Depth Perception using X-Ray Visualizations

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Abstract

Augmented Reality's ability to create visual cues that extend reality allows for many new abilities to enhance the way we work, problem solve and evaluate activities. Combining the digital and physical world's information requires new understandings of how we perceive reality. The ability to look through physical objects without getting conflicting depth cues (X-Ray vision) is one challenge that is currently an open research question. The current research states several methods for improving depth perception such as providing extra occlusion by utilizing X-ray vision effects [4, 11, 12, 18, 23]. Currently, there is a lack of knowledge around this space into how and why some of these aspects work or the different strengths that using these techniques can offer. My research aims at developing a deeper understanding of X-Ray vision effects and how they can and should be used.

1 Research Situation

I am a PhD student at the University of South Australia studying Advanced Human Computer Interactions. I have completed my candidacy and been in my PhD for about 1 year prior to that. And I have done work with Siemens Healthineers Forchheim working on a system that overlaid CT data over a patient in the CT scanner. I am in the process of writing a literature review on a related topic on X-ray Vision in Augmented Reality. My first Study is focusing on X-Ray vision is finished and I am currently writing up my results. My hopes with attending the ISMAR Doctoral Consortium is that I may get some different perspectives on my research and receive some constructive criticism from other researchers.

2 Context and Motivation

X-ray vision based on Superman's x-ray vision allows us to see inside of another object while correcting the physical to virtual mismatch caused by the act of trying to look inside of a physical object. This effect was first reported by Bajura et al. [4] and they were also the first to find create a solution to this mismatch by creating a virtual hole inside of the target and since then a lot of work has been done to further our ability to work within occluded environments.

From my personal experience within the medical community there is a growing desire to place volumetric medical data so it appears within patients [4,20,22,24] This is being done to potentially reduce the human error within surgeries, aiding the decision making of many disciplines of medical practitioners and streamline the understanding of anatomy for medical students. This same logic can also be applied to construction [5] and maintenance fields [14, 27]. This involves first by passing the human understanding leading to the belief that we cannot see through occlusive physical matter. The field of augmented reality research that experiments with this state is called augmented Reality enabled x-ray vision. Work in this field has progressed a long way with a ton of new x-ray vision effects but there is still a lot of work left to do in regard to learning how these effects work exactly and developing strategies for them to work on new systems that work outside of direct human vision.

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3 Background

In the field of there has been a lot of work in the field augmented reality lots of work has been done with depth perception but there is a lack of literature based on the ability of depth perception of objects that should be but are not concealed by physical matter. Early work by Bajura et al. [4] showcased the mismatch effect of virtual visualizations and the real world and provided a method to fix them with his discovery of the virtual hole effect in AR. This work provided a strong foundation to repair the mismatch caused by the real world and occluded world's miss match and since this point a lot of work has been done to further repair this mismatch. Such as looking through building not just into them [11], using various visual effects on the surface to also create depth cues. Some of these techniques use the image capture information used to create the AR experience to illustrate the effect [3, 11, 12, 23]. While others use depth information and present static cues to the user [18, 19].

All of the research mentioned above have a shared issue, they have all used various types of desktops [11, 12], handheld devices [23] or video see-through augmented reality head mounted display [3,18,19]. The effects from these devices can work well in their own in certain environments. However, for high-risk settings like surgery and many other hands-on settings obscuring the user's vision isn't practical and can be potentially dangerous. To this end for many applications the only augmented reality that makes sense is ocular see-through head mounted display. One of these that has grown popular in the last couple of years is superimposing medical [16, 22, 28]. This caused researchers like Paolis and Luca [6] to address similar issues in this area using technology that is common in medical situations.

However, superimposing virtual data onto real world objects is difficult, since virtual objects rendered in AR may be perceived to be at the wrong depth due to mismatch between human depth perception and capabilities of the AR technology. rending objects at the correct position so they will be located within a object will cause you to perceive a virtual object in front of the real one rather than within it. [3, 4, 18]. This is due the lack of the occlusion depth cue which expects it to be, they will assume that it appears the most logical place for themselves, and since the virtual objects is physically closer than the real one it will normally be placed in front of the physical object [3, 4, 23]. X-ray visualizations are required to provide a partial occlusive Que to the user. Unfortunately, there is a limited amount of research in this area in regards to Ocular See Though AR [10,17]. Most of the work in x-ray vision has focused on video see-through displays like phones and VR headsets. Causing gaps in the findings of the previous research done.

