The Effects of Direct and Global Illumination on Presence in Augmented Reality

Peter Kán[1], Andreas Dünser[2], Mark Billinghurst[3], Christian Schönauer[1], Hannes Kaufmann[1]

Institute of Software Technology and Interactive Systems, Vienna University of Technology, Vienna, Austria[1]

CSIRO Computational Informatics, Hobart, Australia[2]

The HIT Lab NZ, University of Canterbury, Christchurch, New Zealand[3]

Corresponding Author:

Peter Kán

Address: VUT, A-1040 Vienna, Favoritenstrasse 9-11/188, Austria

E-Mail: peterkan@peterkan.com

Phone: +431 5880 1188 645

Article Type: Full paper

Abstract

In this paper we present an experiment, which was designed and conducted with the goal to study the effect of lighting on the sense of presence in Augmented Reality. We compared presence ratings between global illumination rendering and direct illumination and asked study participants to judge which of the shown objects are virtual and which ones are real. Thirty people participated in a within-group experiment. A set of questionnaires was used to measure the sense of presence, perception of realism and the rate of interpretation of virtual objects as real ones with both global and direct illumination conditions. The results of our experiment show that global illumination rendering increases the sense of presence in comparison to direct illumination and that there is a correlation between perception of realism and feeling of presence in augmented reality. We discuss the major differences between real and virtual objects as observed by the users and the categories of important features for visual realism in Augmented Reality.

Keywords: Presence; Augmented Reality; Global Illumination; Visual Realism

Introduction

The main concept of Augmented Reality (AR) is to overlay spatially aligned virtual objects onto the real world. Ideally, the user perceives that the virtual and real objects coexist in the same space (Azuma, 1997). Visual coherence between virtual and real objects is an important property, which can be achieved by taking light transport between real and virtual objects into account. Therefore, a proper light transport algorithm is required. Presence has been studied in previous research mainly in Virtual Reality (VR) scenarios but less so in AR. Studying presence in AR can help to better understand the perception of virtual information and increase the user experience of applications. Although there is previous research of presence in VR, there are still open questions about the sense of presence and the factors which influence it especially in AR. The dependence between the illumination model used in rendering and the perceived presence is important for the future development of AR applications. This knowledge is essential to improve visual coherence in AR.

We present an experiment studying the effect of illumination calculation methods on the sense of presence in AR. Thirty people participated in our experiment. We found that the sense of presence is significantly higher with global illumination than with direct illumination for specific scenes. Our results show that people perceive virtual objects as real objects to a higher degree with global illumination than with direct illumination. Moreover, we found a positive correlation between the sense of presence and perceived realism and identified the major differences between virtual and real objects perceived by the users.

The results of our research show that accurate illumination calculation has significant advantages for AR applications. The selection of the illumination method has a significant impact on users' perception of virtual objects in AR. The outcome of our research gives useful guidelines for enhancing presence in AR.

Related Work

The sense of presence has been a topic of research in VR for many years. Several experiments have been conducted to study the effect of different parameters on presence. The influence of rendering quality on presence was studied by (Zimmons & Panter, 2003) and (Mania & Robinson, 2004), but neither could confirm that presence depends on rendering quality. Visual realism in VR was also studied using an environment that displays a precipice, a pit that the participant looks over (Slater, Khanna, Mortensen, & Yu, 2009). The results of the experiment suggested that the participants observing the VR with ray-tracing rendering reported a higher level of presence than participants using VR with ray-casting rendering. Ray-casting uses only the primary rays from the camera in comparison to ray-tracing, where the reflected light rays are traced as well. An overview of research on presence in VR can be found in (Schuemie, van der Straaten, & Krijn, 2001).

Similar to our study was that of Sugano et al. (Sugano, Kato, & Tachibana, 2003). They conducted an experiment, which examined the effect of shadow representation of virtual objects in AR. The results showed that shadow representation is important for increasing object presence. An experimental framework for studying perceptual issues in photorealistic AR was presented by Knecht et al. (Knecht, Dünser, Traxler, Wimmer, & Grasset, 2011). The authors performed a study to investigate the influence of different shadows and lighting calculation methods on user performance in five different tasks. Their results indicated that there were no significant effects of the studied rendering conditions on task performance. While this study focuses on task performance, we study the effect of different lighting conditions on the sense of presence rather than task performance and use a high-quality global illumination algorithm.

