Title	Research on the reduction of VR motion sickness based on dynamical changes the blur filter in peripheral vision
Author(s)	王, 麒森
Citation	
Issue Date	2020-03
Type	Thesis or Dissertation
Text version	author
URL	http://hdl.handle.net/10119/16331
Rights	
Description	Supervisor: 藤波 努, 先端科学技術研究科, 修士(知識科学)

Master’s Thesis

Research on the reduction of VR motion sickness based on dynamical changes the blur filter in peripheral vision

QISEN WANG

Supervisor TSUTOMU FUJINAMI

Graduate School of Advanced Science and Technology
Japan Advanced Institute of Science and Technology
(Knowledge Science)

03.2020

Abstract

Virtual reality (VR) has become more and more as an approach for media presentation or gameplay with the development of technology. From a technical perspective that emphasizing the leading role of the user in a virtual environment, VR systems show the following three basic characteristics: immersion, interaction, and conception. However, users motion sickness is a serious problem affecting user experience during experiencing VR environments, especially with a head-mounted display (HMD), which due to the conflict between the user's real actions and their visual actions that may lead to unnatural vision-vestibular sensory mismatch causing side effects such as nausea, oculomotor, disorientation, visual fatigue (eye fatigue).

Such a situation demanding the computing performance very much if we consider only by hardware ways, say, reducing this conflict with a higher refresh rate and resolution. On the software way, alternatively, we can use the field of view (FoV) restriction to reduce the impact of motion sickness, previous research has shown that decreasing (FoV) tends to decrease VR motion sickness. However, the user's vision will be affected due to the VR presenting contents are lost.

Here, I demonstrate an innovative approach that changes the blur filter dynamically in peripheral vision for visual restriction. Future, a user study will be implemented to evaluate the impact of the blur effect in reducing motion sickness. The test environment is crate by Unity3D. 19 participants joined the present study, who use Oculus Quest with Oculus touch controller to operate in the VR environment. There are 10 waypoints in the current VR environment, in which participants are asked to complete the seek task. different visual effects are used for each task. The VR sickness questionnaire (VRSQ) was administered immediately after each task.

VRSQ is a self-reported questionnaire that can be used to quickly measure a degree of simulator sickness in a participant. Which includes fatigue, eyestrain, difficulty focusing, headache, and other questions. the participants evaluated VR motion sickness through the VRSQ using a 4-point Likert scale (0=not at all, 1=slightly, 2=moderately, and 3=very). The final VRSQ score can be obtained through a series of calculations. The results indicate that blur filters in peripheral vision are more effective than traditional methods in reducing motion sickness and have less impact on users.

Besides, when we need to use the high level of FoV limitations for reducing motion sickness, the user who does not want to lose more content better adapt to blur filters

in peripheral vision effects. In practice, this study is expected to be used to help developers design VR environments that reducing motion sickness more effectively.

Future work should explore using a diffident blur parameter. Further experimentation with different degrees of blur and restrict levels could make the effect of reducing motion sickness different. The emergence of more and more standalone head-mounted displays makes VR devices used in different ways, motion sickness in a free-moving state may differ from sitting. We will try to deploy our approach to more VR device and usage scenarios in the future, to find more effective ways to reduce motion sickness.

Contents

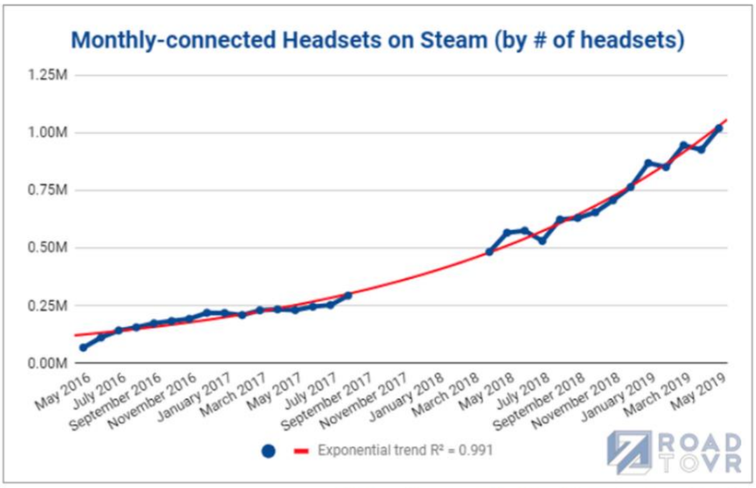
List of Figure

List of Tables

Chapter 1
Introduction

1.1 Background

With the increasing demand for information display platforms, virtual reality (VR) is becoming an increasingly popular solution. At the same time, the head-mounted displays (HMD) are becoming the mainstream of VR solutions. More and more people are using HMD to experience VR technology. However, there is a conflict between the user's actual actions and visual actions. The one problem that can seriously affect the user experience is VR sickness, which can cause symptoms similar to those of motion sickness. These symptoms include headaches, fatigue, pallor, stomach awareness, nausea, vomiting, sweating, and disorientation[1], these symptoms are explicitly listed in the “Health and Safety Warnings”[2] accompanying current VR platforms. This symptom will become more and more serious with the increase in playtime. VR motion sickness has gradually become the most serious problem affecting the virtual reality user experience.



Data gap from seven months of data misreported by Valve

Figure 1. Virtual reality devices have grown rapidly in recent years[3].

Usually, the HMD with high resolution, refresh rate, and low-latency tracking can effectively alleviate the problem of motion sickness, insofar as they can minimize the mismatch between a user's visual perception of the VR environment and the response of their vestibular system. However, under current conditions, the hardware requirements of most HMD cannot meet the needs of users. And HMD is getting smaller and more portable so that we should try to solve problems from the aspect of software design.

In earlier work, the researchers used dynamically field of view (FoV) restrictions to reduce motion sickness in the VR environment [4]. It has been claimed to reduce VR motion sickness to a certain extent, but it also affects the VR environment image information. We begin by noting the well known the human eye has the function of autofocus, which can blur out the image beyond the fixation point but will not affect the recognition of the image information[5].

So, we can try to use dynamically changes the blur filter in peripheral vision instead of traditional dynamically FoV restrictions. Could this increase a user's comfort in a VR environment and reduce motion sickness? Further, would it be a natural enough way for participants to be less easily aware of high FoV restrictions, yet could still feel comfortable while not experiencing a noticeably decreased sense of immersive?

Figure 2. A seated participant wearing the Oculus Quest during the VR environment exploration task.

To explore this possibility, we implemented a VR environment for users to explore and used different filters to limit their FoV in the process. Example views from which are shown in Figure 2. Our testbed uses the Oculus Quest stereoscopic HMD with the oculus touch player controller and is built by Unity3D with the oculus integration. The participants will explore the VR environment through touch controllers and HMD in various conditions we set. We performed a study with seated participants to determine how well our blur filter in peripheral vision intervention works.

1.2 Research purposes

Under current hardware conditions, we try to reduce motion sickness in the VR environment by dynamically FoV restrictions condition. at the same time, we also design the restrictions filter in peripheral vision in a sufficiently subtle way that users might not perceive. We propose a method similar to the human eye using a blur filter also use dynamic changes, meanwhile, we try to be using VRSQ based on SSQ (Simulator Sickness Questionnaire) to verify users' degree of motion sickness, which is more efficient for modern virtual reality head-mounted display. The research results could help developers to better design virtual reality content.

1.3 Organization of the dissertation

This thesis consists of 4 chapters, In the next chapters, I will explain in detail the virtual reality technology and the current level of hardware development and application scenarios. Based on the current virtual reality device, especially head-mounted displays, the results of previous research, and my improvement methods. Chapter 3 explains the details of the participants, the design of the VR environment task, and the progress of the experiment. According to the experimental results, data analysis, conclusions, and future work will be introduced in Chapter 4.

Chapter 2
Related Work

2.1 Virtual reality technology

The core of virtual reality is computer technology, which generates a digital environment similar to the real environment in terms of vision, hearing, and touch. In this respect the ultimate form of equipment is to replace the human senses with electronic technology. With the development of the times and science and technology, Researchers pay more and more attention to VR technology, VR technology has also made great progress, and gradually become a new field of science and technology.

Virtual reality systems have the following three basic characteristics: the three "I" (immersion-interaction-imagination)[6], which emphasize the dominant role of people in the virtual system. Many research directions are also based on the three "I", especially immersion, which is particularly important for the experience of virtual reality.

