Enabling Interactive Experiences for Asymmetrical Augmented Reality

A Thesis Submitted to the Department of Computer Science and Communications Engineering,
the Graduate School of Fundamental Science and Engineering of Waseda University
in Partial Fulfillment of the Requirements for the Degree of Master of Engineering

Submission Date: July 22nd, 2019

Mingshu Zhang
(5117FG25-2)
Advisor: Prof. Tatsuo Nakajima
Research guidance: Research on Distributed System

ACKNOWLEDGEMENTS

As the reseracher of this work, I would like to thank the following persons for their contribution to my thesis:

Throughout this thesis and project I have received numerous support, advice and assistance. The most help and guidance I received is from my supervisor, Prof. Tatsuo Nakajima. I would like to express my deepest appreaciation to him. Without his kind and patient instructions, this work cannot be done.

Multiple valuable suggestions and ideas come from other lab members, therefore I would like to thank my colleagues in Waseda University as well.

I would like to thank my family and friend for supporting me to finish this thesis. At last, I want to show gratitude to all of my friends who directly and indirectly helped and supported me when I am persuing the master’s degree.

MINGSHU ZHANG

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

AR	Augmented Reality
VR	Virtual Reality
DoF	Degree of freedom
HMD	Head-mounted display
FPS	First-person perspective
TPS	Third-person perspective
OST	Optical-see-through
VST	Video-see-through
SLAM	Simultaneous localization and mapping
GEQ	Game experience questionnaire

SUMMARY

Virtual reality and augmented reality are gaining increasing attention for their capability of providing an immerse experience over the combination of real and virtual environments. Enabling social experience and interactions between multiple users in the virtual environment has drawn interest from the research community recently. Other than conventional collaborative virtual environments that enable HMD users to work collectively, asymmetric virtual reality technologies that focus on the communication and interactions between HMD and non-HMD users resolved many limitations of current virtual reality systems. Augmented reality technology promotes the integration of real-world information and virtual content, but most existing augmented reality researches are focusing on a symmetric user experience by synchronizing the mapping between the virtual environment and the real environment. Since users generally stay in the same physical environment, the effect of asymmetric interactions remains unknown. In this work, we propose a novel design of asymmetric augmented reality experience. We developed a proof-of-concept implementation and conducted a comprehensive user study to evaluate the effectiveness of asymmetric augmented reality experience. By compared to traditional environments including desktop and conventional augmented environment, the results showed that the asymmetric augmented reality can enhance the enjoyment and involvement of the user. We envision that this technology can be further expanded to services such as medical, education and navigation.

Keywords: Virtual Reality, Augmented Reality, Asymmetric Augmented Reality

CHAPTER 1. INTRODUCTION

1.1 Background

Virtual reality (VR) has been a popular topic in recent years for its unique capability of resembling the real world or rendering a complete imaginary environment from scratch. This distinguish virtual reality from other technologies and make it valuable in wide range of applications. From shooting aliens on a foreign planet (entertainment) [1], to learning the structure of human body (education) [2] or simulating the process of walking to rehabilitate (medical) [3], virtual reality technology shows a great potential across various fields. With the ability to inspect and interact with the virtual environment freely, users of 6 DoF virtual reality can have a completely different experience from traditional form of media [6].

Similar to traditional media, enabling social experience [4] and interactions between multiple users in the virtual environment has drawn interest from the research community recently. Other than conventional symmetrical multi-user experience in which virtual reality users work with or play against each other [5], asymmetrical virtual reality experience [7] is also an interesting topic for several reasons. The problems of expensive costs of virtual reality equipment, confined area of room-scale environment [8] and potential collision [9] between users are non-trivial when studying the multi-user virtual reality experience. As a solution, some studies [10] provide virtual reality systems that let one user dive into the immersive environment while leaving the other player operates without wearing the head-mounted display (HMD). Gajadhar et al. firstly found that the user experience is preferable under an interactive scenario to meditate [11], Dedual et al.

later introduced a hybrid user interface with a touch-tabletop and a 3D see-through HMD [13]. Other asymmetric virtual reality collaborative systems [14] [15] are also designed and studied to further improve the experience.

In comparison, augmented reality (AR) draws interest from the research community with its capability of enhancing the reality with digital contents instead of completely take over the real world like virtual reality technology. augmented reality technology is a relatively new technology that promotes the integration of real-world information and virtual world information content. By overlapping the digital contents onto users' vision, such experience can be applied to multiple fields to assist different tasks as well. However, compared to asymmetrical virtual reality technology, asymmetrical augmented reality is a less studied topic because of its real-world-oriented characteristic. Stafford et al. introduced an interactive application that enables the collaboration between outdoor augmented reality and indoor tabletop users. [12]. Since users generally stay in the same physical environment, the effect of asymmetrical enhancement to co-located multi-user augmented reality experience remains unknown.

1.2 Objective

Despite augmented reality has been a popular technology across different fields to enhance the experience [16], a majority of existing augmented reality system are mainly focusing on the only augmented reality user. Even there are emerging multi-user augmented reality systems proposed recently, most of them are remote systems with symmetrical digital information [17] [18] projected to the same location of the real world by synchronizing the tracked feature points in the scene. Similar to asymmetrical virtual reality experience, in this work, we present a design of co-located asymmetric augmented reality system that provides multiple users with diverse information to enhance the experience of all users. To verify the effectiveness and influence of asymmetrical augmented reality to the user experience, we implemented a proof-of-concept collaborative augmented reality system for users to communicate and interact with each other in order to finish a shared goal. By conducting a comprehensive user study, we assess the impact of asymmetry in social interaction and user experience.