Illumination models

Two illumination models were examined in our experiment, direct illumination and global illumination in interactive AR. The differential rendering method (Debevec, 1998) was used in our ray-tracing framework to composite virtual objects into the real-time video. We implemented the one-pass version of a differential rendering algorithm (Kán & Kaufmann, 2012).

Global Illumination

Light transport in the real world includes light emitting from light sources and multiple reflections in the scene. These reflections have to be taken into account if the correct lighting is required. Global illumination calculates multiple light reflections and consists of direct and indirect illumination. We simulate direct and indirect illumination separately and finally combine them to calculate the final radiance value for each pixel and display it. Direct illumination is calculated by real-time ray-tracing on the GPU and indirect illumination is calculated by Differential Irradiance Caching (Kán & Kaufmann, 2013). This method calculates the accurate indirect illumination at sparse scene points called irradiance cache records. Spatial coherence of indirect illumination is utilized and the calculated illumination is later interpolated in-between the cache records.

Direct Illumination

Direct illumination accounts for the light that is emitted from the light source and reflected from the surfaces directly towards the observer (camera). Shadows are included in the result of the direct illumination. We used GPU ray-tracing to calculate the direct illumination in an interactive AR setup. The difference between global and direct illumination used in our experiment can be seen in Figure 1.

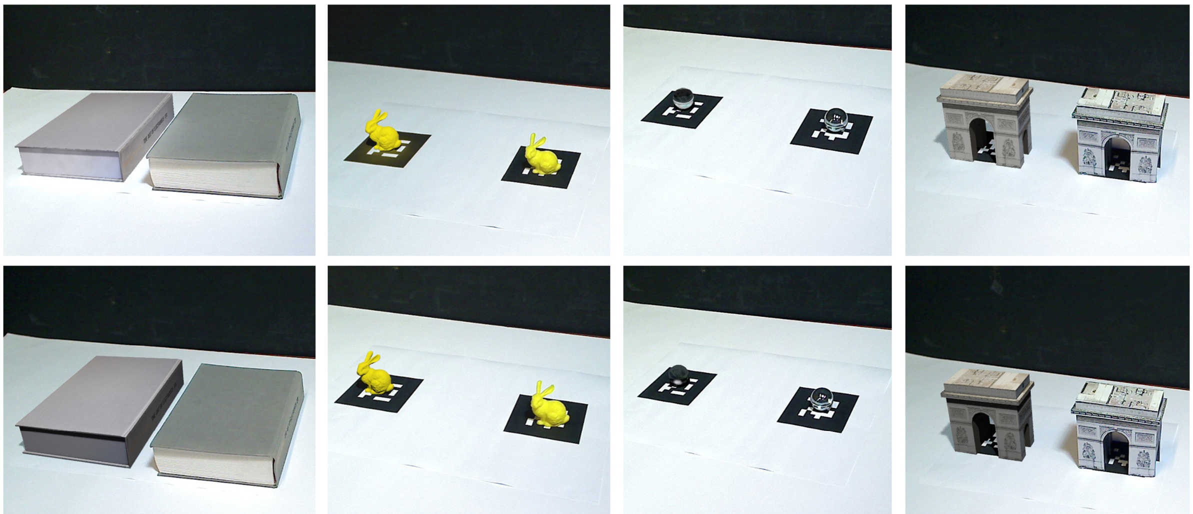

Figure 1: (Top row) Global illumination rendering in AR. (Bottom row) Direct illumination rendering in AR. Objects from left: Book, Bunny, Glass sphere, Arc de triomphe. The left object is virtual and the right one is real in all images.

Methods

The main aim of our experiment was to study the relation between the illumination models and the sense of presence in AR. The study was designed as a within-group experiment using questionnaires to measure the sense of presence and realism perceived by the user. Two lighting algorithms were examined: global illumination and direct illumination.

Hypotheses

We posed three hypotheses to examine the effect of lighting in AR on presence:

H1: The sense of presence is higher with global illumination rendering than with direct illumination.

H2: The number of virtual objects mistakenly judged as real ones is higher with global illumination rendering than with direct illumination.

H3: There is a positive correlation between the sense of presence and the perceived realism of virtual objects.

Experimental Design

Two different experimental setups were used to verify the hypotheses:

1. Observation of videos recorded from AR.
2. A real-time AR setup.

The first setup in our experiment was based on videos recorded from interactive AR. This setup was designed to test the hypothesis H2. Two AR scenes were created. Both scenes contained 4 virtual and 3 real objects with different objects being used. Both scenes were recorded with global illumination and direct illumination. All four videos were shown to the participants in a random order. They could watch each video repeatedly and were allowed to pause the video. After each observation the participants were asked to identify which objects were real and which were virtual. The recorded videos were used in this task instead of interactive AR to minimize the bias caused by recognition of virtual objects due to tracking imperfections.