Figure 3. The Sensorama (left) was a machine that is one of the earliest known examples of immersive, multi-sensory (now known as multimodal) technology. which was introduced in 1962 by Morton Heilig[7]**, the picture on the right shows a modern virtual reality cinema**[8]**.**

According to the current situation, virtual reality technology is still difficult to generate a highly realistic virtual reality environment, the main reason is the technical limitations. These limitations come from computer processing power, image resolution, and communication bandwidth. However, Processor, image, and data communication technologies become more powerful as time has passed, and these limitations will eventually be overcome.

Most of the current virtual reality technologies are visual experiences, which are usually obtained through computer screens, special Giant screens or stereo display devices, but some simulation devices also include other sensory processing, such as sound effects from audio and headphones. In some advanced haptic systems, it also contains haptic information, also known as force feedback, and has widely used in medicine and gaming.

Figure 4. Doctors use virtual reality equipment to assist with the surgery[9]**.**

The best device to show the visual effects of virtual reality at this stage is the head-mounted display, which can give the user a complete visual immersion. With the stereo sound system and stereo tracking system, HMD is the best virtual reality device at this stage.

2.2 Head-Mounted Display

VR head-mounted display is a product combining various technologies such as simulation technology and computer graphics, human-machine interaction (HMI) technology, multimedia technology, sensing technology, network technology, etc. It is a brand-new means of human-computer interaction created by the help of computer graphics cards and the latest sensor technology.

The principle of a VR head-mounted display is similar to our eyes, usually, HMD consists of two screens, by display a different image to each eye, it can be used to show stereoscopic images. As early as 1849, David Brewster made a lenticular stereoscope, which allows people to see stereoscopic images from flat paintings. Until 1960, Morton Heilig invented the Telesphere-Mask. The basic construction of the Telesphere-Mask is very similar to a modern head-mounted display[7]. Although it did not have any motion tracking and interactive media, as a prototype of a head-mounted display in that era, it was very close to the current head-mounted display.

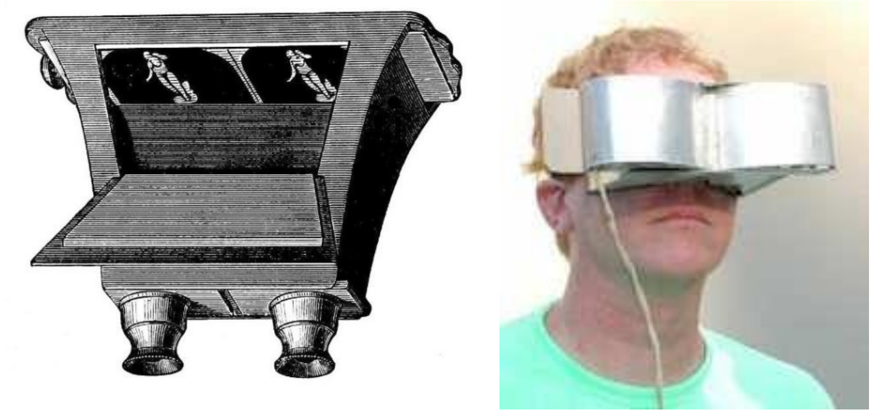


Figure 5. Left: lenticular stereoscope, made by David Brewster (1849)[10] **Right: Telesphere-Mask, made by Morton Heilig (1960)**[11]

In modern times, by virtual reality head-mounted display, we usually mean the Oculus series developed by Facebook, the Vive series developed by HTC, and the PSVR series developed by SONY. Most of them require connection to a high-performance computer, the image is rendered by a high-performance computer graphics card, which is then passed to the HMD device.

In recent years, there have also been many integrated standalone VR head-mounted displays, such as Oculus Quest, Pico VR Neo, and HTC Vive Focus, etc. Because users don't need high-performance computers, the standalone head-mounted display can be used in more free scenarios with better user experience.

The main functional parameters of the VR head-mounted display include resolution, refresh rate, field of view, weight, etc. Resolution represents the image rendering capability of the HMD, the higher the resolution, the more realistic the user experience. 60

pixels/° is usually referred to as eye limiting resolution[12][13], to achieve full immersion in virtual reality, the resolution of the head-mounted display needs to achieve a more than 8K (7680 × 4320) per eye[14]. To fully imitate the effect of the human eye requires a resolution of 9000 x 7200 or higher per eye[15]. This has high requirements for industrial production capacity and graphical computing and rendering capabilities. At this stage, the VR device cannot reach this level. Usually, 4K resolution is the limit[16].

Figure 6. The mainstream modern VR head-mounted display that requires a cable connection to a computer[17][18]**.**

As movies are usually filmed at a rate of 24 frames per second, the computer's liquid crystal display (LCD) normally refreshes at 60 Hz[19], at this level, humans are barely aware of the frames transitions. But in the virtual reality environment, most people experience mild discomfort unless the refresh is set to 72 Hz or higher. For the untrained eye, the 150-240 FPS is realistic enough[20]. This is still a high requirement for the quality of the display equipment and the rendering capability of the computer. The current device typically operates at around a minimum of 90 Hz.

Field of view, or field of vision. This is the range of what a user can see in the VR environment[21]. The range of the visual field in humans is around 180 degrees[22]. However, the FoV performance parameters of most HMD do not reach this level, Generally, a larger field of view leads to better immersion and better situational awareness. Consumer-grade HMD typically provides FoV of approximately 110°.

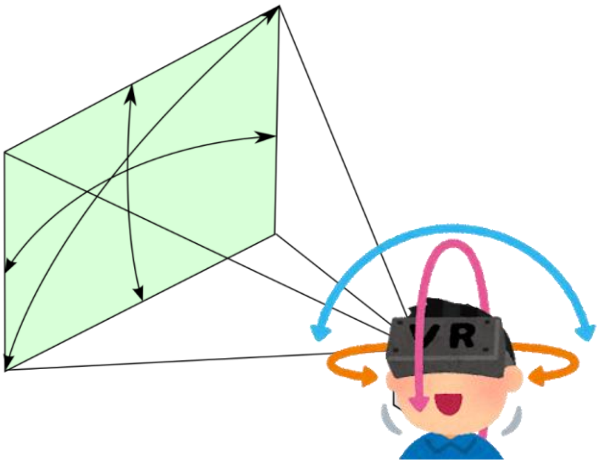


Figure 7. Field of view (FOV) refers to the range of views a user can observe in a VR environment.

In addition, some VR head-mounted displays are equipped with stereo headsets and a stereo tracking system that allows users to interact in a virtual display environment[23]. Generally, the VR controller is generally designed to a position with six degrees of freedom (6Dof)[24], Through this hardware, virtual reality headsets bring users a virtual reality experience that is closer to reality.

2.3 Simulation sickness & Questionnaire

However, due to the limitation of hardware capabilities, whether it is a head-mounted display device or a rendered computer performance, at this stage, the virtual reality experience cannot reach the level that human beings cannot perceive the difference. Because of this difference, users tend to experience a strong sense of discomfort. In simulator environments like virtual reality, we call this discomfort a motion sickness. The sensory conflict theory is perhaps the most accepted motion sickness theory and is that passive movement creates a mismatch between information relating to orientation and movement supplied by the visual and the vestibular systems, and it is this mismatch that induces feelings of nausea that is being shown through the HMD[25].

Since the invention of simulator devices, motion sickness has plagued more and more people with the development of devices. This research aims to reduce the user's motion sickness when using the head-mounted display to experience a virtual reality environment.

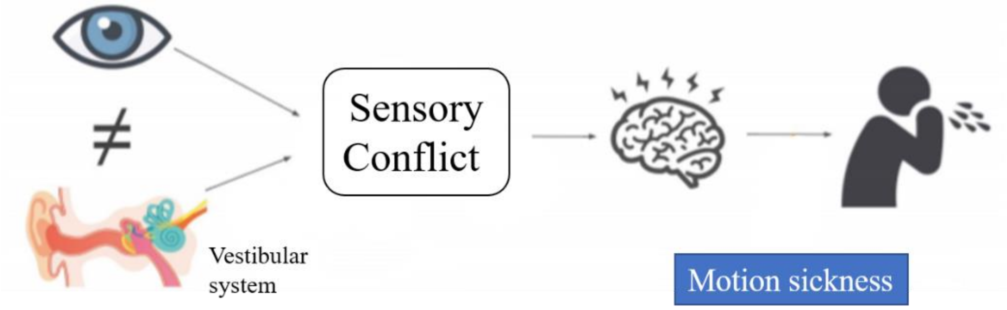


Figure 8. Sensory conflict causes motion sickness.