1.3 Structure of the Thesis

This thesis is organized as follows. In chapter 2, we recall the previous researches on traditional virtual reality and collaborative and asymmetric virtual reality, followed by a review of traditional augmented reality. In chapter 3, we describe the proposed asymmetrical augmented reality in detail. Based on our design, we further elaborate our proof-of-concept implementation with hardware and software information. In chapter 4, we explain the design of the user study and experiments details under each condition. We then analyzed the collected data to conclude the result of the user study. Possible limitations, user feedbacks and future works are discussed in chapter 5. Finally, we draw the general conclusion to end this thesis in chapter 6.

CHAPTER 2. ASYMMETRICAL AUGMENTED REALITY

2.1 Traditional Virtual Reality

Specifically, the term virtual reality stands for using head-mounted displays (HMDs) to fully dive into a virtual environment rendered by computers, consoles or smart-phones. Compared with augmented reality, which overlays the rendered digital objects onto the real-world scenes, traditional virtual reality provides a highly immersive virtual environment rather than mixing the real and virtual environments [16].

Fig. 2.1. Different applications of virtual reality. Left: rehabilitation by simulating the process of walking [20], middle: VR rhythms games [21], and right: learning molecule structures [19].

There are affordable options for consumers who want to join in the rising virtual reality world without substantial expenses, i.e. using hand-held devices for them such as mobile phones (e.g. Google Cardboard). There are also standalone virtual reality devices which are equipped with dedicated screens and adjustable lens for more immersive virtual reality experiences (e.g. Oculus Rift and HTC Vive). With the rapid development of computing power of graphics and CPUs, virtual reality experience are rapidly improving and gaining more attention more than ever (Fig. 2.2, market increase over recent years). With the technical progress in body tracking, users are even allowed to navigate through the virtual reality physically and have a higher spatial understanding of the current virtual environments without extra outside-in sensors [23].

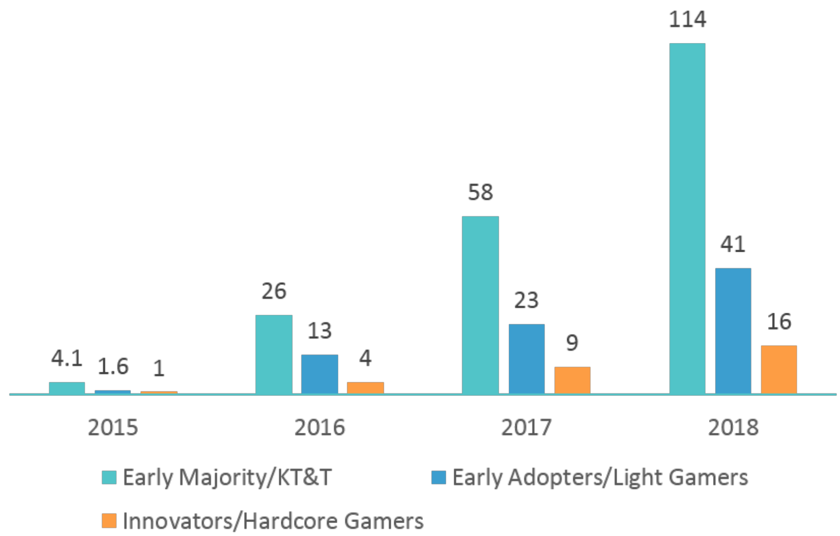

Fig. 2.2. Number of estimated global virtual reality users (in millions) over recent years. [22]

Since a high level of engagement can improve the enjoyment of multiple users in real-world scenarios [11], a multi-user virtual reality experience is proposed [5] [24] to improve current virtual reality experience. Since collaborative virtual environment firstly introduced in 1998 [25], various systems and approaches that focus on improving the multi-user experience are proposed [5]. Carlsson et al. proposed a multi-user virtual environment that enable users to interact with each other [26]. A collaborative virtual reality system that designed with a theme of archaeological excavations is proposed by Benko et al. Users use hand-held devices to inspect the virtual environment and interact with others. Sra et al. proposed a shared virtual reality experience for remotely located users [27]. By matching and mapping the room-scale virtual environment from one user to the other, the system can enable social virtual experiences between multiple users. Cinema-like virtual environments also provide social experiences for multiple virtual reality users [28].

2.2 Asymmetric Virtual Reality

Despite virtual reality has great advances over recent years, most of applications and researches are mainly focusing on the HMD user by enhancing the immersive experience, improving the tracking precision, etc. The expensive price and limited applications prevent HMD users to interact with people that are outside their immersive environment. Compared to conventional symmetrical virtual reality experience that lets multiple users work with or play against each other in the same configuration [5], there are a set of unique problems lie in co-located symmetrical virtual reality. Other than the expensive costs of virtual reality equipment, confined area of room-scale environment [8] and potential collision [9] between users are both non-trivial potential factors that can affect multi-user virtual reality experience. Some researches provide the asymmetric virtual reality system [10] that lets one HMD user dive into the immersive environment while leaving others operate or observe with a non-HMD setup, for instance, traditional desktop environments.

Oliveira et al. [29] presented an asymmetric virtual reality system, which let the HMD user in the virtual environment communicate with another user in traditional desktop environment. Chan et al. [30] presented FrontFace that utilize a special HMD with a front-facing screen to visualize virtual environment to non-HMD users for communication and other form of interactions.