The second setup was the real-time AR scenario, where users could freely observe the virtual and real objects in a video-see-through scenario. The real scene was captured by a single camera and displayed on a Head Mounted Display (HMD) (Sony HMZ-T1 HMD; resolution 800x600 per eye). The camera was mounted on the HMD. Either direct or global illumination was calculated to render the virtual objects in the AR scenes. In global illumination the inter-reflections between virtual and real objects were included.

A visual marker-based ARToolkitPlus (Wagner & Schmalstieg, 2007) tracking system was used to calculate the position and orientation of the real camera. The scene consisted of two markers with a virtual object positioned on one of them. A real object, similar to the virtual one, was positioned onto the second marker. Users were informed which object was real and which was virtual. Participants could freely walk and observe the objects from different viewpoints as long as they wished. A participant and the corresponding AR view during the experiment can be seen in Figure 2.

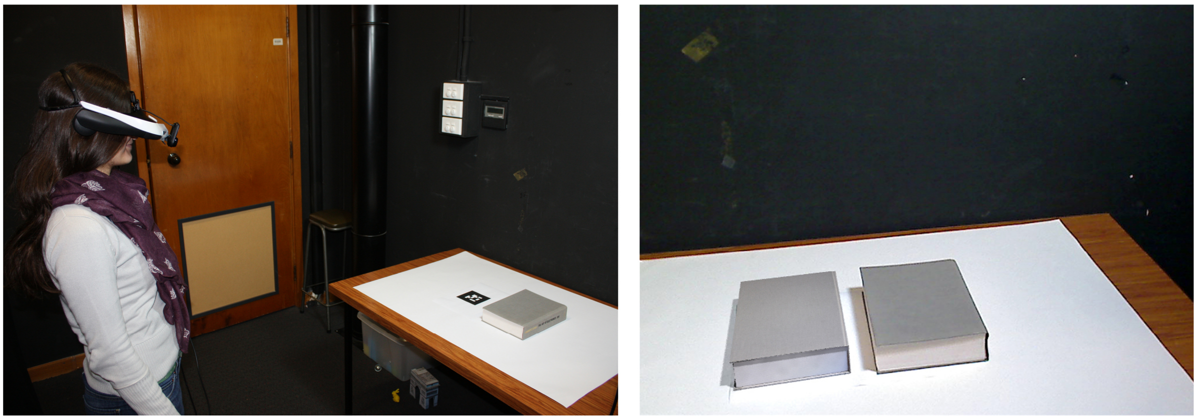

Figure 2: (Left) Participant wearing an HMD is observing the AR scene. (Right) The view of the participant shows a virtual book (left) and a real book (right).

Each participant observed eight trials. After each observation the users filled in a questionnaire (Table 1) using specific mixed reality (MR) presence questions designed by Regenbrecht et. al (Regenbrecht, Botella, Banos, & Schubert, Unpublished; Regenbrecht & Schubert, 2002). Moreover, we added a question for comparing virtual and real objects. All questions were answered on 7 point Likert type items (1 strongly disagree, 7 strongly agree)

Table 1: Presence questionnaire

1.	Watching the virtual object was just as natural as watching the real world.
2.	The virtual object and I were in the same environment. (I felt I could have touched the virtual object)
3.	Virtual and real environments formed one, common space.
4.	I perceived virtual element as being only a computerized image, not as a real object.
5.	The virtual element seemed real for me.
6.	I could not distinguish between real object and virtual object.
7.	The virtual object looked visually the same as its real counterpart.

The participants observed four virtual objects with each illumination condition. The order of the conditions and objects displayed were randomized to minimize a positioning effect. The following virtual objects (Figure 1) were observed: Standford Bunny (69K triangles), Glass Sphere (962 triangles), Book (1278 triangles), and textured building Arc de triomphe (346 triangles). After the participants had observed the objects with a respective illumination model, they completed an additional questionnaire measuring the overall presence and perceived realism with this illumination model (Table 2) (Regenbrecht et al., Unpublished), using Likert scale ranging from 1 to 7, (1 - very low, 7 - very high).

Table 2: Overall questionnaire for sense of presence and perception of realism.

1.	Overall, how would you rate the sense of presence generated by the virtual elements; to what extent “they were here”?
2.	Overall, how would you rate the degree of realness achieved by the virtual elements; to what extent “they seemed real to you”?