Augmented reality seems to introduce a lot of variances in how we perceive depth compared to the real-world. Augmented reality causes people to underestimate depth [2, 7, 9, 26]. This seems to be an effect that gets worse the more virtualized an augmented environment is, but it seems to improve the more realistic a environment becomes more realistic. [1, 7, 9, 21].

Grunesfeild et al.'s [10] research focused on studies that used ocular see-through augmented reality devices. With a focus on x-ray visualisations that were built originally for ocular see through devices. From this point we still need to better understand how x-ray vision effects depth perception within the near field. And is there a difference between the types of visualisations that where created for video see though techniques when they are used on ocular see though devices. There are still many different types of x-ray visualisations that need to be tested in on ocular see-through devices that have not been ported over yet.

4 Statement of Thesis

The aim of my research is to explore the use of x-ray vision to support the presentation of internal anatomy in-situ with effective depth perception and to learn the best implementation. This could assist people in performing hands on tasks that require them to work in areas that they cannot see well. These be but are not limited to mechanics, security workers and medical practitioners which is my focus. A simulated surgical task such as performing such as performing a biopsy on a physical phantom model while using a HoloLens, a optical see-through display.

5 Research Goals and Methods

My research questions are split out over three questions that will be answered by three user studies that span over the different attributes requird to work.

- RQ1 (Outside of the physical object): Do different x-ray vision blending techniques have an impact on near field depth perception when viewing head mounted stereo display?
- RQ2 (Inside of the physical object): What is the effect in regards to depth perception on the amount of interior graphics perceived augmented reality x-ray visualizations?
- RQ3 (Usability of the data within the object): What effect does the quality of visual data have within augmented reality when working within physical objects?

6 Expected Contributions

My first study should produce findings that will increase our understanding of:

- The impact of different x-ray visualizations on depth perception within arm's reach.
- The impact of having deeply clustered objects and sparsely clustered objects within an x-ray visualisations.
- Adapted techniques that can migrate techniques designed from other devices to ocular see-through headsets.

My second study should produce findings that will highlight.

- The appropriate amount of detail and data is required for a user to be able to interact within an occluded space for a near field operation.
- How efficiently can users process certain amounts of data within an object.
- A representation of x-ray vision working with volumetric data.

My third study will

- How data within physical objects can be rendered to represent depth the best level of depth perception within arm's reach of the user.
- A deeper understanding of the amount of data that should be presented to guide a user to perform a task outside of their vision.
- Some guidelines to how displaying data within physical objects should work.

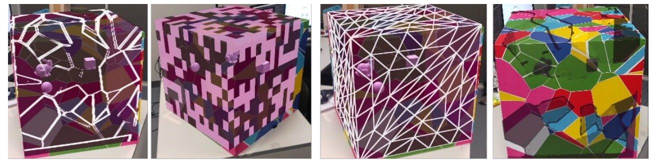

Figure 1: x-ray Visualization snapshots taken from the HoloLens while in development. These include Edge-based [11], Random Dot [18], Wireframe, Saliency [23] (shown in the same order from left to right)

Figure 2: The basic study set up for user study 1

7 Research Methodology

My research questions will be mainly trying to answer their respective user studies by using both quantitative and qualitative methods. This will be achieved with a user study that will look at a series of conditions and have the users answer several questionnaires aimed at determining the systems usability and the users mental load for the task.

7.1 User Study 1

By using depth perception of as a metric I want to determine what is the most practical method for navigating within an occluded space, but I also care about how well the user is able quickly is the user able to judge the space while allowing the users to operate however they please to come to the best answer. I also want to gain a better understanding about what why and when should various blending effects be used. If they work well in one form of AR does that mean they can translate into other versions of AR. I want to give users as much freedom as they would expect to get from a real use case and have them and record how they interact with the various visualizations within arm's reach.

