus changes color to pink. (c) After target is touched, task completion feedback is shown to participant, where green dot represents touch-event and black dot shows desired destination.

minimal accuracy of 0.4 centimeters. This requirement was made to define what level of performance is expected and make the task appropriately challenging. The minimal accuracy level was defined through preliminary test runs prior to the study.

Study Design

The study is a repeated measure design where all participants are required to perform task selection using both magic-lenses. Participants always started with magic-lens implemented on a mobile phone and performed 10 task repetitions before completing 10 task repetitions with a glass replica. At the end of the test, participants were asked to choose preferred magic-lens and provide rationale for their decision.

The experiment setup (see Figure 2) consists of a 23 inch touch-screen display laying in horizontal orientation. The display is used to render textures, targets and enable the recording of touch events. The two magic-lenses used where an off the shelf mobile device (HTC Sensation) and a transparent glass replica of the same size (see Figure 3).

Each task attempt asks the participant to touch the target while looking through the magic-lens. The task is started by user taping the phone screen which generates the target on the interactive surface (yellow dot on Figure 4a). Target only becomes touchable once it appears within the magic-lens view. Target activation is indicated by target color change from yellow to pink (see Figure 4a and 4b). This was added to the task in order to make sure participants look through the magic-lens as they approaches and touch the target. In case of phone magic lens, the target activation is done automatically whilst in case of the transparent glass replica it is remotely activated by the experiment administrator. After touching each target, task completion results are displayed (see Figure 4c).

Results and Discussion

The study was conducted on 18 participants aged between 23 and 36, were 12 were male and 6 were female. All participants chose the transparent glass magic-lens as their preferred device. Reasons for their choice were classified into 4 categories, namely, (1) improved depth perception; (2) poor phone rendering performance; (3) non-realistic hand rendering; and (4) non-realistic scale.

From the 18 participants: 10 participants ~56%([95% CI [44%, 67%]) found it difficult to estimate when their finger will touch the surface when interacting with phone magic-lens; Six participants ~33% (95% CI[22%, 44%]) found the phone performance problematic and highlighted lack of clarity and responsiveness when compared to the transparent glass replica; Four participants ~ 22% (95% CI [12%, 32%]) did not like the non-realistic hand rendering caused by color mismatch (observe hand color difference of the hand in the scene and phone screen on Figure 6); Finally, only 2 participants ~6% (95% CI [0.1%, 11%]) identified non-realistic scale of the phone magic-lens render as problematic.

Both magic-lenses support motion parallax and render content in correct depth order. However, contrary to phone magic-lens, the glass magic-lens maintains coherent scale with the surrounding context (observe the actual and rendered hand size on Figure 6). Consequently, in case of phone magic-lens, depth perception might be affected by unrealistic scale. As

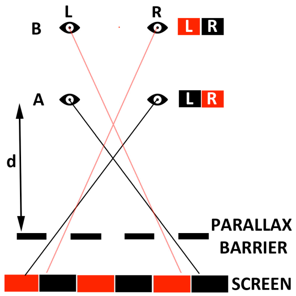


Figure 5. Parallax barriers are used to enable stereoscopic rendering without the need for glasses. However, this limits magic lens operational distance and angle (d).

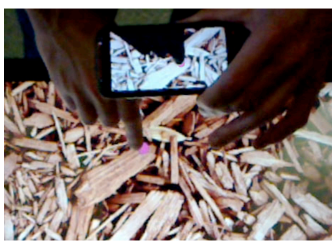


Figure 6. Shows how user's hand is rendered in dark color and is smaller than one would expect.

Figure 7. Stereoscopic rendering prototype running on HTC EVO 3D.

results show that only two participants identified unrealistic scale rendering as a problem, the lack of stereoscopic vision is recognized as the primary reason why participants had problems with depth perception. However, due to substantial form factor and quality differences between the two magic-lenses on the study, it is not possible to draw final conclusions. Nevertheless, promising results motivate us to implement a stereoscopic magic-lens prototype.

Prototype Implementation

Stereoscopic AR rendering solution is implemented on a handheld device with parallax barrier 3D display technology (HTC 3D EVO). The demo augments a target onto the predefined printed texture as shown in Figure 7. Due to the limitation of the device platform, which meant that only images from one camera could be captured at any one time, a decision was made to replicate the AR scene by introducing a predefined texture onto the scene base plane. This limits the current implementation to planar static predefined environments and only allows stereoscopic rendering of predefined region. Nevertheless, it is sufficient to demonstrate potential of stereoscopic rendering within the context of handheld AR.

Conclusion Future Work

The user study indicates that when binocular-disparity is not present, depth perception may become a problem especially in tasks that require hand interaction within the augmented space. This was highlighted in cases where participants accidently touch the interactive surface whilst still trying to achieve accurate placement of their finger. Such observations were also supported by participant's comments when asked to justify their choices of preferred magic-lens.

Irrespective of the recent introduction of stereoscopic capabilities to mobile devices, the prototype demonstrates that the usability of such technology is limited in context of handheld AR as it restricts observer's point-of-view to small angle and distance variations. Restrictions force the user to hold the magic-lens at a constant distance to their POV. Whilst this constraint is not a significant problem in outdoor setting, not being able to zoom-in closer without moving your body when interacting in table-top sized environments is expected to effect usability of such a system. Nonetheless, the developed prototype is still likely to improve depth perception and should be further tested in future user-studies in order to confirm that introducing stereoscopic rendering to handheld devices can significant improve user's spatial perception when interacting with handheld AR.

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