At the end of the experiment we asked users to tell what they perceived as the major differences between virtual and real objects in order to get a better understanding of the importance of different lighting features for visual coherence in AR.

Participants

Thirty people aged between 19 and 42 years participated in our experiment. All had normal or corrected-to-normal vision. The participants provided informed consent and ethical approval was obtained from the University of Canterbury Human Ethics Committee. The group of participants consisted of 14 women and 16 men. Nine had previous experience with AR and eight had knowledge in computer graphics.

Data Analysis

After recoding question 4 (values 1-7 were recoded to 7-1), Cronbach's alpha was calculated to analyze the internal consistency of the presence questionnaire. Then the questions were merged together and a mean was calculated. A Wilcoxon signed-rank test was used to test the difference in answers between global and direct illumination conditions.

For the trials in which the participants were asked to judge which objects were real and which were virtual, the number of virtual objects mistakenly marked as real ones was counted for both global and direct illumination. In order to test for difference between the two illumination models we again used a Wilcoxon signed-rank test. The decision of using a non-parametric test was made because the data didn't follow the normal distribution.

Hypothesis 3 was tested by calculating Pearson's correlation for responses in the overall questionnaire.

Results

Calculating Cronbach's alpha showed high internal consistency of the presence questionnaire ($\alpha = .938$). We merged the questions using the mean for analyzing the questionnaire results. The difference was calculated by subtracting the mean presence questionnaire result for direct illumination from mean result for global illumination. For the majority of observations the difference is positive, which indicates that the sense of presence was rated higher for global illumination than for direct illumination.

Taken all scenes together the Wilcoxon signed-rank test showed that the sense of presence is significantly higher with global illumination than with direct illumination

($Z = -4.043$, $p < .001$)[1]. However a more detailed analysis showed that this result is scene or object dependent. We found significant differences in presence for the Book scene and the Arc de triomphe scene. The remaining two scenes showed no significant difference (see Table 3). Figure 4 shows the means of presence for global and direct illumination.

Table 3: Results of Wilcoxon signed-rank test on data from presence questionnaire.

	All scenes	**Book**	**Bunny**	**Arc de triomphe**	**Glass sphere**
Z	-4.043	-2.883	-1.574	-2.888	-0.649
p	< **.001**	**.004**	**.116**	**.004**	**.516**

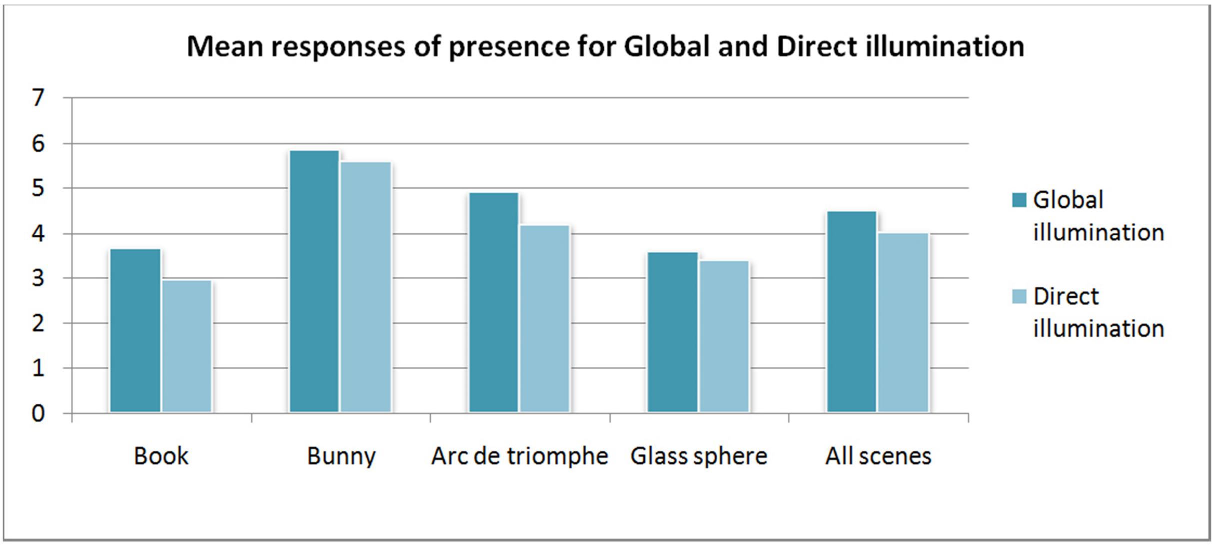

Figure 4: Mean of presence questionnaire responses for global and direct illumination.

