Proposed Method to Simulate Dynamic Change in Scale in Virtual Reality

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Abstract—For video game players, part of the experience is when crafted game effects are so realistic that they feel almost real. Lately, virtual Reality (VR) Head-Mounted Displays (HMDs) have gained a lot of attention in the media and on the world market. They are opening up new dimensions in video game experiences and create opportunities to invent new types of game effects. One such effect could be to make the player feel as if they are growing larger. That is precisely what we tried to achieve in the game we developed.

This research report is part of a B.Sc final project at the School of Computer Science, spring 2016. The project is titled "Growth - A virtual reality game and controller system". This document contains the results of a preliminary research experiment, where volunteer participants were tested with a method to make people feel like they are growing within a Virtual Reality (VR) simulation. The simulation was rendered on Head-Mounted Displays (HMDs) worn by the participants. The document contains an introduction to the research and why we are conducting it. It also contains a background section, a description of the research process, the results of the research and the conclusions reached by the team.

The focus of this research was to examine if the method we implemented could cause the player to feel as if they were growing larger. The method used to simulate the growth was to move the two cameras, each projected onto one viewport on the head-mounted display, within the virtual scene further apart and increase their vertical height. In addition to this there were also changes to the directional vector of the cameras to form a new convergence (focal) point.

To test this effect, 20 volunteers participated in an experiment which took place over the course of two days. The result of this experiment was a confirmation that this method was not effective but gave a strong indication what might be done to improve it. Furthermore the results of the experiment indicated that people did maintain a good sense of scale and distance within virtual environments.

1 Introduction

The reason the team decided to tackle this research is linked directly to the development of a small game for Virtual Reality (VR) rendered on Head-Mounted Displays (HMDs). During the design phase of our game development there came an idea for a feature where the player character is growing in size. We asked ourselves the question:

Does the method we have implemented give people the illusion that they feel like they are growing or shrinking?

With this question and some rudimentary testing we came up with the testable hypothesis:

> People can feel as if they are growing vertically and horizontally within a virtual reality environment using

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head-mounted displays, by increasing horizontal distance between cameras and vertical distance between the cameras and the ground surface.

The experience of growing as fast as the game demanded is very alien to humans. It seemed to work for team members but we did not want to presume the effect was working as intended. Therefore we wanted to test our hypothesis on a small sample of 20 volunteers and record our findings in this document.

2 Background

To find out if our question had previously been answered, the team looked online for projects that had utilized similar methods. At the time of writing the team had not found more than one such article. This article focused on studying how the sense of scale works in VR using purely visual stimuli. The results of that examination concluded that people using HMDs in a VR environment could reliably estimate the size of and distance to objects in relation to their virtual selves. This article provided a promising point of reference for this research.[1]

That article discussed the problem of changing a player's size while the simulation was running. The author's method of changing the player's size caused substantial eye-strain, we presumed the same would apply to our method.

3 Process

The environment participants were tested in is explained first. Following that we have the reasoning for the questions we asked along with a description of the sample group.

3.1 Scene / environment

The virtual reality experiment took place inside a small tropical island scene(see Figure 10). The scene contained four boxes of different color, all except one hidden from the participant at the beginning but one additional box at a time becoming visible at each stage in the experiment. Once a box was revealed it would remain within visible range of the participant until the end of the experiment. In addition to these boxes the environment contained a small lighthouse structure, two generic boxes, a cylindrical object with an open top, a burlap sack and a wooden pier. These stages were determined by the participant's virtual size. The virtual size could be controlled in increments or growth levels with a secondary device, which the interviewer had control over. The growth stages were four in total, starting size included. The four colored boxes and their positions were:

1. Yellow box which was visible from the beginning of the experiment, positioned behind and below the participant's perspective.

2. Purple box which was placed inside a cylindrical object with an open top, situated on the island. It would only be visible after the experiment entered the second stage.

3. Red box which was placed on top of a larger generic box placed out in the ocean and would be visible after the experiment entered the third stage. The two boxes occluded by a third larger box situated on the island and near the subject.

4. Blue box which was placed inside a lighthouse situated in the ocean and would only be visible at the final stage of the experiment.

3.2 Method

The experiment took place within the facilities of Reykjavik University. Participants were gathered through advertisement on social media and people who were walking by were asked to take part in the study. Participants were incentivized to participate with a candy bar that they would receive at the end of the experiment. Each instance of the experiment took 6-8 minutes to complete. All the experiments took place within two days.