I am using a simple task of moving a virtual object to the position of a physical object in relative space within an occluded object will show case the user's ability to use the visualizations. The users are given a physical guide object that is a 1:1 scale with the physical object they are working within to counteract the systemic underestimation noted frequently in depth perception research. In half of the instances of this study users will experience more than just one object in the scene that have been designed to be used as guides to test the different how the different visualisations react to different amounts of information held within them. I will test the users results in accuracy and time taken between all Kalkofen et al.'s [11] edge-based system and Sandor et al.'s [23] Sailency system to Otoski et al. [18] Random dot, and a basic wireframe used by many applications against a baseline condition of none.

7.2 User Study 2

In medical environments there are many different ways we can demonstrate internal data in many different ways. Generally the raw output of a MRI or a CT scanner is represented in a series of images. This allows us to both show case this data in its pure format by using volumetric rending [8, 13] and algorithms that convert this data to polygons, like marching cubes [15]. The concept of putting this data within physical objects is a common goal in Augmented Reality x-ray vison Starting with Bajura et al. [4] and being further examined by researchers like Pratt et al. [22] just to name a few.

Early research by Seilhorst et al. [24] showcases a difference between viewing volumetric graphics in AR and polygonal graphics when viewed inside of a physical object they showcased different perspectives on depth. I want to perform a similar study on a human head phantom. In contrast my research will make use of a more interactive study that makes use of a x-ray visualization decided by the first study. This study will also work in the near field of the user's depth perception. It will be modelled from MRI or CT data and then 3D printed into a physical human phantom with a brain cavity that will either be filled with a jelly or a kinetic sand like substance to provide haptic feedback back to the user. The user will be tasked with using a fake syringe to simulate performing a mock brain biopsy. Data will be collected by using an opti-track set up along with other sensors integrated in to the mock syringe to test the physical result from the user interacting with the jelly or sand. While the user proceeds to extract many different samples from the models.

7.3 User Study 3

This study will attempt to answer the question how much is too much and what is not enough. For example, is there a value to displaying periphery data at that isn't directly related to the area of impact. Should this data be displayed at the same resolution as the rest of the image or can the resolution be lowered if it isn't of interest to the user. This question will be answered by a similar set up as the second question but rather then rendering everything equally will look into rendering less and more and seeing what is the difference of depth perception. Some examples of possible visualizations for this study include showing only the areas that mater in high resolution or at all, fading the x-ray visualization around the region where the user is looking by using eye tracking. This will all be influenced by the findings from my first two studies.

8 Dissertation Status

Early on in my PhD I built a system that superimposes medical data over patients lying in a CT scanner using HoloLens was created in collaboration with Siemens Healthineers. This system is capable of representing many visualizations in several different ways from marching cubes to volumetric rendering. This system working in conjunction with the CT scanner that it was paired with. At the same time I helped write one book chapter in Springer's Biomedical Visualisation book [25] based around the use of medical data in Augmented Reality before writing my proposal. Data collection for the first study has been completed and the first paper has been drafted. I am also in the process of writing a lit review on x-ray vision in Augmented Reality. Moving forward I have been testing will be testing out new ideas for different implementations of x-ray vision in Augmented Reality and setting up my Mock surgical environment for future studies. Development of the second study is underway with a fair amount of the software built while the final study is still quite early in its planning phase.

9 Summery

From my research I expect to collect a wide amount of information regarding how people interact within occluded environments in occlusive AR. I would like it to be possible for us to begin to understand how to help us work in a field that isn't visible. My hope is that my research can open new ways to visualize and use data in augmented reality resulting in more efficient effective visual aids

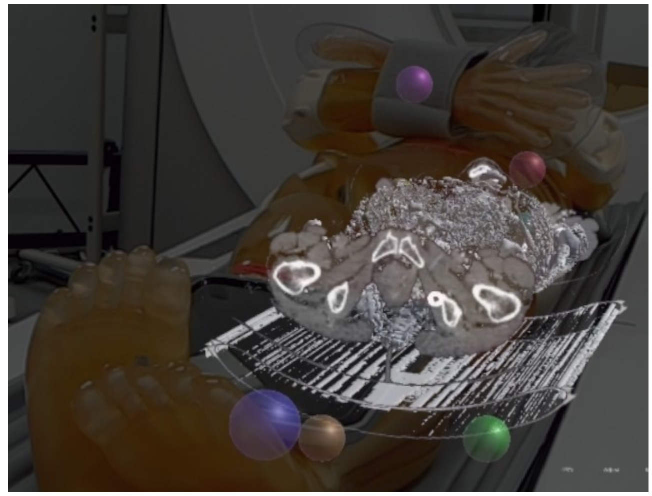

Figure 3: A snap shot of the Holographic Overlay System from the view point of the HoloLens camera (used with permission from Siemens Healthineers Forchheim)

for people who work in occluded spaces. Which should allow us to begin to build systems that would allow us to see into occluded spaces.