Using a projector to visualize the virtual environment for the non-HMD user is another popular solution. Gugenheimer et al. designed a collaborative virtual reality system called

ShareVR [10] that projects the virtual objects to the corresponding displacement in the physical environment for non-HMD users to perceive and interact, as shown in Fig 2.3. MagicTorch [31] proposed by Li et al. shares a similar design that projects virtual environment onto physical environment for non-HMD users to observe. Kulik et al. introduced a co-located virtual reality system that uses 6 projectors to provide respective information for multiple virtual reality users [32]. A primary found of their work is that users show more excitement and enthusiasm when exploring the virtual environment as a group. Therefore, we believe that the potential of enhanced enjoyment for multi-user augmented environment is worth studying as well.

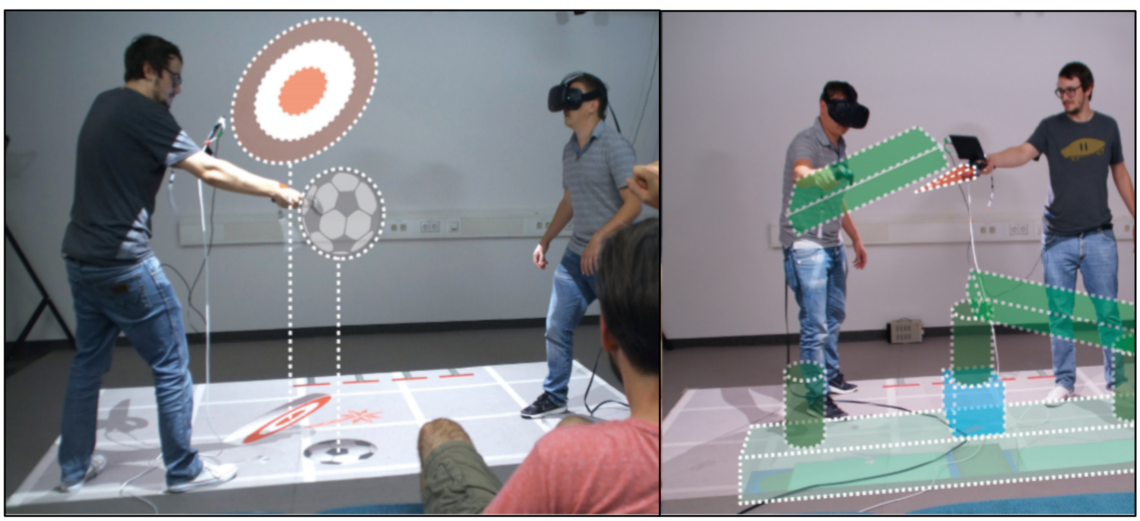

Fig. 2.3. An example of asymmetrical virtual reality [10]. The HMD user and non-HMD user are interacting with the virtual ball and blocks simultaneously in a room-scale virtual environment.

2.3 Traditional Augmented Reality

Fig. 2.4. Augmenting the real-world environment with a virtual sofa.

On the other hand, augmented reality is a technology that combines virtual information with the real-world ones. It uses a variety of techniques such as 3D modeling and reconstruction, real-time tracking and registration. After the virtual information simulation of text, image, 3D model, music, video, etc. is applied to the real world, the two kinds of information complement each other, thus realizing the "enhancement" of the real world [16]. An example is shown in Fig. 2.4.

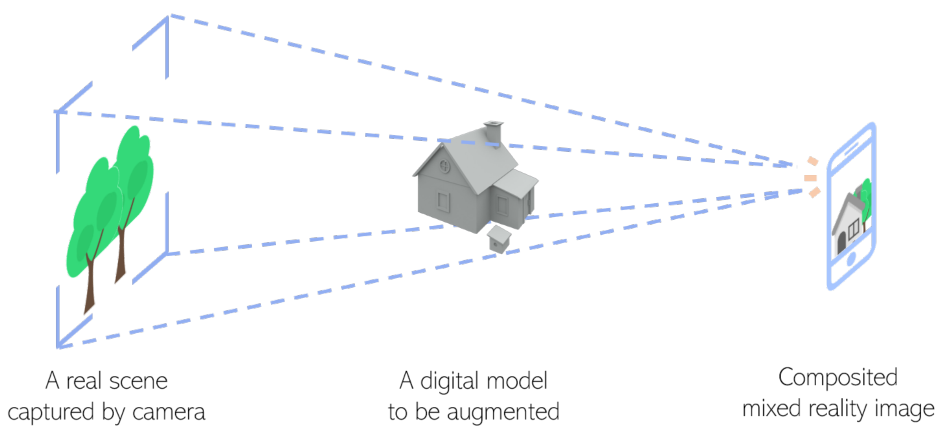

Fig. 2.5. The process of augmenting the real-world environment with a virtual object.

To effectively apply the virtual information content to the real world, and can be perceived by users in the process, Fig. 2.5 describes this process of augmenting the virtual objects onto the real scene captured by the camera. After the real environment and the virtual objects overlap, they can exist simultaneously in the same picture and space.

Augmented reality technology can not only effectively reflect the real-world content, but also promote the display of virtual information content, which complements and superimposes each other. With the current limitations in realistic rendering, utilizing the real-world lighting and textures can further improve the quality of the composition.

There are also various augmented reality applications designed to aid tasks and enhance user experience. From rehabilitation [33], entertainment [34], engineering [35], education [36] to medical [37], using the technology of augmented reality can enhance the understanding of the users to improve their performance.