There are many reasons for motion sickness, Due to delays in the rendering of the HMD, When the user moves, the screen does not render the corresponding screen in time, The human body perceives this difference and produces a confusing signal, these signals accumulate over time and cause a variety of reactions. If the operation in virtual reality violates the user's common sense or the way of picture generation is not natural, the user experience in virtual reality is going to be terrible.

Figure 9. The user feels motion sickness when using VR devices[26][27]**.**

There are many ways to avoid motion sickness in a VR environment. Ajoy S Fernandes and Steven K. Feiner propose combating VR sickness through subtle dynamic field-of-view modification[4]. Based on their research, Helmut Buhler, Sebastian Misztal, and Jonas Schild also show some effects in reducing VR sickness by using circle and dot effect in peripheral vision[28]. Here, we show an approach that dynamically changes the blur filter in peripheral vision for visual restriction and designed a VR task to evaluate the impact of blur effect in reducing motion sickness.

In order to be able to verify our hypothesis, we used the Virtual Reality Sickness Questionnaire to measure the motion sickness in the VR environment[29]. The virtual reality sickness questionnaire as obtained from the Simulation Sickness Questionnaire (SSQ)[30], sickness is a complex and subjective feeling, in order to quantify this feeling, Lane, and Kennedy determined 16 symptoms of motion sickness as psychometrically sound indicators of simulator sickness. On this basis, Kim[29] et al. proposed the Virtual Reality Sickness Questionnaire, employing 9 symptoms of original SSQ to indicate Oculomotor and Disorientation constructs. The design of VRSQ is more suitable for the use of a head-mounted display. Finally, we will combine the calculation results of VRSQ with the subjective feedback of users to verify our conjecture.

2.4 FoV restriction

In previous studies, it was found that by dynamically limiting FoV can effectively reduce the user's motion sickness when using the virtual reality head-mounted display. First, they designed a pre-experiment, they ran with eight participants to find a suitable minimum FoV, participants were not told about the existence of the FoV restrictors[4].

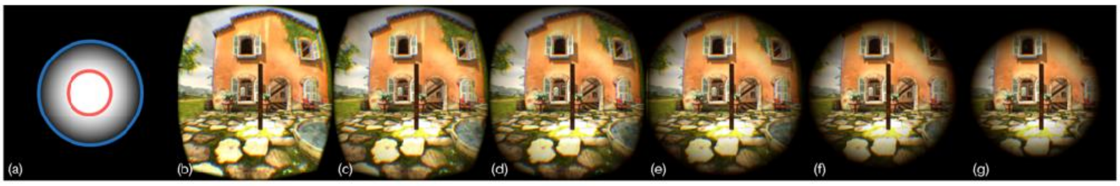


Figure 10. (a) Minimum FoV reserved value. (b)-(g) constantly changing FoV restriction[4]**.**

Through constant adjustment of FoV restriction. the participant was told to report if they noticed any visual effect. Through pre-experiment, the minimum retention value of the viewing angle under the FoV limit was determined. The minimum retention value is also retained in my experimental methods.

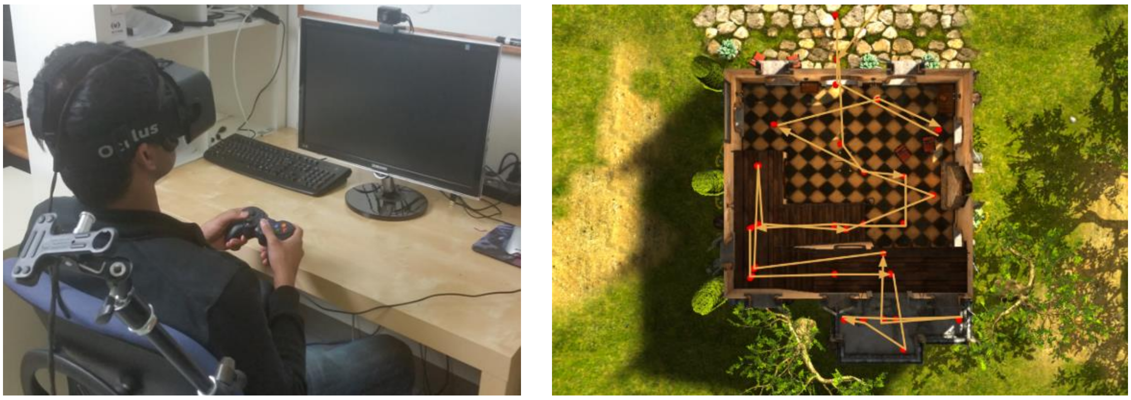
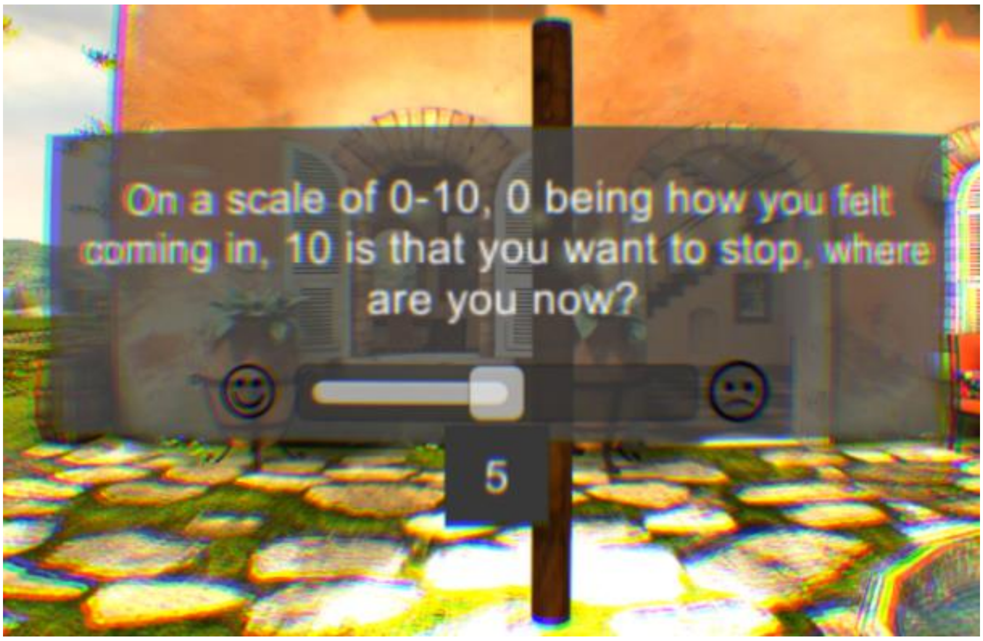


Figure 11. On the left is the experimental environment designed by Fernandes et al. On the right is a road map for participants to explore in virtual reality[4]**.**

Next, they conducted a series of experiments to reduce the user's motion sickness through changing FoV limits. In the process of participants' exploration, there was apparently a questionnaire when they arrive at each waypoint to collect their data.



On a scale of 0-10, 0 being how you felt coming in, 10 is that you want to stop, where are you now?

5

Figure 12. Questionnaire in virtual reality as the experiment progresses[4]**.**

Finally, they have experimentally demonstrated that the subtle changes in dynamic FoV of a seated participant have an effect on reducing motion sickness[4]. Based on their research, I proposed my experimental design to verify my experimental purpose.

Chapter 3
Experiment

3.1 Equipment

We use an Oculus Quest with Oculus Touch Controller which 6DoF position and orientation tracking, driven by Oculus Unity integration on an Intel Core i7-8750H CPU (2.2 GHz), 16G RAM, with NVIDIA GeForce RTX 2070 with Max-Q Design running Windows 10. 6DOF head tracking with Oculus Touch Controller allows the seated Participants to rotate and translate their head within the tracking volume of the Oculus Quest. As shown in Figure 2, the head-mounted display is connected to the computer through a USB type-c cable, driven by is Oculus Link[31].

Figure 13. Participants use Oculus Quest HMD (Left) and Oculus touch controller (Right) to move in the VR environment.

The weight of Oculus Quest is 571g, it uses two diamond Pentile OLED displays, and each with a resolution of 1440 × 1600 per eye and a refresh rate of 72 Hz. The CPU of Oculus Quest is Qualcomm Snapdragon 835 which has 4 Kryo 280 Gold (2.45 GHz) + 4 Kryo 280 Silver (1.9 GHz)[32][33]. With the Oculus touch controller, The Oculus Quest features the inside-out tracking system named Oculus Insight that relies on four wide-angle cameras located on each corner of the headset to track the headset spatially[34].

