Resolving Cue Conflicts in Augmented Reality

Conference Paper · March 2020

DOI: 10.1109/VRW50115.2020.00125

1 author:

Haley Adams
Google

Resolving Cue Conflicts in Augmented Reality

Haley Adams*
Dept. of Computer Science
Vanderbilt University

1 Motivation

Virtual objects in augmented reality (AR) often appear ”floaty”–a visual indication that augmented objects are poorly integrated into real world environments through shading. As a result, it is difficult to determine where objects are positioned in space. However, accurate depth perception is crucial for many applications in AR. I begin investigating this issue by evaluating different shading techniques for shadows, because shadows represent an important depth cue for creating a point of contact with surfaces beneath objects in three-dimensional space. As my research progresses, I hope to extend my investigation to other relative depth cues that may further resolve cue conflicts present in AR displays. My goal is to develop graphics based solutions to mitigate cue conflicts that result in perceptual uncertainty, especially in optical see-through (OST) AR displays. Resolving perceptual limitations will allow us to provide guidelines for software and hardware development of both future and current AR devices.

1.1 Distance Perception in AR is Inconsistent

The variability in prior augmented reality distance perception research provides evidence to the inadequacy of depth cues provided by current AR displays. Curiously, when estimating egocentric distances (distances from the observer to a target), some prior studies have found that people underestimate distances in augmented reality [12]–a pattern similar to the one consistently elicited by virtual reality devices [1]. However, other AR studies have found patterns of accurate estimation or even overestimation [7, 11]. This volatility in depth perception is unacceptable for many applications that rely on accurate spatial information. It is, therefore, critical that we identify factors that contribute to inaccurate depth perception and that we develop solutions to improve depth perception in OST AR.

1.2 The Importance of Consistent Depth Cues

Although real world depth cues are consistent and reliable, in augmented reality only a subset of these cues are available. Furthermore, the available depth information presented by augmented objects often conflicts with the depth information provided by the real world environment (e.g., inconsistent shading), resulting in cue conflicts and perceptual uncertainty [3]. This ambiguous depth perception may be alleviated through the development of perceptually valid rendering techniques.

It has been demonstrated that perceptual uncertainty decreases as the number of consistent depth cues increases to the limits of the perceptual system [6]. Therefore, increasing the number of depth cues rendered in AR that are consistent with the real world environment–and therefore more perceptually valid–may improve depth perception in AR devices.

1.3 Providing Better Depth Cues

Researchers have begun investigating how graphically provided depth cues must be rendered to enhance depth perception in these devices. Although the results of nascent research evaluating depth cues like shading and texture have been ambiguous [2], it has been demonstrated that shadows successfully improve the accuracy of distance perception [4, 2]. This same literature suggests that the manner in which shadows are rendered makes a difference. For example, lighting misalignment may adversely affect distance perception [4]–unless the misalignment is due to the use of drop shadows [2]. It has also been suggested that the salience of a shadow may affect depth perception such that more transparent shadows are less effective as depth cues [2].

In order to reduce perceptual uncertainty in OST devices, it is necessary to develop and evaluate perceptually motivated graphical solutions. Shadows present a promising starting point for resolving cue conflicts in AR; however, a cast shadow is only one depth cue of many. To illustrate, the difference in luminance (relative brightness) between rendered and real objects or the difference in digital resolution and a person’s visual acuity may adversely affect depth perception in AR.

1.4 Perceptually Valid Surface Contact

For my initial project in this line of research, I focus on creating a sense of contact between virtual objects and surfaces using shadows. In traditional computer graphics, evidence shows that shadows function as ”visual glue” to attach virtual objects to surfaces [13, 8]. Furthermore, people become more accurate when estimating egocentric distances when objects are clearly connected to the ground via shadow [10]. However, it is unclear how we can best create ”visual glue” for additive light displays. These displays cannot remove light–and thereby darken–virtual or real objects. As a result, depth from shading cues are less reliable and the visual position of rendered objects in space becomes ambiguous.