2.4 Asymmetrical Augmented Reality

Like asymmetric virtual reality, allowing multiple users to interact in the augmented environment with different setups and different overlaid information can solve current problems and limitations as well. For co-located augmented reality technology, most existing research focus on synchronizing the mapping between the real environment and augmented environments of multiple users. With shared feature mapping and SLAM algorithms, it is possible for symmetric augmented reality users to interact with same virtual objects at the same time [38]. However, the latency between each operation and false localization are inevitable in current implementations. To solve these problems and study the experience of the users, we propose an asymmetric augmented reality system that allows multiple users to interact with each other in a co-located augmented environment with different setups. More details of software and hardware implementation will be given in the following chapter.

CHAPTER 3. DESIGN AND IMPLEMENTATION

3.1 Software Concept

To verify our hypothesis, software-wise, we implemented a room-scale augmented environment to investigate the user's experience, as shown in Fig. 3.1.

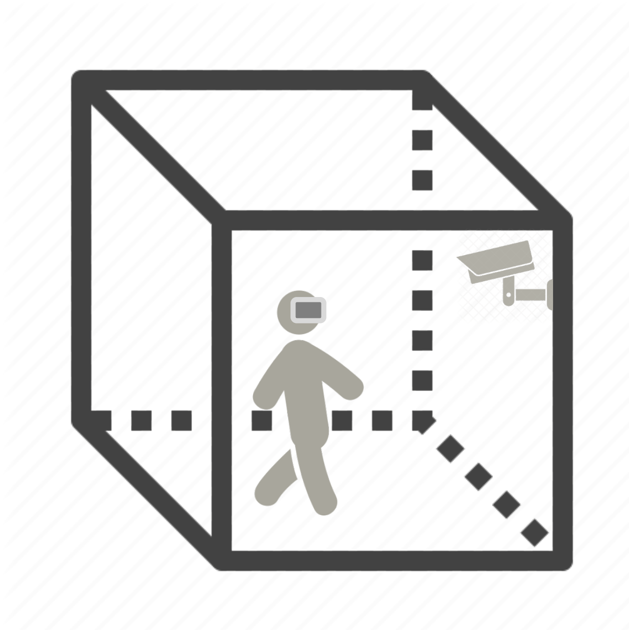

Fig. 3.1. The room-scale augmented environment in our experiments.

To realize perspectives from both the explorer and the instructor, we choose a rectangular room as our experimental space. With surveillance-like cameras mounted at the corners, instructors are able to switch their view to observe the room in real-time from the video stream. To augment the real environment, we manually modeled the real environment beforehand, and synchronized the augmented and the real environment during experiments (see Fig. 3.2).

With accurate spatial correspondence, we overlay digital contents onto the real environment to realize augmented third-person-perspective instructor view. With the room model available, we also made a traditional desktop version with the virtual environment to establish the baseline (see Fig. 3.3). Users must navigate from the perspective of a virtual character to finish the task.

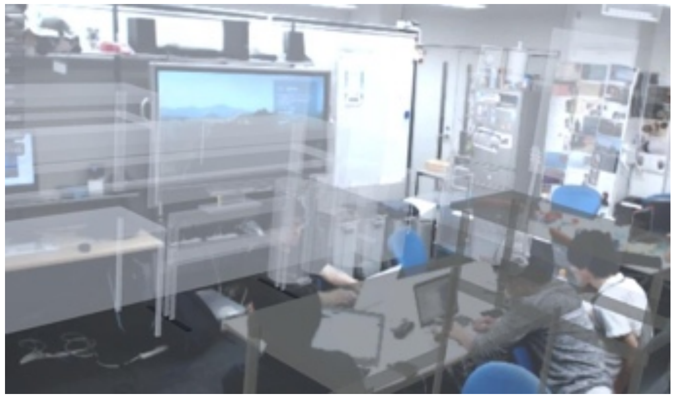

Fig. 3.2. Modeled room-scale augmented environment.

To synthesize vivid first-person-perspective augmented reality experience as well, we mounted a camera to the HMD and adopted Vuforia framework to receive real-time color information. With a video-see-through system, we overlay the digital contents onto the first-person perspective as most augmented reality applications do.

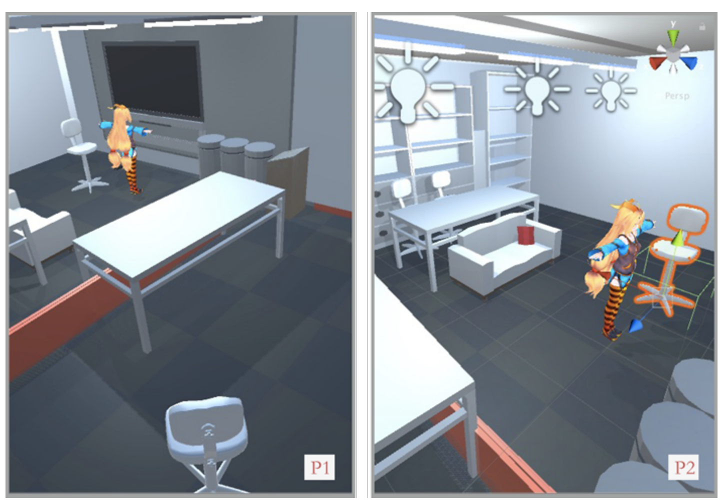

Fig. 3.3. A traditional desktop version with the modeled virtual environment.

3.2 Hardware Implementation

Hardware-wise, to satisfy the requirement of the software design, the experiment environment and the apparatus are shown in Fig. 3.4. The camera is mounted in the corner of the room. The video-see-through augmented reality is realized by mounting an overhead webcam to the HTC Vive HMD. During the experiment, users can use Vive's default motion controllers to interact with the augmented environment.