The number of virtual objects mistakenly judged as real ones was counted in each video watched by the participants in the video observation task and summed for the two global illumination videos and the two direct illumination videos. Our assumption in H2 was

[1] To minimize the risk of type I error we use a Bonferroni adjusted p-value for interpreting significance of p =.01

that the number of virtual objects mistakenly marked as real ones will be higher with global illumination rendering. We tested the hypothesis H2 using the Wilcoxon signed-rank test. Results showed that the number of virtual objects mistakenly marked as real ones is significantly higher with global illumination than with direct illumination (Z = -2.207, p = .027) (Figure 5).

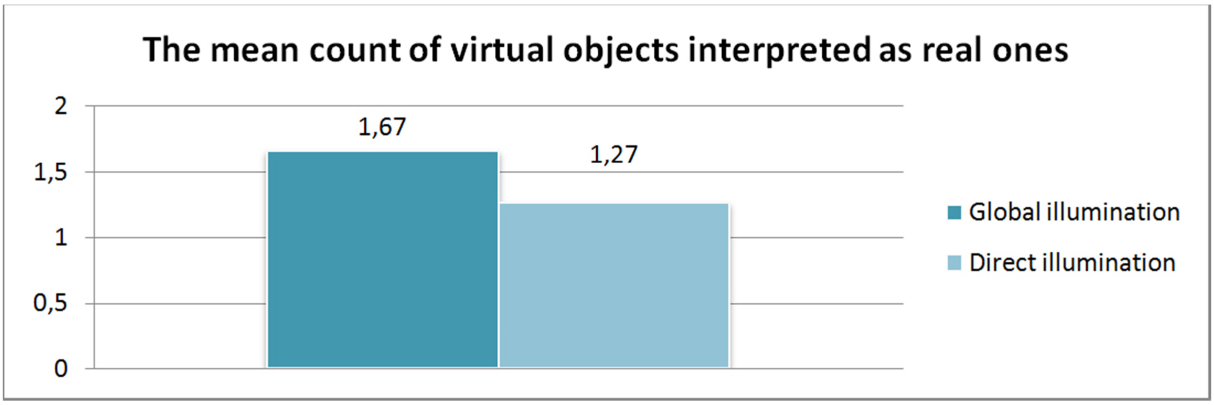

Figure 5: The number of virtual objects interpreted as real ones for global and direct illumination conditions.

The overall questionnaire (Table 2) was completed after observations of each global and direct illumination condition. In H3 we assume a positive correlation between the sense of presence and the realism of virtual objects perceived by the users. A Pearson product-moment correlation showed that there was a significant strong, positive correlation between the sense of presence and realism perceived by the users (r = .717, n = 60, p < .001).

In addition to the questionnaires we asked the users what they perceived as the major differences between the appearance of virtual and real objects. The answers were processed by axial coding. We focused on finding the most important features of rendering, which can contribute to visual realism. The following codes were extracted from the text ordered by the frequency of occurrence: Shadows, Colors, Textures, HDR reflections on glass, Imperfections of tracking, Sharpness of edges, Camera distortions. The four categories in which the mentioned items fit are: Lighting, Material, Camera, Tracking. According to the frequency of occurrence the most frequent aspects are shadows. Inconsistency in shadows can be obvious especially in the case when real shadows are present for comparison. In addition material properties and proper simulation of camera distortion turned out to play significant role. Precise camera pose tracking is important for the spatial coherence between virtual and real scenes.

Discussion

Our results show that overall the sense of presence is higher with global illumination calculation in comparison to direct illumination. However a separate analysis of different AR scenes shows that only in two out of the four scenes this is significant. Therefore, hypothesis H1 was only partially confirmed. We assume that the difference between rendering of global and direct illumination was small in the Bunny and Glass sphere scenes causing low significance of difference in presence in these scenes.

Hypothesis H2 was supported by the analysis of video observation data. The number of virtual objects marked as real ones was significantly higher with global illumination than with direct illumination.

With Hypothesis H3 we assumed that the realism of virtual objects perceived by users correlates with the sense of presence. This hypothesis was confirmed and we found evidence of a significant strong, positive correlation between the sense of presence and realism perceived by the users.