Fortunately, it may be possible to leverage the human visual system to create perceptually valid shadows to help determine the three-dimensional layout of a scene in these devices. For example, one may use simultaneous contrast to change the visual appearance of two adjacent colors and give the illusion of a shadow by rendering light near the outer edge of the shape of a shadow [9]. This technique is illustrated in Figure 1.

2 Project Framework

To improve the accuracy of spatial perception in augmented reality, I will conduct a series of psychophysical studies from which I can isolate rendering and design techniques that resolve cue conflicts in AR. I believe that it is possible to improve depth perception in AR by developing graphics based techniques that adapt to human perception, despite limits in optical technology.

During the first phase of my project, I intend to establish baselines for the perception of surface contact across multiple immersive display types: optical see-through (OST) AR, video see-through (VST) AR, and virtual reality (VR). At the onset of this project, I have chosen to evaluate different types of immersive displays to better understand how contemporary immersive technologies interact with depth perception in my experimental setup. However, moving forward, I will focus my research more narrowly on optical see-through devices.

I will identify virtual depth cues that introduce perceptual ambiguity between real and virtual stimuli. For example, relative

*e-mail:haley.a.adams@vanderbilt.edu

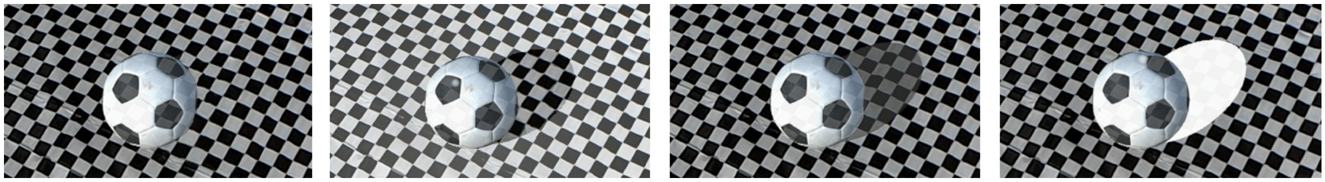

Figure 1: (1) No shadow, (2) simultaneous contrast, (3) dark gray, and (4) photometrically incorrect shading conditions

brightness–in which objects that are brighter are often perceived as closer–may be contributing to cue conflicts in additive light displays used by OST AR. Relative brightness expresses itself most prominently in vista space but it can also affect depth perception in near and action space. A consequence of using additive light to render virtual overlays is that virtual objects typically have far brighter luminance values than those present in the real world. Other factors, I have considered addressing include: shadow position, environmental variance, image resolution, and object familiarity.

In addition, since depth cues vary in their availability and potency across distance, I will evaluate depth cues across multiple distances in both the current and future studies. There is some evidence that the variability seen in AR distance estimation literature may be influenced by the distance of presented stimuli from the viewer [12, 5, 7, 11], which further supports the evaluation of novel rending techniques across personal, action, and vista spaces.

2.1 Current Progress

My initial work evaluates a particularly strong depth cue for surface contact: shadows. My protocol is modeled after the Madison et al. [8] protocol in which research participants are asked to rate the degree of contact between a target object and the ground surface using a Likert scale when presented with a stimuli that is either above or in contact with a surface. In this study, I evaluate four shadow shading techniques across multiple displays. And I evaluate how object placement affects a viewer's sense of surface contact.

Surface Contact Hypotheses In this experiment, I assess how different shadow rendering techniques affect one's perception of ground contact across OST AR, Video see-through (VST) AR, and VR displays. I predict that the presence of a shadow will enhance one's sense of ground contact and that more salient shadows–for example, those generated through simultaneous contrast illusion and photometrically incorrect shadows in OST devices–will improve a viewer's sense of ground contact the most. I evaluate four shadow shading conditions in total: (1) simultaneous contrast illusion, (2) dark gray, (3) photometrically incorrect, and (4) no shadows. A depiction of each shading condition can be seen in Figure 1.

Surface Contact Method The experiment looks at the perception of ground contact of objects in personal space (1m) and action space (3m), where objects in personal space are either placed on the ground or on a nearby table and objects in action space are placed on the ground. The devices employed to evaluate OST AR, VST AR, and VR displays, respectively, were the Microsoft HoloLens, the Zed Mini with the HTC Vive Pro, and the HTC Vive Pro. At present, this experiment is ongoing. The development for the simulations is complete, and I will commence user testing shortly.