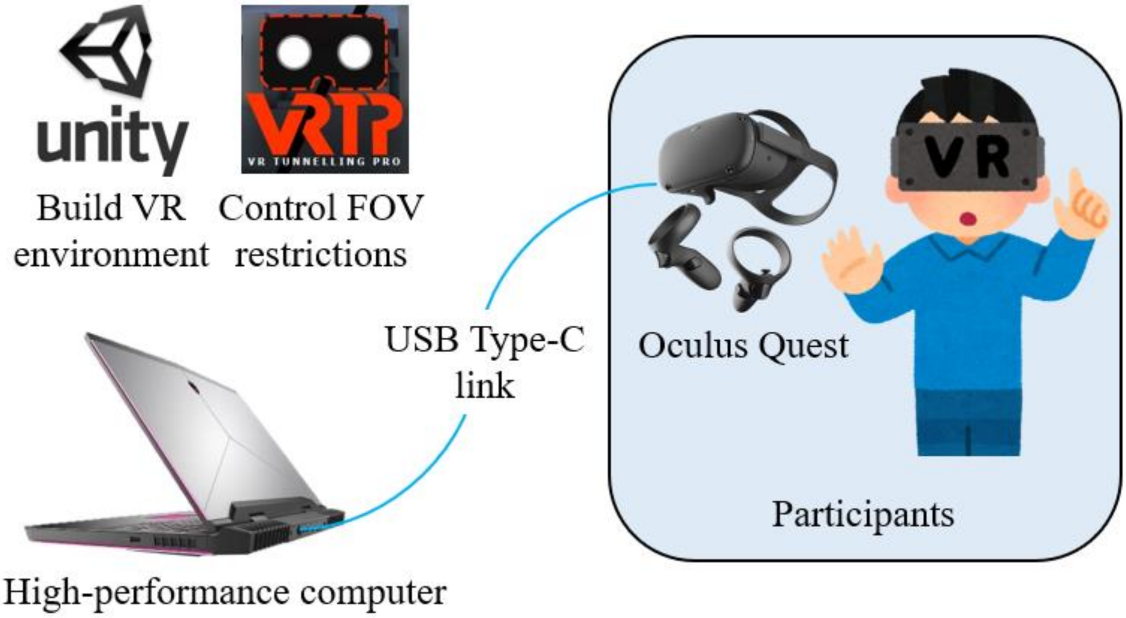


Figure 14. Experimental system composition diagram.

3.2 VR environment and task

To measure participants' feelings of motion sickness in virtual reality, we need to generate a virtual reality environment. VR environment is built by Unity 3D 2.14f1. HMD connects with a computer via Oculus Link[31][35]. Participants use Oculus touch to move around the virtual reality environment. Participants can also use their heads with HMD to observe the virtual reality environment.

Participants were asked to explore in a VR environment. They move at a constant speed through the oculus touch controller in the VR environment. A set of 10 sequential waypoints as flags, only one visible at a time, were added to guide the participant's movement in the VR environment. Each waypoint is a vertical post with a surrounding light effect. Beginning with the first waypoint, the waypoint would disappear as a participant approached of a waypoint, and the next would appear. At the same time, the top of the participant's view will also display an arrow indicating the direction, the direction of the arrow is the nearest waypoint. Participants' goal is to achieve 10 waypoints.

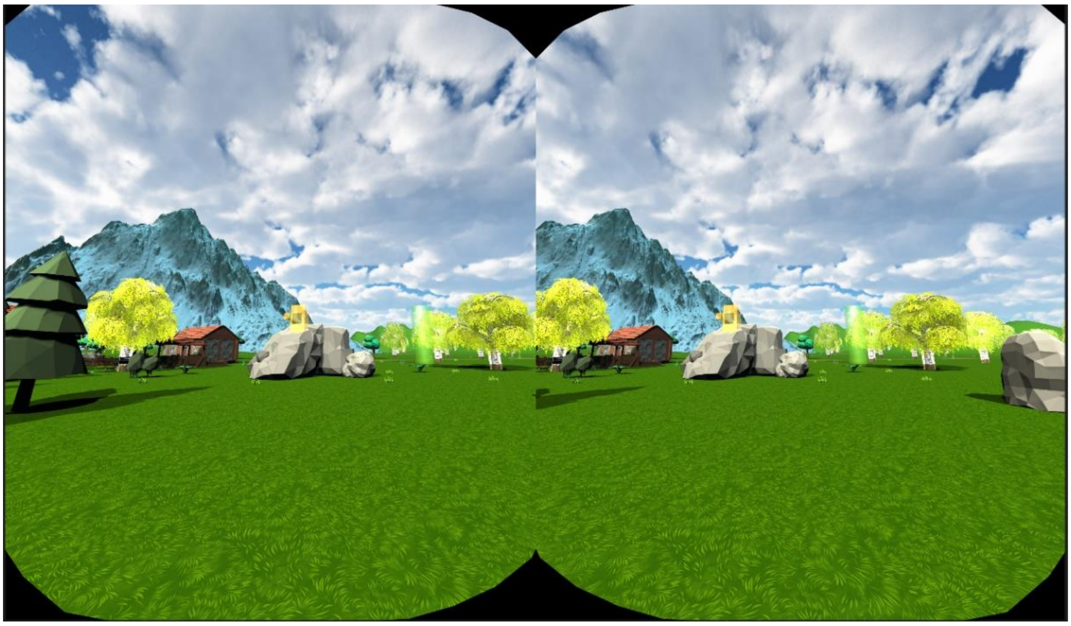


Figure 15. An arrow (yellow) pointing to the next waypoint appears in the vision.

Participants look for the direction according to the arrow. There will be obstructions between each waypoint, participants also need to explore the environment using an HMD and controller while looking for the waypoint. Participants need to actively find their way to next waypoint. In this process, we will use different visual FoV restrictions to compare the impact of different effects.

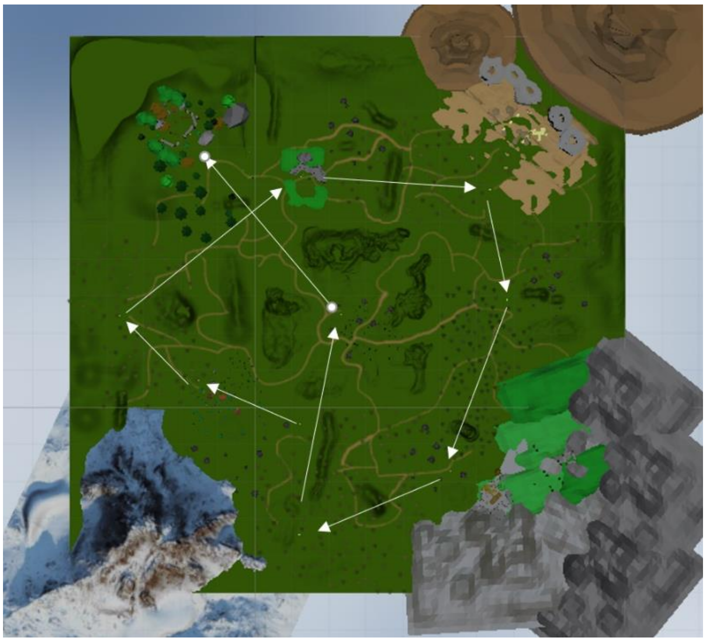


Figure 16. Overhead view of the VR environment, with the lines to indicate the order in the waypoints.

We employed an experimental process that testing the effectiveness of a dynamically changes the blur filter in peripheral vision for visual restriction vs. the traditional dynamically changing FoV of the HMD. FoV's limiting effect is achieved by the Unity3D with Tunneling plug-in[36]. Based on feedback from pre-experiments, we've kept 10 percent of the FoV's dead zone to ensure visibility. Meanwhile, to create a soft fading on the inner edge, the feather effect set to 0.1. In the whole experimental process, the effect of FoV restriction will change with the completion of waypoints.

3.3 Participants

19 postgraduates from Japan Advanced Institute of Science and Technology (JAIST) or live nearby joined this investigation as participants. The male to female rate is 15 to 4, the age distribution is 20 to 31 that with an average of 25.67. Participants had varying degrees of VR experience and traditional gaming experience. All participants were able-bodied and had either normal or corrected vision. Glasses can be worn using a head-mounted display. Participants not in total health, such as with flu symptoms or cold[37],

were excluded as these symptoms would impact their results. After each round of experiments, participants will be fully rested, and the experiment will not continue until they report the ability to perform the next experiment. The rest time is usually 10 to 20 minutes[38]. After each experiment of 10 waypoint search, participants were asked to fill out a VR sickness questionnaire to measure the effect of reducing motion sickness.