Fig. 3.4. An asymmetric augmented reality system that allow HMD and non-HMD users interact with each other.

CHAPTER 4. EXPERIMENTS AND RESULTS

4.1 Experiment Design

4.1.1 Overview of the Experiment

Based on the software and hardware implementation, we overview our experiment design in this section. To establish the baseline, we assigned the users with the role of *explorer*, to defuse a virtual bomb hidden in the virtual environment, with a traditional desktop environment and a video-see-through augmented reality configuration. To study the asymmetric augmented reality, we then assign different roles to a group of two users to take part in the asymmetric augmented reality experiments. One user is still assigned to defuse a virtual bomb, called the *explorer*. Meanwhile, the other user will stay in a traditional desktop environment to receive additional information and inspect the explorer from a third-person perspective, called the *instructor*. The group must finish the task within a certain time limit by communicating with each other.

4.1.2 Establishing the Baseline

To study the influence of asymmetric augmented reality, it is important to design control experiments to establish a baseline. Instead of interactively defusing the bomb, we add two more control experiments. As the first control group (A), users need to wear the HMD and navigate through the augmented environment by himself to reach the bomb, and then defuse the bomb according to the prompt displayed on the screen. For the second control group (B), users need to navigate through the augmented environment with a traditional desktop setup. By controlling a virtual body with keyboards, they need to reach the bomb and defuse it according to the hints given on the screen. After each trial is finished, users' experience of enjoyment and satisfaction are recorded to establish the baseline.

4.1.3 Asymmetric Augmented Reality Experiments

After the baseline is established, we divided the users into two groups to finish different tasks during experiments. The users that take part in the experiments are divided into either group (C), to disarm the bomb as an explorer or (D), instructor, to give instructions to the explorer to disarm the bomb. Users will switch the identity between explorer and instructor after each trial is finished. Before the experiment, all participants take instructions of the experiments. More specifically, the common goal for the explorer and the instructor is to disarm the bomb within the specified time limit (3 minutes).

For the explorer, he must navigate and interact with the augmented environment from the first-person perspective. The explorer is equipped with the HMD and a pair of motion controllers.

For the instructor, he observes the scene in real-time from a traditional desktop configuration. By observing the explorer from the perspective of fixed surveillance camera, in other words, third-person perspective, he is required to communicate additional tips and information displayed on the screen with the explorer to guide him to the bomb.

We limited the length of each trial to 3 minutes. Groups that enter the correct passwords within three minutes at the designated location will succeed, while either exceeding the time limit or entering the wrong password will fail the trial.

After each trial, we record the time, results, and the respective user's experience by asking them to fill in the Game Experience Questionnaire (GEQ) [39] afterwards. The survey includes users' previous augmented reality/virtual reality experience, social experience and the overall satisfaction. We adopted the five-point Likert scale (1 - disagree/bad, 5 - agree/good) to develop ten rating queries. We asked the participants to complete the questionnaire right after the experiment. We observed that each experiment cost about 10 minutes averagely and the questioning and interview cost roughly 15 minutes for each participant.

4.2 Experiment Details

4.2.1 Experiment 1. Traditional Monitor and Controller

Since most of the participants have gaming experience, it is not hard for them to control the virtual character to navigate in the virtual environment and finish the tasks. However, because that the task is a relatively simple one, during the interview, a majority of the participants gave the feedback of easily getting bored during the traditional desktop experiment. Nevertheless, the efficiency and enjoyment are still good due to their acquaintance to the desktop environment.

Table 4.1. Result of rating questions for the traditional desktop implementation.

	Average Points	Standard Deviation
Traditional Desktop (Efficiency)	3.45	1.04
Traditional Desktop (Satisfaction)	3.18	1.07
Traditional Desktop (Enjoyment)	3.67	1.04

4.2.2 *Experiment 2. Traditional Video-See-Through Augmented Reality*

Surprisingly, we receive a worse feedback of enjoyment, efficiency and satisfaction with a smaller deviation compared to the desktop implementation. According to the interview after the trial, some users struggle with the video-see-through configuration due to the latency of streaming the video footage. As a future topic, we believe that using an optical-see-through device can alleviate such problem.

Table 4.2. Result of rating questions for the video-see-through AR implementation.

	Average Points	Standard Deviation
Single AR (Efficiency)	3.09	0.7
Single AR (Satisfaction)	3	0.77
Single AR (Enjoyment)	3.546666667	0.85

4.2.3 *Experiment 3. Asymmetric Augmented Reality*

We conclude the user experience respectively for the explorer and the instructor in the asymmetric augmented reality experiments. The results are shown in table 4.3 and table 4.4. As we can see from the tables, explorers experience a higher enjoyment compared to the instructor with a traditional desktop setup. Their satisfaction is also higher for them being the one to actually finish the task. On the other hand, the instructor shows a higher social experience for guiding the other user to the goal. However, constrained by a desktop setup inevitably reduced their enjoyment. Surprisingly, with collaborations between two users, asymmetric augmented reality users can achieve a higher efficiency than acquainted desktop implementation. We believe this result is useful and can provide insight for further investigation.

Table 4.3. Result of rating questions for the explorer in asymmetric augmented reality experiments.

	Average Points	Standard Deviation
Explorer (Efficiency)	3.64	1.03
Explorer (Satisfaction)	3.54	0.69
Explorer (Enjoyment)	4.06	0.72
Explorer (Social experience)	3.72	0.71

Table 4.4. Result of rating questions for the instructor in asymmetric augmented reality experiments.