First, participants were asked to answer a background question form (see appendix A). When the participants had finished filling out the form, they were handed the virtual reality head mounted display. Once the participant was comfortable the experiment could begin. Participants were asked a few questions on what they were seeing inside the virtual world. The questions were asked periodically, where each stage of the experiment had dedicated questions assigned to it.

What was happening within the virtual world when the interviewer advanced the experiment towards the next stage was that the distance between the virtual eyes, E, and the distance to the ground from the eyes, H, was increasing at a fixed rate. To be more precise, E was growing at a rate of $0.090 \frac{unit}{s}$ and H at a rate of $0.683 \frac{unit}{s}$ maintaining a ratio between them of around $\frac{E}{H} = 0.01318$. The actual distances at each stage are listed in Table 1. The lines of sight of the two virtual eyes were not parallel but rather rotated around the up-axis towards each other as can be seen in Figure 1. This rotation did not change during the experiment but when E is increased the focal point i.e. the intersection point of the two lines, moves further away from the cameras thus changing the distance at which objects are in focus.

Stage	E	H
1	0.600	4.554
2	1.200	9.104
3	1.650	12.516
4	4.801	36.444

Table 1: *Sizes at different stages.*

After the participant was done with the virtual reality portion of the experiment they were asked to fill out a question form about their experience (see appendix A).

On day one the experiment was conducted with half the amount of planned participants. This group was not informed of the purpose of the experiment until afterwards, instead they were falsely informed that they were testing the performance of a game engine. This falsehood was corrected once the post-experiment questionnaire was filled out.

On day two the experiment was conducted with the rest of the planned participants. This second group was informed of the purpose of the experiment at the start of the experiment.
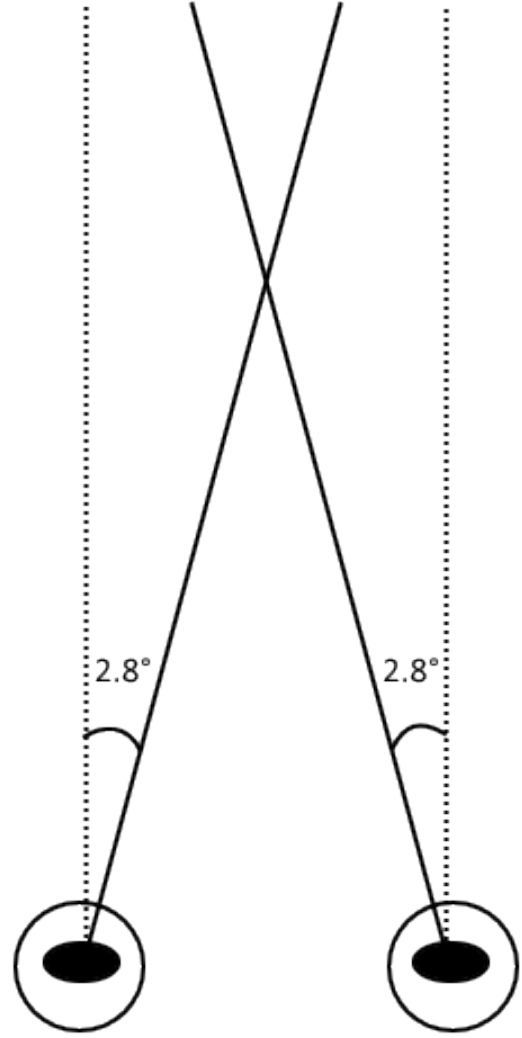

Figure 1: *Top-down view of the cameras, dotted lines are parallel.*

3.3 Questions

Subjects were questioned at three different points of the experiment as explained in section 3.2. The questions are enumerated in Appendix A.

3.3.1 Background questionnaire

Questions chosen for the background question form were to see if there were any indicators that these parameters influenced the results of the experiment in any meaningful way.

Age, sex and professional background/education were included to represent the demographic of our participants to some degree. The height parameter was to see if a participant would experience a similar or dissimilar sense of scale when compared with participants of a different height. A very basic question about vision impairment was also included to potentially explain extreme differences in sense of scale. The last two questions were selected to potentially see if there was any correlation between hours spent each

week playing games or having used a HMD before and nausea from participating in the experiment.

3.3.2 Mid-experiment questions

Questions asked during the experiment. There were several questions that the interviewer asked the participants while they had the HMD on. These questions were asked in the aforementioned four stages. In the first stage, the participant's size had not grown.