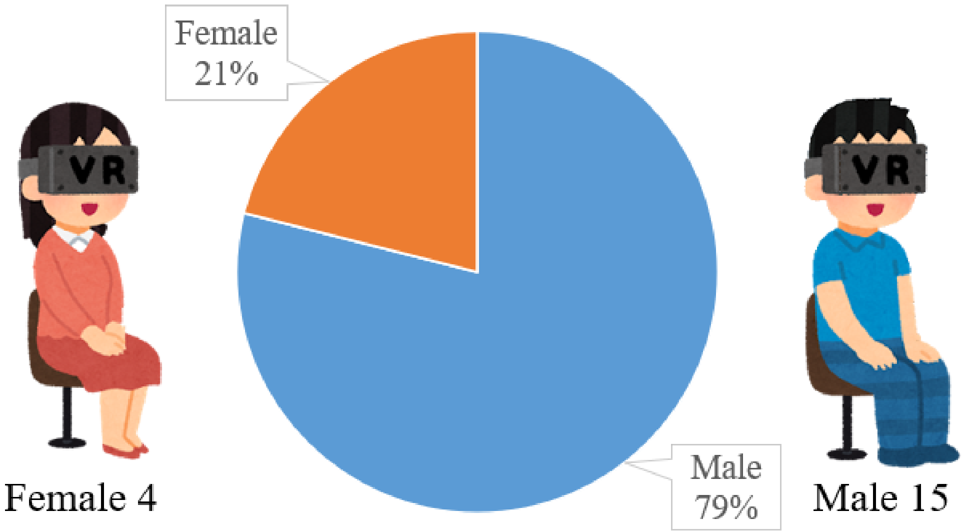


Figure 17. Participants Gender

3.4 Measurement methods

The SSQ is a self-reported questionnaire that can be used to quickly measure a degree of simulator sickness in a participant. A revised version proposed by Professor Kim in 2018 that for measuring VR motion sickness, based on the SSQ, called the Virtual Reality Sickness Questionnaire. Kim's questionnaire excludes some symptoms of the SSQ that are were determined to be not applicable for a head-mounted display, such as burping, stomach awareness, and nausea, resulting in a faster and simpler question. The scores generated are not a quantitative measure of anything but can be used as a comparison between people using the same simulator, or a single person using numerous simulators[37].

VRSQ symptom	Oculomotor	Disorientation
1. General discomfort	√	
2. Fatigue	√	
3. Eyestrain	√	
4. Difficulty focusing	√	
5. Headache		√
6. Fullness of head		√
7. Blurred vision		√
8. Dizzy (eyes closed)		√
9. Vertigo		√
Total	[1]	[2]

Table 1. Virtual reality sickness questionnaire (VRSQ)[29].

SSQ components	Computation
Oculomotor	([1]/12) x 100
Disorientation	([2]/15) x 100
Total	(Oculomotor score + Disorientation score)/2

Table 2. Computation score of VRSQ[29].

The use of VRSQ is relatively simple, the participants evaluated VR motion sickness through the VRSQ using a 4-point Likert scale (0=not at all, 1=slightly, 2=moderately, and 3=very). The scores are then tallied to generate both sub-scores for oculomotor, and disorientation, as well as a final total score.

3.5 Experimental process

First, we explained the purpose and contents of the experiment and introduced and the VRSQ questionnaire. The informed consent was also explained to the participants, including the fact that

☐ The VRSQ questionnaire is anonymous.

☐ The experiment will last about 40 min.

☐ The experiment can be finished freely at any time when participants feel severe physical discomfort.

☐ The purpose of the experiment is to experience a virtual reality environment and finish the task.

To avoid giving participants too much information to affect results, Participants were only informed of the tasks and procedures of the experiment and how to operate the equipment. The task of each experiment is the same. Participants will take sufficient rest after completing one experiment until they report that they can proceed to the next experiment. The experiment was performed four times in total. The contents are as follows

1st) Experiments without any restrictive effect.

2nd) Experiments with traditional FoV restriction effect (black mask)

3rd) Experiment with blur filters in peripheral vision

4th) Experiments without any restrictive effect as a control group.

At the beginning of the experiment, participants were presented with experimental contents and then asked preliminary physical information, such as whether they had had enough rest and whether they with cold or flu symptoms. Participants in good physical condition complete VRSQ to determine initial status[39], Then the participants learn to use the experimental instruments which is Oculus Quest. When the participants can use the controller, which is Oculus touch, to explore in the virtual reality environment, they start the formal experiment.

After each virtual reality task, participants will continue to wear the head-mounted display to complete the VRSQ questionnaire, and at the same time, give some subjective feedback, then end the experiment and start to rest. Rest time is usually 10 to 20 minutes

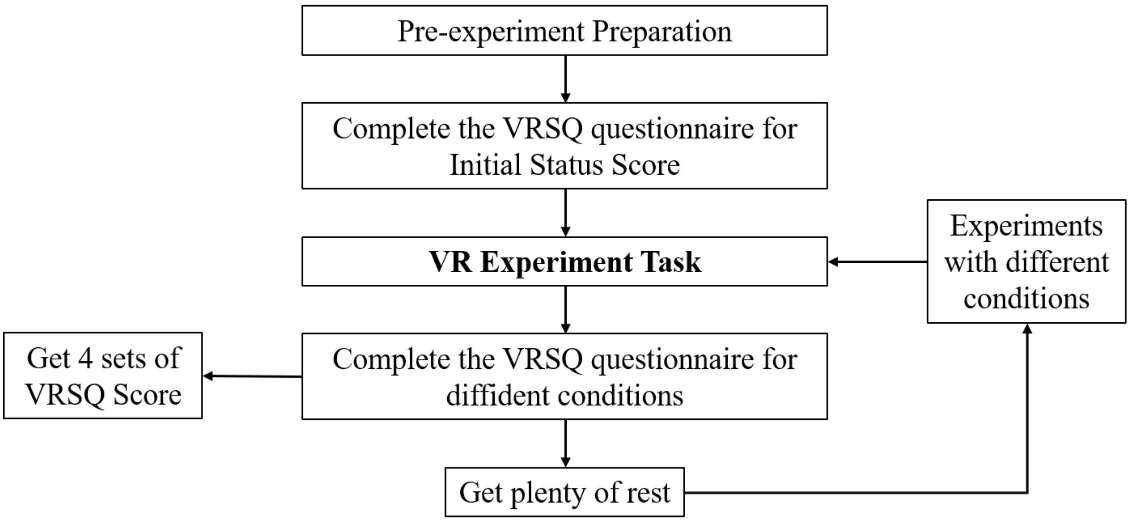


Figure 18. Flow Diagram of Experiment

In the second and third experiments, the FoV restriction effect was continuously dynamic, which was related to the participants' completion of the task. In this process, participants should report their acceptance of the degree of restriction, that is, whether the effect of restriction will affect the user experience of participants and whether it will hinder participants from completing tasks in a virtual reality environment. Both methods will appear randomly. Without affecting participants' observation of the virtual reality environment and completion of experiment tasks, the highest degree of restriction should be given.

The purpose of the last experiment was to verify the effectiveness of the limiting effect on reducing motion sickness and whether fatigue in virtual reality was superimposed.

In the 2nd experiment, we will use the traditional method in the previous research[4], using a black mask to dynamically limit FOV. In the 3rd experiment, we will use the blur effect around the vision to dynamically limit FOV, according to the data of the pre-experiment, set downsampling to 3, blur distance to 3, passes to 3, and the number of samplings is 5 times.