	Average Points	Standard Deviation
Instructor (Efficiency)	3.64	0.92
Instructor (Satisfaction)	3.18	1.08
Instructor (Enjoyment)	3.42	1.01
Instructor (Social experience)	3.77	0.97

4.3 User Study and Results

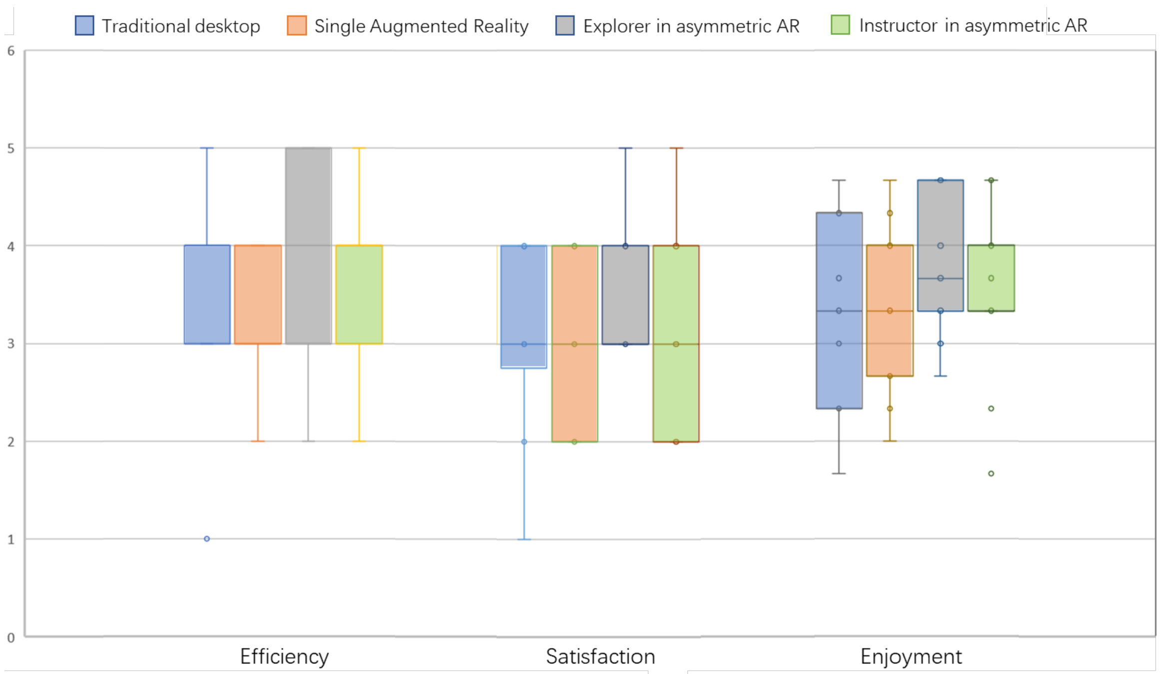

Fig. 4.1. The user experience from three aspects, efficiency, satisfaction and enjoyment according to the feedback.

The experiment was held in a laboratory in the university that resemble a normal room environment, which contains desks and chairs. The participants are randomly ordered and counterbalanced to make the comparison fair. Users between each trial will rest for 10 minutes to answer a brief interview and give qualitative feedback.

From the result of the preliminary survey, we know 91.7% of the participants have VR experience before the experiment. Even the user study suffers from a potential problem of biased demographics, we believe that it can still verify our design and concept, because that the biased user group can well represent the typical users of innovative technologies. Even users of traditional environments including desktop and conventional video-see-through augmented environment get bored easier, the first group still managed to finish the task with higher efficiency. From the answers to the questionnaire and interviews with the participants, we found that the experience of video-see-through augmented reality can be easily improved by decreasing the latency of the video streaming. As we mentioned above, an optical-see-through device such as Microsoft Hololens can serve the purpose.

CHAPTER 5. DISCUSSION

5.1 Additional Findings

With interactions between the explorer and the instructor, the verbal hints and social connection as a group significantly promoted the efficiency of the participants. Asymmetric augmented reality users generally achieve a better performance compared to single user scenarios. Even the problem of video-see-through augmented reality's latency persists, the negative influence is partially canceled by the guidance from the instructor. Furthermore, with a more enjoyable experience, this potential problem is sometimes overlooked by the explorer according to the feedback of the participants. On the other hand, since the instructor cannot move freely as the explorer do, a lower enjoyment is expected. Compared to the single user experience, the incapability to control a virtual character to navigate around the scene further reduced the enjoyment of the instructor.

In addition, our current design only allows the interaction between two users at the same time. More thorough study must be considered to better understand the social experience inside larger asymmetric user groups.

5.2 Future Work

As a potential solution to the decreased enjoyment of the instructor, designing a more enjoyable experience for the instructor is necessary.

Besides the traditional desktop environment and conventional augmented environment, the users reported that it would be much meaningful to compare the asymmetric augmented reality experience to the asymmetric virtual reality experience, which let one user to guide the other user navigate through an immersive virtual environment instead of real world overlapped with digital contents. Since the aim of this project is to study the influence of the asymmetric augmented reality system on enjoyment, satisfaction and social experience between augmented reality and non-augmented reality users compared to baseline conditions, we believe that the significance of different environments may rely more on the experimental design. In the future, designing different tasks to compare the experience in asymmetric augmented reality and virtual reality is an interesting topic.