3 Conclusion

The reduction of cue conflicts will make immersive AR usable for complex spatial tasks like navigation and surgical operation. If successful, my research will result in tangible guidelines to reduce incorrect depth perception for developers and designers of augmented reality applications. In pursuit of this goal, I will also develop novel rendering solutions that leverage the limitations of human perception. The knowledge gleaned from my research may be used to improve software and hardware development of OST AR devices.

4 Open Questions

- Have I taken an appropriate, general approach to addressing a medium scale research project? How might I deepen it to become a dissertation?
- The hardware for AR devices is rapidly changing. How can I ensure that my research makes lasting contributions?

References

[1] S. H. Creem-Regehr, J. K. Stefanucci, W. B. Thompson, N. Nash, and M. McCardell. Egocentric distance perception in the oculus rift (dk2). In *Proceedings of the ACM SIGGRAPH Symposium on Applied Perception*, SAP '15, pages 47–50, New York, NY, USA, 2015. ACM.

[2] C. Diaz, M. Walker, D. A. Szafir, and D. Szafir. Designing for depth perceptions in augmented reality. In *2017 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*, pages 111–122, Oct 2017.

[3] D. Drascic and P. Milgram. Perceptual issues in augmented reality. In M. T. Bolas, S. S. Fisher, M. T. Bolas, S. S. Fisher, and J. O. Merritt, editors, *Stereoscopic Displays and Virtual Reality Systems III*, volume 2653, pages 123 – 134. International Society for Optics and Photonics, SPIE, 1996.

[4] Y. Gao, E. Peillard, J.-M. Normand, G. Moreau, Y. Liu, and Y. Wang. Influence of virtual objects' shadows and lighting coherence on distance perception in optical see-through augmented reality. *Journal of the Society for Information Display*, 2019.

[5] T. Y. Grechkin, T. D. Nguyen, J. M. Plumert, J. F. Cremer, and J. K. Kearney. How does presentation method and measurement protocol affect distance estimation in real and virtual environments? *ACM Trans. Appl. Percept.*, 7:26:1–26:18, July 2010.

[6] R. A. Jacobs. What determines visual cue reliability? *Trends in Cognitive Sciences*, 6(8):345 – 350, 2002.

[7] J. A. Jones, J. E. Swan, II, G. Singh, E. Kolstad, and S. R. Ellis. The effects of virtual reality, augmented reality, and motion parallax on egocentric depth perception. In *Proceedings of the 5th symposium on Applied perception in graphics and visualization*, APGV '08, pages 9–14, New York, NY, USA, 2008. ACM.

[8] C. Madison, W. Thompson, D. Kersten, P. Shirley, and B. Smits. Use of interreflection and shadow for surface contact. *Perception & Psychophysics*, 63(2):187–194, 2001.

[9] S. Manabe, S. Ikeda, A. Kimura, and F. Shibata. Shadow inducers: Inconspicuous highlights for casting virtual shadows on ost-hmds. In *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, pages 1331–1332, March 2019.

[10] R. Ni, M. L. Braunstein, and G. J. Andersen. Perception of scene layout from optical contact, shadows, and motion. *Perception*, 33(11):1305–1318, 2004.

[11] G. Pointon, C. Thompson, S. Creem-Regehr, J. Stefanucci, M. Joshi, R. Paris, and B. Bodenheimer. Judging action capabilities in augmented reality. In *Proceedings of the 15th ACM Symposium on Applied Perception*, SAP '18, pages 6:1–6:8. ACM, 2018.

[12] J. E. Swan, A. Jones, E. Kolstad, M. A. Livingston, and H. S. Smallman. Egocentric depth judgments in optical, see-through augmented reality. *IEEE transactions on visualization and computer graphics*, 13(3):429–442, 2007.

[13] W. B. Thompson, P. Shirley, B. Smits, D. J. Kersten, and C. Madison. Visual glue. *University of Utah Technical Report UUCS-98-007*, 1998.