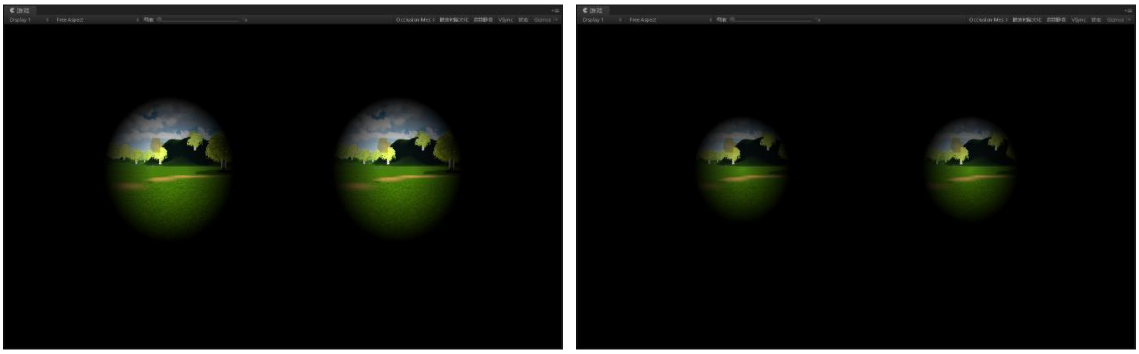
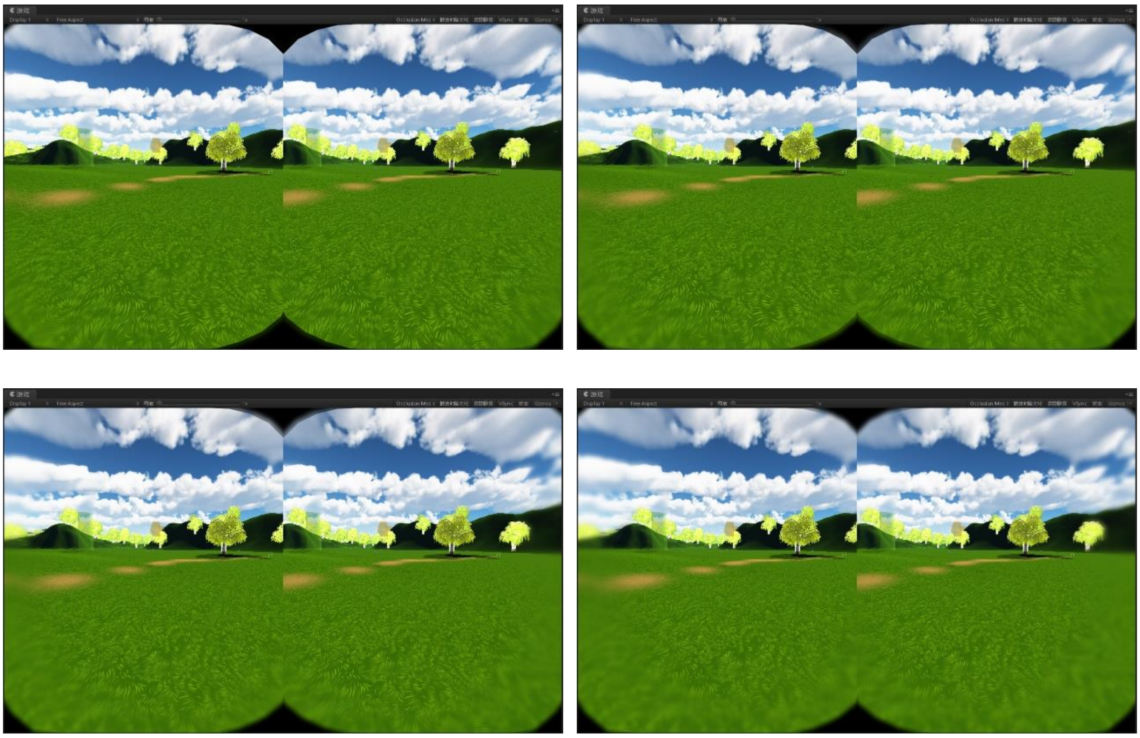
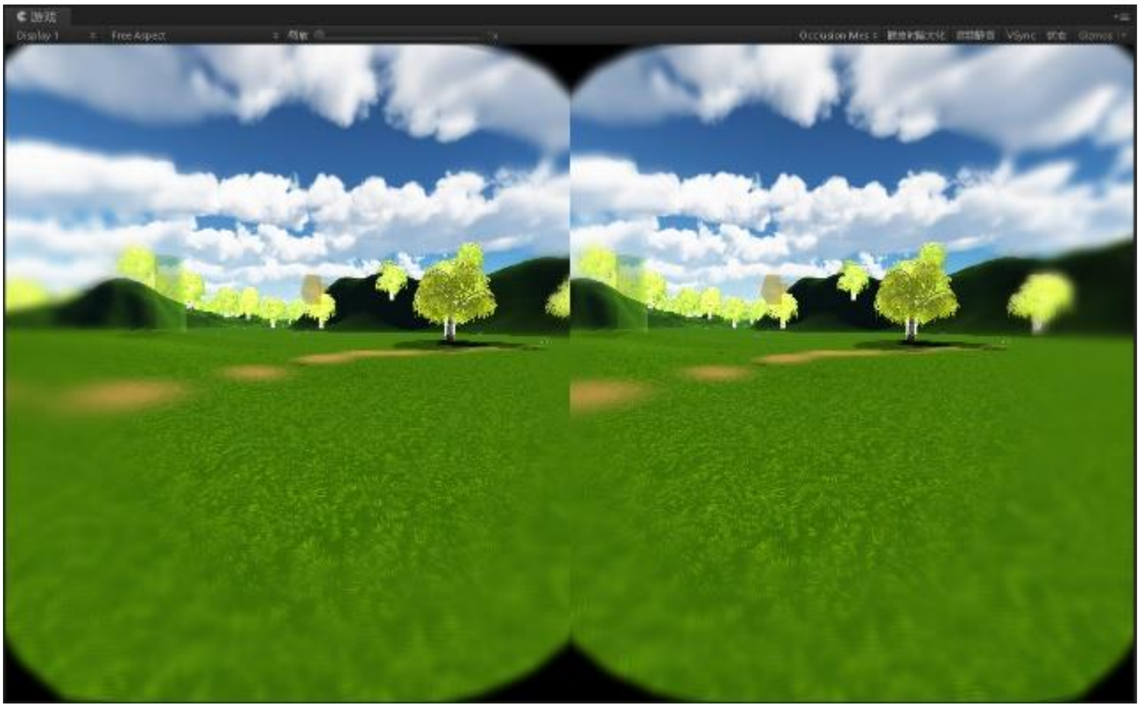
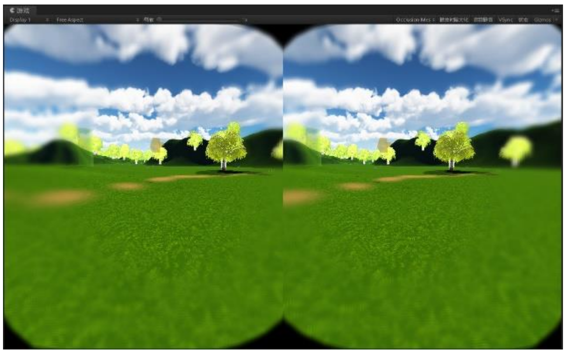
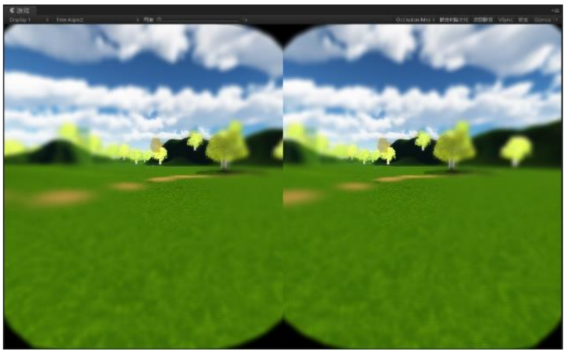


Figure 19. Limiting methods from previous studies (Black Mask) FoV limit percentage from 10% to 100%