In the future, we envision more diverse software design and implementations to verify the improvement of asymmetric augmented reality under different conditions. At the same time, ensuring a latency-free experience with optical-see-through devices can further improve the experience as well.

CHAPTER 6. CONCLUSION

In this work, we present a novel software design of asymmetric augmented reality experience that can improve the enjoyment and involvement compared to traditional environments. With a appropriate hardware setup, our proof-of-concept implementation and the user study successfully verified that effectiveness of asymmetric augmented reality experience when compared to traditional environments including desktop and conventional augmented environment. Other than the significantly improved enjoyment and satisfaction to finish certain tasks, we also verify a positive feedback of the social experience with other asymmetric augmented reality users.

With the study of the user experience, we concluded the limitations and challenges of our asymmetric augmented reality system, and give insights for further research of co-located asymmetric augmented reality experience based on the feedback of early adopters of asymmetric augmented reality. The design can be further expanded to other fields and services such as augmented e-commerce, medical, education and navigation.

APPENDIX A. USER STUDY QUESTIONNAIRE

In this appendix, we elaborate the details of our questionnaire, interactive experience of asymmetrical augmented reality, for the user study.

6.1 Common Section

1. What is your gender? *

a. Male b. Female c. Other

2. Have you ever tried Virtual Reality (VR)/Augmented Reality (AR) before? *

a. Yes b. No

3. Have you ever tried interactive virtual reality/augmented reality before? (E.g. multiplayer VR games, etc.) *

a. Yes b. No

6.2 Desktop Experiment Section

(Rate from 1 to 5, 1 is not at all and 5 is extremely, same for the following questions):

1. While playing with a traditional gaming configuration (desktop), I was fast at reaching the game's targets.
2. While playing with a traditional gaming configuration (desktop), I was good at it.
3. While playing with a traditional gaming configuration (desktop), I found it enjoyable.

4. While playing with a traditional gaming configuration (desktop), I felt bored.
5. While playing with a traditional gaming configuration (desktop), I thought it was fun.

6.3 Video-See-Through Augmented Reality (VST-AR) Experiment Section

1. While playing with a VST-AR setup, I was fast at reaching the game's targets.
2. While playing with a VST-AR setup, I was good at it.
3. While playing with a VST-AR setup, I found it enjoyable.
4. While playing with a VST-AR setup, I felt bored.
5. While playing with a VST-AR setup, I thought it was fun.

6.4 Interactive Experiment – Explorer Section

1. While playing as the explorer, our team was fast at reaching the game's targets.
2. While playing as the explorer, I felt bored.
3. While playing as the explorer, I felt connected to the other(s).
4. While playing as the explorer, I found it enjoyable to be with the other(s).
5. While playing as the explorer, my actions depended on the other(s) actions.
6. While playing as the explorer, I influenced the mood of the other(s).
7. While playing as the explorer, I thought it was fun.

6.5 Interactive Experiment – Instructor Section

1. While playing as the instructor, our team was fast at reaching the game's targets.
2. While playing as the instructor, I felt bored.
3. While playing as the instructor, I felt connected to the other(s).

4. While playing as the instructor, I found it enjoyable to be with the other(s).
5. While playing as the instructor, my actions depended on the other(s) actions.
6. While playing as the instructor, I influenced the mood of the other(s).
7. While playing as the instructor, I thought it was fun.

REFERENCES

[1] Bates, Joseph. "Virtual reality, art, and entertainment." Presence: Teleoperators & Virtual Environments 1.1 (1992): 133-138.

[2] Psotka, Joseph. "Immersive training systems: Virtual reality and education and training." Instructional science 23.5-6 (1995): 405-431.

[3] Marescaux, Jacques, et al. "Virtual reality applied to hepatic surgery simulation: the next revolution." Annals of surgery 228.5 (1998): 627.

[4] Parsons, Sarah, and Peter Mitchell. "The potential of virtual reality in social skills training for people with autistic spectrum disorders." Journal of intellectual disability research 46.5 (2002): 430-443.

[5] Jackson, Randolph L., and Eileen Fagan. "Collaboration and learning within immersive virtual reality." Proceedings of the third international conference on Collaborative virtual environments. ACM, 2000.

[6] Bowman, Doug A., and Ryan P. McMahan. "Virtual reality: how much immersion is enough?." Computer 40.7 (2007): 36-43.

[7] Gajadhar, Brian, Yvonne De Kort, and Wijnand IJsselsteijn. "Influence of social setting on player experience of digital games." CHI'08 extended abstracts on Human factors in computing systems. ACM, 2008.

[8] Rizzo, Albert A., et al. "The virtual classroom: a virtual reality environment for the assessment and rehabilitation of attention deficits." CyberPsychology & Behavior 3.3 (2000): 483-499.

[9] Scavarelli, Anthony, and Robert J. Teather. "Vr collide! comparing collision-avoidance methods between co-located virtual reality users." Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems. ACM, 2017.

[10] Gugenheimer, Jan, et al. "Sharevr: Enabling co-located experiences for virtual reality between hmd and non-hmd users." Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems. ACM, 2017.

[11] Gajadhar, Brian, Yvonne De Kort, and Wijnand IJsselsteijn. "Influence of social setting on player experience of digital games." CHI'08 extended abstracts on Human factors in computing systems. ACM, 2008.

[12] Stafford, Aaron, Wayne Piekarski, and Bruce H. Thomas. "Implementation of god-like interaction techniques for supporting collaboration between outdoor AR and indoor tabletop users." 2006 IEEE/ACM International Symposium on Mixed and Augmented Reality. IEEE, 2006.