The technical setup used in this experiment poses some possible limitations. There were several technical issues that could affect the quality of gathered data such as the precision of camera tracking. This can be improved in future work to ensure correct spatial registration. Also, the single camera setup can be extended to stereo cameras to allow using a 3D AR scenario. Possible methodological limitation can be caused by the fact that eight participants had previous knowledge in the computer graphics area. These people could possibly tend to prefer global illumination based on their knowledge.

The results of our experiment suggest that the illumination model used in AR rendering has a significant effect on presence and realism in some scenes. This finding poses an important guideline for future research and development in the field of AR.

Conclusion

In this paper we presented an experiment evaluating the effect of global and direct illumination to the sense of presence in AR. We found that global illumination leads to a higher sense of presence for certain scenes. Moreover we have found significant correlation between the perception of realism and presence. We showed that our participants more likely judged virtual objects as real objects with global illumination compared to direct illumination. Finally, we analyzed the differences between real and virtual objects observed by users and identified the most important features for visual realism in AR such as rendering of shadows.

Acknowledgements

This research was conducted at HIT Lab New Zealand. We thank Adrian Clark, Gun Lee, and other HIT Lab NZ staff and students for their help with this study, for their valuable suggestions and comments. We would like to thank Holger Regenbrecht for providing us with his new AR presence questionnaire. The Bunny model is courtesy of Stanford University. The Arc de triomphe model belongs to the City of Sights project (Gruber et al., 2010). Peter Kán is financially supported by the Vienna PhD School of Informatics and the IMS group.

References

Azuma, R. T. (1997). A survey of augmented reality. *Presence: Teleoperators and Virtual Environments*, *6*(4), 355–385.

Debevec, P. (1998). Rendering synthetic objects into real scenes: bridging traditional and image-based graphics with global illumination and high dynamic range photography. In *SIGGRAPH 98* (pp. 189–198). New York, NY, USA: ACM.

Gruber, L., Gauglitz, S., Ventura, J., Zollmann, S., Huber, M., Schlegel, M., … Höllerer, T. (2010). The City of Sights: Design, Construction, and Measurement of an Augmented Reality Stage Set. In *IEEE ISMAR 2010* (pp. 157–163). Seoul, Korea.

Kán, P., & Kaufmann, H. (2012). Physically-Based Depth of Field in Augmented Reality. In *EG 2012* (pp. 89–92). Cagliari, Italy: Eurographics Association.

Kán, P., & Kaufmann, H. (2013). Differential Irradiance Caching for Fast High-Quality Light Transport Between Virtual and Real Worlds. In *IEEE ISMAR 2013* (pp. 133–141).

Knecht, M., Dünser, A., Traxler, C., Wimmer, M., & Grasset, R. (2011). A Framework For Perceptual Studies In Photorealistic Augmented Reality. In *Proceedings of the 3rd IEEE VR 2011 Workshop on Perceptual Illusions in Virtual Environments* (pp. 27–32).

Mania, K., & Robinson, A. (2004). The effect of quality of rendering on user lighting impressions and presence in virtual environments. In *International conference on Virtual Reality continuum and its applications in industry* (pp. 200–205). NY, USA: ACM.

Regenbrecht, H., Botella, C., Banos, R., & Schubert, T. (2013). Mixed Reality Experience Questionnaire v1.0. Unpublished online document. http://www.hci.otago.ac.nz/mreq/MixedRealityExperienceQuestionnaireWeb.htm, last accessed 23/May/2013.

Regenbrecht, H., & Schubert, T. (2002). Measuring Presence in Augmented Reality Environments: Design and a First Test of a Questionnaire. In *Proceedings of the Fifth Annual International Workshop Presence 2002*.

Schuemie, M. J., van der Straaten, P., & Krijn, M. (2001). Research on Presence in Virtual Reality: A Survey, *4*(2), 183–201.

Slater, M., Khanna, P., Mortensen, J., & Yu, I. (2009). Visual Realism Enhances Realistic Response in an Immersive Virtual Environment. *IEEE Computer Graphics and Applications*, *29*(3), 76–84.

Sugano, N., Kato, H., & Tachibana, K. (2003). The effects of shadow representation of virtual objects in augmented reality. *IEEE ISMAR 2003*, 76–83.

Wagner, D., & Schmalstieg, D. (2007). *ARToolKitPlus for Pose Tracking on Mobile Devices*. (M. Grabner & H. Grabner, Eds.)*Computer Vision Winter Workshop*.

Zimmons, P., & Panter, A. (2003). The influence of rendering quality on presence and task performance in a virtual environment. In *IEEE Virtual Reality, 2003.* (pp. 293–294).