游戏
Display 1
Free Aspect
Occlusion Mes
VSync
Gizmos





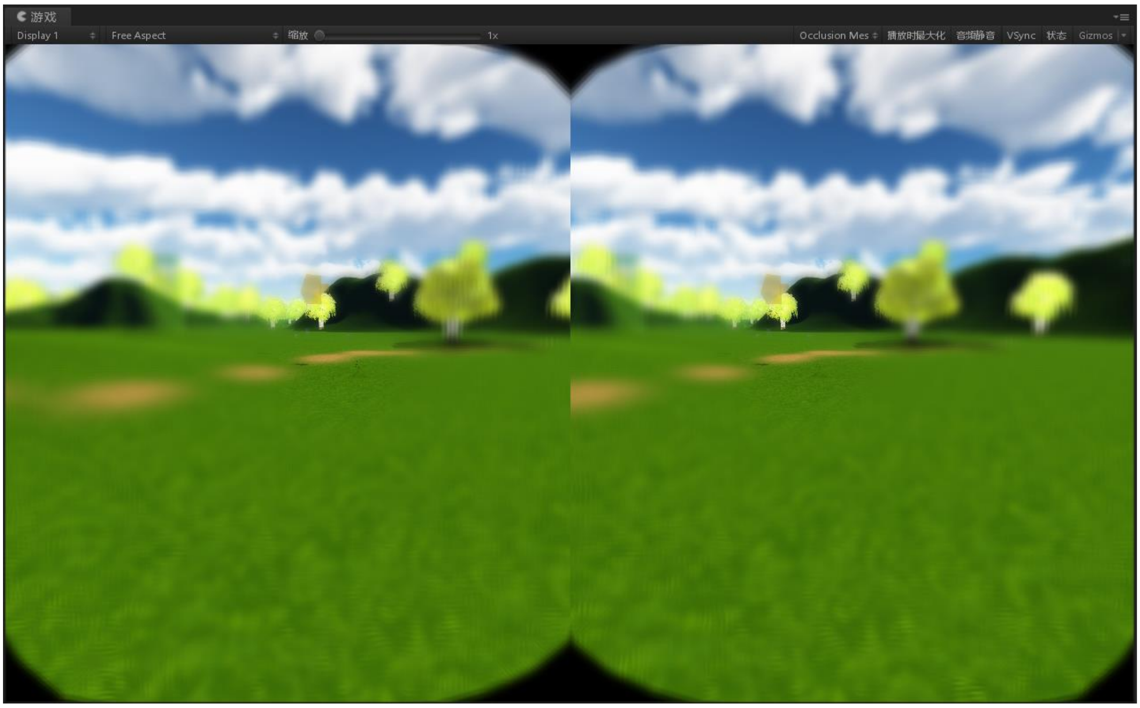


Figure 20. Blur filter dynamically in peripheral vision for visual restriction, FoV limit percentage from 10% to 100% (50% and 100% zoom in to show details)

3.6 Experiment Results

Through the VRSQ questionnaire, we obtained the motion sickness degrees of participants in each experiment. At the same time, through subjective feedback, we also obtained the maximum FoV limit percentage that users can accept under different restrictions.

Participants	Previous Effect	Blur Effect
1	60.00%	90.00%
2	80.00%	90.00%
3	50.00%	80.00%
4	40.00%	70.00%
5	60.00%	90.00%
6	50.00%	90.00%
7	50.00%	70.00%
8	70.00%	80.00%
9	60.00%	70.00%
10	60.00%	80.00%
11	80.00%	80.00%
12	50.00%	80.00%
13	80.00%	80.00%
14	60.00%	90.00%
15	60.00%	80.00%
16	80.00%	90.00%
17	50.00%	80.00%
18	50.00%	80.00%
19	60.00%	80.00%
Average	60.53%	81.58%

Table 3. Maximum FoV limit values that participants can accept without compromising task completion and VR exploration

8 of the 19 participants had no virtual reality experience before, and two of the females had no experience of 3D games at all. Four people were unable to complete all experiments due to excessive motion sickness, so the final score is 100.

Participants	Initial state	1st	2nd	3rd	4th
1	0.00	7.50	4.17	0.00	0.00
2	0.00	33.33	30.83	20.00	11.67
3	12.50	59.17	40.42	32.50	45.00
4	8.33	26.67	36.67	40.83	100.00
5	8.33	28.33	20.83	12.50	20.83
6	0.00	14.17	0.00	0.00	0.00
7	22.50	55.00	62.50	48.33	100.00
8	0.00	11.67	10.83	7.50	15.00
9	18.33	22.50	10.83	20.00	34.17
10	4.17	19.17	15.00	10.83	19.17
11	0.00	22.50	18.33	21.67	0.00
12	4.17	40.83	46.67	45.00	45.83
13	15.83	49.16	44.16	34.16	100.00
14	11.66	21.66	15.00	10.83	3.33
15	10.83	43.33	100.00	100.00	100.00
16	0.00	25.83	12.50	8.30	24.16
17	8.30	11.67	8.30	0.00	0.00
18	4.17	55.00	28.33	20.00	34.17
19	18.33	49.16	46.67	32.50	45.83
Average	7.76	31.40	29.05	24.47	36.80

Table 4. VRSQ scores of participants under different experimental conditions

We aggregate the scores of all participants and calculate the average value. It can be seen that the blur effect in peripheral vision can reduce the motion sickness more than the traditional limitation method. At the same time, from the subjective feedback of the participants, the motion sickness of virtual reality is superimposed with fatigue. The average score from the last experiment is higher than the first one, this is consistent with the participants' subjective feelings. The first and last experiments didn’t add effect. The average value shows how motion sickness the participants were throughout the experiment. Our method not only reduces the motion sickness, but the effect is better than the previous method.

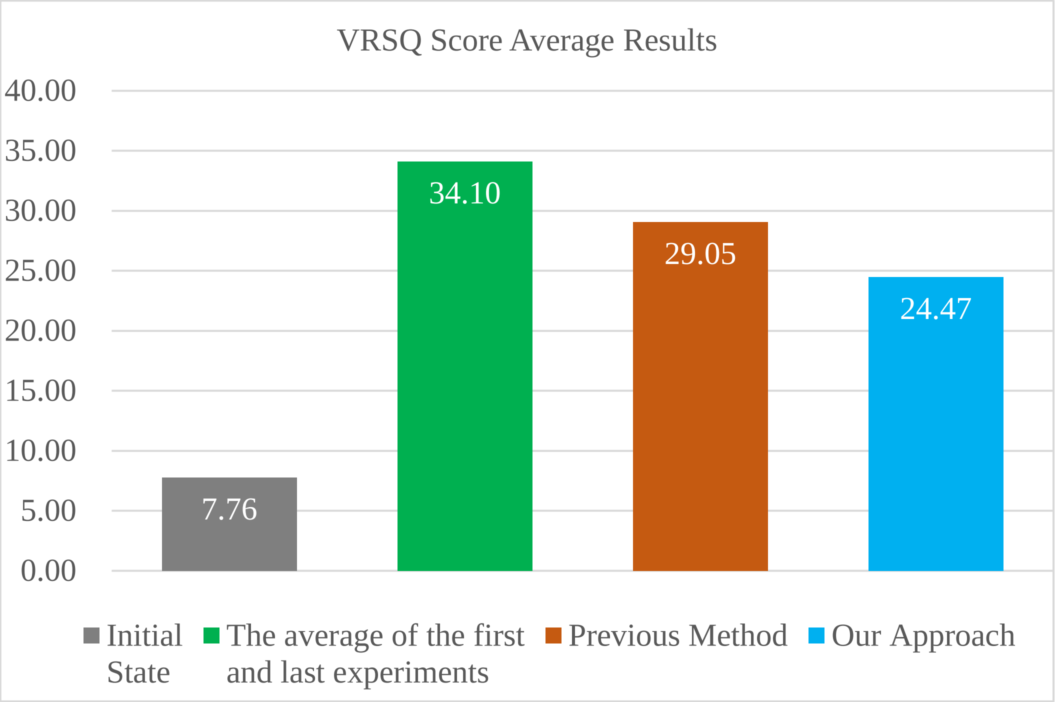


Figure 21. VRSQ Score average results figure from different experimental conditions

Chapter 4

Conclusions and Future Work

4.1 Conclusions

We performed an experiment with FoV limiting conditions that explored the various effects of peripheral vision, Even though we had a relatively small number of participants, our data indicate that blur filter in peripheral vision restrictors helped participants reduce the motion sickness in VR environment and feel more comfortable than they did in the traditional dynamically FoV restrictions condition.

Participants who used the blur filter in peripheral vision restrictors effects had lower average VRSQ scores than the traditional group and control group. In their feedback and VRSQ scores, we prove that our blur filter was more likely to reduce motion sickness than traditional methods. Compared to traditional methods, our data also suggest that the majority of participants who use blur filters in peripheral vision restrictors at high restrict levels have less likely to notice restrictors. In contrast, traditional methods are easily noticed by participants. Yet those who did notice the restrictors generally preferred to have them. blur filter in peripheral vision restrictors thus better helpful than traditional FoV restrictors, even if we adjust the limit to a very high level. In our questionnaire and feedback, we found that participants who without 3D gaming experience were more likely to have motion sickness. Some participants also gradually adapt to the VR environment thus reduce the VRSQ score.

4.2 Limitation

There were 19 participants in this study, all of whom were young people, and the experimental results could not prove that methods were suitable for people of all ages. Meanwhile, the experiments were designed to imitate ordinary VR exploration tasks and could not provide suggestions for intense VR games or applications.

4.3 Future Work

We found that female participants were more likely to motion sickness. This seems to have something to do with female's less experience of 3D games. And female is not sensitive to limiting FoV. Maybe in the future we need to design special ways to reduce motion sickness for female in VR.

And future work should explore using a diffident blur parameter. Further experimentation with different degrees of blur and restrict levels could make the effect of reducing motion sickness different. The emergence of more and more standalone head-mounted displays makes VR devices used in different ways, motion sickness in a free-moving state may differ from sitting. We will try to deploy our approach to more VR device and usage scenarios in the future, to find more effective ways to reduce motion sickness.