[13] Dedual, Nicolas J., Ohan Oda, and Steven K. Feiner. "Creating hybrid user interfaces with a 2D multi-touch tabletop and a 3D see-through head-worn display." 2011 10th IEEE International Symposium on Mixed and Augmented Reality. IEEE, 2011.

[14] Holm, Roland, et al. "A combined immersive and desktop authoring tool for virtual environments." Proceedings IEEE Virtual Reality 2002. IEEE, 2002.

[15] Ibayashi, Hikaru, et al. "Dollhouse vr: a multi-view, multi-user collaborative design workspace with vr technology." SIGGRAPH Asia 2015 Emerging Technologies. ACM, 2015.

[16] Azuma, Ronald, et al. "Recent advances in augmented reality." IEEE computer graphics and applications 21.6 (2001): 34-47.

[17] Kato, Hirokazu, and Mark Billinghurst. "Marker tracking and hmd calibration for a video-based augmented reality conferencing system." Proceedings 2nd IEEE and ACM International Workshop on Augmented Reality (IWAR'99). IEEE, 1999.

[18] Piumsomboon, Thammathip, et al. "CoVAR: a collaborative virtual and augmented reality system for remote collaboration." SIGGRAPH Asia 2017 Emerging Technologies. ACM, 2017.

[19] Balo, Aidin R., Merry Wang, and Oliver P. Ernst. "Accessible virtual reality of biomolecular structural models using the Autodesk Molecule Viewer." Nature methods 14.12 (2017): 1122.

[20] Howard, Matt C. "A meta-analysis and systematic literature review of virtual reality rehabilitation programs." Computers in Human Behavior 70 (2017): 317-327.

[21] Georgiou, Orestis, et al. "Touchless haptic feedback for VR rhythm games." 2018 IEEE Conference on Virtual Reality and 3D User Interfaces (VR). IEEE, 2018.

[22] (2019, May. 10) Virtual Reality (VR) market - growth, trends, and forecast (2019 - 2024), Retrieved from https://www.mordorintelligence.com/industry-reports/virtual-reality-market.

[23] Hilfert, Thomas, and Markus König. "Low-cost virtual reality environment for engineering and construction." Visualization in Engineering 4.1 (2016): 2.

[24] Mütterlein, Joschka, and Thomas Hess. "Immersion, presence, interactivity: towards a joint understanding of factors influencing virtual reality acceptance and use." (2017).

[25] Elizabeth F Churchill and Dave Snowdon. 1998. Collaborative virtual environments: an introductory review of issues and systems. Virtual Reality 3, 1 (1998), 3–15.

[26] Christer Carlsson and Olof Hagsand. 1993. DIVE: A multi-user virtual reality system. In Virtual Reality Annual International Symposium, 1993., 1993 IEEE. IEEE, 394–400.

[27] Sra, Misha, Aske Mottelson, and Pattie Maes. "Your place and mine: Designing a shared VR experience for remotely located users." Proceedings of the 2018 Designing Interactive Systems Conference. ACM, 2018.

[28] Rothe, Sylvia, et al. "Social Viewing in Cinematic Virtual Reality: Challenges and Opportunities." International Conference on Interactive Digital Storytelling. Springer, Cham, 2018.

[29] Jauvane C Oliveira, Xiaojun Shen, and Nicolas D Georganas. 2000. Collaborative virtual environment for industrial training and e-commerce. IEEE VRTS 288 (2000).

[30] Chan, Liwei, and Kouta Minamizawa. "FrontFace: facilitating communication between HMD users and outsiders using front-facing-screen HMDs." Proceedings of the 19th International Conference on Human-Computer Interaction with Mobile Devices and Services. ACM, 2017.

[31] Li, Jiabao, Honghao Deng, and Panagiotis Michalatos. "MagicTorch: A Context-aware Projection System for Asymmetrical VR Games." Extended Abstracts Publication of the Annual Symposium on Computer-Human Interaction in Play. ACM, 2017.

[32] Kulik, Alexander, et al. "C1x6: a stereoscopic six-user display for co-located collaboration in shared virtual environments." ACM Transactions on Graphics (TOG). Vol. 30. No. 6. ACM, 2011.

[33] Burke, James William, et al. "Augmented reality games for upper-limb stroke rehabilitation." 2010 Second International Conference on Games and Virtual Worlds for Serious Applications. IEEE, 2010.

[34] Piekarski, Wayne, and Bruce Thomas. "ARQuake: the outdoor augmented reality gaming system." Communications of the ACM 45.1 (2002): 36-38.

[35] Chi, Hung-Lin, Shih-Chung Kang, and Xiangyu Wang. "Research trends and opportunities of augmented reality applications in architecture, engineering, and construction." Automation in construction 33 (2013): 116-122.

[36] Liarokapis, Fotis, et al. "Web3D and augmented reality to support engineering education." World transactions on engineering and technology education 3.1 (2004): 11-14.

[37] Birkfellner, Wolfgang, et al. "A head-mounted operating binocular for augmented reality visualization in medicine-design and initial evaluation." IEEE Transactions on Medical Imaging 21.8 (2002): 991-997.

[38] Gauglitz, Steffen, et al. "In touch with the remote world: Remote collaboration with augmented reality drawings and virtual navigation." Proceedings of the 20th ACM Symposium on Virtual Reality Software and Technology. ACM, 2014.

[39] Brockmyer, Jeanne H., et al. "The development of the Game Engagement Questionnaire: A measure of engagement in video game-playing." Journal of Experimental Social Psychology 45.4 (2009): 624-634.