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References

[1] M. Al-Kalbani, M. Frutos-Pascual, and I. Williams. Virtual object grasping in augmented reality: Drop shadows for improved interaction. *2019 11th International Conference on Virtual Worlds and Games for Serious Applications, VS-Games 2019 - Proceedings*, p. 1DUUMY, 2019. doi: 10.1109/VS-Games.2019.8864596

[2] C. Armbrüster, M. Wolter, T. Kuhlen, W. Spijkers, and B. Fimm. Depth perception in virtual reality: Distance estimations in peri- and extrapersonal space. *Cyberpsychology and Behavior*, 11(1):9–15, 2008. doi: 10.1089/cpb.2007.9935

[3] B. Avery, C. Sandor, and B. H. Thomas. Improving Spatial Perception for Augmented Reality X-Ray Vision. In *2009 IEEE Virtual Reality Conference*, pp. 79–82, 2009. doi: 10.1109/VR.2009.4811002

[4] M. Bajura, H. Fuchs, and R. Ohbuchi. Merging virtual objects with the real world: seeing ultrasound imagery within the patient. *Computer Graphics (ACM)*, 26(2):203–210, 1992. doi: 10.1145/142920.134061

[5] S. Côté and A. Mercier. Augmentation of Road Surfaces with Subsurface Utility Model Projections. In *2018 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, pp. 535–536, 2018. doi: 10.1109/VR.2018.8446545

[6] L. T. De Paolis and V. De Luca. Augmented visualization with depth perception cues to improve the surgeon's performance in minimally invasive surgery. *Medical and Biological Engineering and Computing*, 57(5):995–1013, 2019. doi: 10.1007/s11517-018-1929-6

[7] C. Diaz, M. Walker, D. A. Szafir, and D. Szafir. Designing for depth perceptions in augmented reality. *Proceedings of the 2017 IEEE International Symposium on Mixed and Augmented Reality, ISMAR 2017*, pp. 111–122, 2017. doi: 10.1109/ISMAR.2017.28

[8] R. A. Drebin, L. Carpenter, and P. Hanrahan. Volume rendering. *Proceedings of the 15th Annual Conference on Computer Graphics and Interactive Techniques, SIGGRAPH 1988*, (August 1988):65–74, 1988. doi: 10.1145/54852.378484

[9] 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, 28(2):117–135, 2020. doi: 10.1002/jsid.832

[10] U. Gruenefeld, Y. Brück, and S. Boll. Behind the Scenes: Comparing X-Ray Visualization Techniques in Head-mounted Optical See-through Augmented Reality. *ACM International Conference Proceeding Series*, pp. 179–185, 2020. doi: 10.1145/3428361.3428402

[11] D. Kalkofen, E. Mendez, and D. Schmalstieg. Comprehensible visualization for augmented reality. *IEEE Transactions on Visualization and Computer Graphics*, 15(2):193–204, 2009. doi: 10.1109/TVCG.2008.96

[12] D. Kalkofen, E. Veas, S. Zollmann, M. Steinberger, and D. Schmalstieg. Adaptive ghosted views for Augmented Reality. *2013 IEEE International Symposium on Mixed and Augmented Reality, ISMAR 2013*, 1(c):1–9, 2013. doi: 10.1109/ISMAR.2013.6671758

[13] A. Kaufman and K. Mueller. *Overview of volume rendering*. Elsevier Inc., 2005. doi: 10.1016/B978-012387582-2/50009-5

[14] K. Lilija, H. Pohl, S. Boring, and K. Hornbæk. Augmented reality views for occluded interaction. *Conference on Human Factors in Computing Systems - Proceedings*, pp. 1–12, 2019. doi: 10.1145/3290605.3300676