I hope my findings will help VR content designers. It can reduce the motion sickness of VR as much as possible so that more people can experience better VR content.

Chapter 5
Acknowledgment

I would like to thank all of you for helping me in writing this paper. My deepest gratitude is first to the professor, Tsutomu Fujinami, my mentor, for his constant encouragement and guidance. He provided a full understanding and support for my entire postgraduate study. Not only generously provided me with experimental equipment and space, but also helped me attend various academic conferences. Without his usual and enlightening guidance, this paper would not have been in its present form.

Finally, I would like to thank my dear family for their love and great faith in me for many years. I also want to thank my friends and lab mates who have given me help and time to listen to my opinions and help me solve my problems in the difficult process of my paper. Thanks to my pet cat 73 for helping me relieve my girlfriend's loneliness during my overseas study. Especially, I still want to thank my favorite girlfriend for her understanding and tolerance during my study abroad, when I graduate, I'll ask her to marry me. Although, if it weren't for her quarrel with me, I would have finished thesis early.

Bibliography

[1] R. S. Kennedy, J. Drexler, and R. C. Kennedy, “Research in visually induced motion sickness,” *Appl. Ergon.*, vol. 41, no. 4, pp. 494–503, 2010.

[2] “Oculus.” [Online]. Available: https://www.oculus.com/legal/health-and-safety-warnings/?locale=zh_TW. [Accessed: 01-Feb-2020].

[3] “2019: The Year Virtual Reality Gets Real.” [Online]. Available: https://www.forbes.com/sites/solrogers/2019/06/21/2019-the-year-virtual-reality-gets-real/#476c2a7a6ba9. [Accessed: 04-Feb-2020].

[4] A. S. Fernandes and S. K. Feiner, “Combating VR sickness through subtle dynamic field-of-view modification,” *2016 IEEE Symp. 3D User Interfaces, 3DUI 2016 - Proc.*, pp. 201–210, 2016.

[5] E. Langbehn, F. Steinicke, T. Raupp, B. Bolte, G. Bruder, and M. Lappe, “Visual blur in immersive virtual environments,” pp. 241–250, 2016.

[6] G. Burdea and P. Coiffet, “Virtual reality technology,” 2003.

[7] H. Brockwell, *Forgotten genius: the man who made a working VR machine in 1957*. Tech Radar, 2016.

[8] “South Korea Develops Virtual Reality Movies for Cinema-Goers | All3DP.” [Online]. Available: https://all3dp.com/south-korea-develops-virtual-reality-movies-cinema-goers/. [Accessed: 04-Feb-2020].

[9] “Fundamental Surgery launches in Australia and New Zealand.” [Online]. Available: https://www.fundamentalvr.com/2018/10/10/haptics-humanity-australia-and-new-zealand/. [Accessed: 04-Feb-2020].

[10] “David Brewster - Wikipedia.” [Online]. Available: https://en.wikipedia.org/wiki/David_Brewster. [Accessed: 04-Feb-2020].

[11] “1 feb 1960 anni - Morton Heilig, Telesphere Mask (Il nastro del tempo).” [Online]. Available: https://time.graphics/it/event/265815. [Accessed: 04-Feb-2020].

[12] “Retina display - Wikipedia.” [Online]. Available: https://en.wikipedia.org/wiki/Retina_display. [Accessed: 02-Feb-2020].

[13] A. F. Fuchs, “Saccadic and smooth pursuit eye movements in the monkey,” *J. Physiol.*, vol. 191, no. 3, pp. 609–631, Aug. 1967.

[14] “Why Retina Isn’t Enough [Feature] | Cult of Mac.” [Online]. Available: https://www.cultofmac.com/173702/why-retina-isnt-enough-feature/. [Accessed: 02-Feb-2020].

[15] C. A. Curcio, K. R. Sloan, R. E. Kalina, and A. E. Hendrickson, “Human photoreceptor topography,” *J. Comp. Neurol.*, vol. 292, no. 4, pp. 497–523, 1990.

[16] A. Patney *et al.*, “Perceptually-based foveated virtual reality,” in *ACM SIGGRAPH 2016 Emerging Technologies, SIGGRAPH 2016*, 2016.

[17] “Oculus Founder Says There’s No Existing or Imminent VR Device Good Enough to Truly Go Mainstream.” [Online]. Available: https://wccftech.com/oculus-founder-no-vr-device-mainstream/. [Accessed: 04-Feb-2020].

[18] “StretchSense MoCap Pro Integration with Vive Pro in Unity - YouTube.” [Online]. Available: https://www.youtube.com/watch?v=dNqq4pSSWBE. [Accessed: 04-Feb-2020].

[19] A. Qazi, “What is Monitor Refresh Rate,” *Tech Gearoid*.

[20] “Refresh rate - Wikipedia.” [Online]. Available: https://en.wikipedia.org/wiki/Refresh_rate. [Accessed: 02-Feb-2020].

[21] P. L. Alfano and G. F. Michel, “Restricting the field of view: Perceptual and performance effects,” *Percept. Mot. Skills*, vol. 70, no. 1, pp. 35–45, 1990.

[22] H. M. Traquair, *An Introduction to Clinical Perimetry, Chpt. 1*. London: Henry Kimpton, 1938.

[23] “Degrees of Freedom | Google VR |,” *Google Dev.*

[24] J. Batallé, “An Introduction to Positional Tracking and Degrees of Freedom (DOF),” *Road to VR*, Feb. 2013.

[25] R. L. Kohl, “Sensory conflict theory of space motion sickness: an anatomical location for the neuroconflict.,” *Aviat. Space. Environ. Med.*, vol. 54, no. 5, pp. 464–5, May 1983.

[26] “How to Overcome VR Motion Sickness | ARPost.” [Online]. Available: https://arpost.co/2018/02/15/overcome-vr-motion-sickness/. [Accessed: 04-Feb-2020].

[27] “How To Avoid VR Motion Sickness - VR News, Games, And Reviews.” [Online]. Available: https://www.vrandfun.com/avoid-vr-motion-sickness/. [Accessed: 04-Feb-2020].

[28] D. P. Barnard and E. H. Scott, “Reducing VR Sickness through Peripheral Visual Effects,” *2018 IEEE Conf. Virtual Real. 3D User Interfaces*, pp. 517–519, 2018.

[29] H. K. Kim, J. Park, Y. Choi, and M. Choe, “Virtual reality sickness questionnaire (VRSQ): Motion sickness measurement index in a virtual reality environment,” *Appl. Ergon.*, 2018.

[30] R. S. Kennedy, N. E. Lane, K. S. Berbaum, and M. G. Lilienthal, “Simulator Sickness Questionnaire: An Enhanced Method for Quantifying Simulator Sickness,” *Int. J. Aviat. Psychol.*, vol. 3, no. 3, pp. 203–220, 1993.

[31] “Oculus Link Compatibility.” [Online]. Available: https://support.oculus.com/444256562873335/. [Accessed: 02-Feb-2020].

[32] R. Wong, “Oculus Quest review: A new milestone for VR,” *Mashable*.

[33] B. Lang, “Hands-on: Oculus’ Wireless ‘Santa Cruz’ Prototype Makes Standalone Room-scale Tracking a Reality,” *Road to VR*, Oct. 2016.

[34] “Oculus Rift S Is Official: Higher Resolution, 5 Camera Inside-Out, $399,” *UploadVR*, Mar. 2019.

[35] “Oculus Link Software: Connecting Oculus Quest to a Gaming PC,” *AnandTech*, Sep. 2019.

[36] “VR Tunnelling Pro - Asset Store.” [Online]. Available: https://assetstore.unity.com/packages/tools/camera/vr-tunnelling-pro-106782. [Accessed: 02-Feb-2020].

[37] X. Hunt and L. E. Potter, “High computer gaming experience may cause higher virtual reality sickness,” *Proc. 30th Aust. Conf. Comput. Interact. - OzCHI ’18*, pp. 598–601, 2018.

[38] K. Carnegie, T. Rhee, and V. R. Software, “Reducing Visual Discomfort with HMDs Using Dynamic Depth of Field,” *IEEE Comput. Graph. Appl.*, vol. 35, no. 5, pp. 34–41, 2015.

[39] P. Budhiraja, M. R. Miller, A. K. Modi, and D. Forsyth, “Rotation Blurring: Use of Artificial Blurring to Reduce Cybersickness in Virtual Reality First Person Shooters,” 2017.