[15] W. Lorensen and H. E. Cline. Marching Cubes: A High Resolution 3D Surface Construction Algorithm. *ACM SIGGRAPH Computer Graphics*, 21:163–, 1987. doi: 10.1145/37401.37422

[16] C. Ma, G. Chen, X. Zhang, G. Ning, and H. Liao. Moving-Tolerant Augmented Reality Surgical Navigation System Using Autostereoscopic Three-Dimensional Image Overlay. *IEEE Journal of Biomedical and Health Informatics*, 23(6):2483–2493, 2019. doi: 10.1109/JBHI.2018.2885378

[17] D. Medeiros, M. Sousa, D. Mendes, A. Raposo, and J. Jorge. Perceiving depth: Optical versus video see-through. *Proceedings of the ACM Symposium on Virtual Reality Software and Technology, VRST*, 02-04-Nove:237–240, 2016. doi: 10.1145/2993369.2993388

[18] M. Otsuki, Y. Kamioka, Y. Kitai, M. Kanzaki, H. Kuzuoka, and H. Uchiyama. Please show me inside: Improving the depth perception using virtual mask in stereoscopic AR. *SIGGRAPH Asia 2015 Emerging Technologies, SA 2015*, (February 2018):2–5, 2015. doi: 10.1145/2818466.2818469

[19] M. Otsuki, P. Milgram, and R. Chellali. Use of Random Dot Patterns in Achieving X-Ray Vision for Near-Field Applications of Stereoscopic Video-Based Augmented Reality Displays. *Presence: Teleoperators & Virtual Environments*, 26(1):42–65, 2017. doi: 10.1162/PRES

[20] E. Ozgur, A. Lafont, and A. Bartoli. Visualizing In-Organ Tumors in Augmented Monocular Laparoscopy. *Adjunct Proceedings of the 2017 IEEE International Symposium on Mixed and Augmented Reality, ISMAR-Adjunct 2017*, pp. 46–51, 2017. doi: 10.1109/ISMAR-Adjunct.2017.30

[21] J. Ping, D. Weng, Y. Liu, and Y. Wang. Depth perception in shuffleboard: Depth cues effect on depth perception in virtual and augmented reality system. *Journal of the Society for Information Display*, 28(2):164–176, 2020. doi: 10.1002/jsid.840

[22] P. Pratt, M. Ives, G. Lawton, J. Simmons, N. Radev, L. Spyropoulou, and D. Amiras. Through the HoloLens™ looking glass: augmented reality for extremity reconstruction surgery using 3D vascular models with perforating vessels. *European Radiology Experimental*, 2(1):0–6, 2018. doi: 10.1186/s41747-017-0033-2

[23] C. Sandor, A. Cunningham, A. Dey, and V. V. Mattila. An augmented reality X-ray system based on visual saliency. *9th IEEE International Symposium on Mixed and Augmented Reality 2010: Science and Technology, ISMAR 2010 - Proceedings*, pp. 27–36, 2010. doi: 10.1109/ISMAR.2010.5643547

[24] T. Sielhorst, C. Bichlmeier, S. M. Heining, and N. Navab. Depth perception - A major issue in medical AR: Evaluation study by twenty surgeons. *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, 4190 LNCS:364–372, 2006. doi: 10.1007/11866565_45

[25] R. T. Smith, T. J. Clarke, W. Mayer, A. Cunningham, B. Matthews, and J. E. Zucco. Mixed reality interaction and presentation techniques for medical visualisations. In *Biomedical Visualisation*, pp. 123–139. Springer, 2020.

[26] 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. doi: 10.1109/TVCG.2007.1035

[27] R. Van Son, S. W. Jaw, J. Yan, H. S. Khoo, W. K. Loo, S. N. Teo, and G. Schrotter. A framework for reliable three-dimensional underground utility mapping for urban planning. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives*, 42(4/W10):209–214, 2018. doi: 10.5194/isprs-archives-XLII-4-W10-209-2018

[28] T. Xie, M. M. Islam, A. B. Lumsden, and I. A. Kakadiaris. Holographic iRay: Exploring Augmentation for Medical Applications. *Adjunct Proceedings of the 2017 IEEE International Symposium on Mixed and Augmented Reality, ISMAR-Adjunct 2017*, (November):220–222, 2017. doi: 10.1109/ISMAR-Adjunct.2017.73