The participants were warmed up with a simple question that also encouraged them to look around the environment. The questions with the boxes also served the purpose of guiding the participants to look around the scene at each stage of the experiment, hopefully noticing changes in their perceived size in relation to the virtual environment. The number of steps to reach the pier was a test to determine how participants considered distance to objects and the scale of the environment in relation to themselves, their answers compared with each other answer. The rest of the questions (numbers 4,5 & 9) were all aimed at how the participants experienced the change in size.

3.3.3 Post-experiment questionnaire

All the questions in the post-experiment questionnaire except question number 4 are based on the Likert scale design with the options ranging from "Strongly agree" to "Strongly disagree".

Questions 1, 2 and 3 are all focused on analyzing how the participants felt the size changes were manifesting during the experiment. Question 4 was to confirm that participants had adequately explored the environment. Question 5 was simply to see if the experiment was causing participants discomfort, some people express a feeling of nausea after using HMDs for even just a short period of time.

3.4 Participants

The participants in this experiment were 20 in total. 19 males and 1 female. Ages ranged between 20-30 years old. The majority of participants were undergraduate students in computer science.

4 Results

The results of the interview questions which were asked and answered during the experiment will be reviewed first, followed by the results of the post-experiment questionnaire.

4.1 Mid-experiment questions

The warm-up question (question 1) was answered affirmatively by every participant, everyone was able to see the lighthouse.

4.1.1 Colored boxes

Most participants seemed to have no trouble finding every box in questions number 2, 6, 8 & 11 (see Figure 2). The blue box was positioned to be barely visible near the top of the lighthouse during the final growth stage, as a result 2 participants did not notice that particular box.

4.1.2 Sense of scale, number of steps to reach the pier

In questions number 3, 7 & 10, participants estimated the distance they would need to walk to reach a nearby pier, most participants were consistently close to the average. Each bar in the charts represents a participant in the experiment, in each question they are
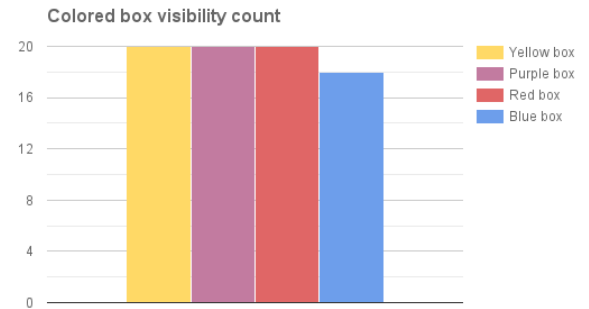

Figure 2: *Box visibility chart.*

ordered according to the number of steps estimated from lowest value to highest value.

The results of question 3, Figure 3.

- Average: 8.7 steps
- Highest value: 17.5 steps
- Lowest value: 4.5 steps

Figure 3: *Step chart part 1.*

The results of question 7, Figure 4.

- Average: 2.98 steps
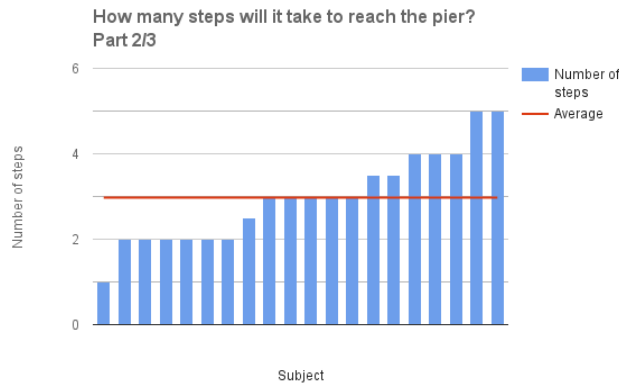- Highest value: 5 steps
- Lowest value: 1 step

The results of question 10, Figure 5.

- Average: 1.09 steps
- Highest value: 2.5 steps
- Lowest value: 0.5 step

4.1.3 Sense of growth

Questions number 4, 5 & 9 focus on the participants' descriptions of their experiences when the growing effect had happened or was happening. Participants were allowed to describe their experience

Figure 4: *Step chart part 2.*

Figure 5: *Step chart part 3.*

Figure 6: *Environment shrinking*

Figure 7: *Player model growing*

Figure 8: *Participants growing*

on more than one occasion with more than one keyword. 18 participants described their experience at least once as being lifted, flying, floating or rising. 7 used the phrase "growing taller" in their description and 5 used the phrase "growing bigger" in their description. We did not make the distinction between "growing taller" and "growing bigger" clear to participants so they may well have meant "growing taller" when they used the phrase "growing bigger". 3 participants expressed discomfort due to fear of heights during the experiment.

4.2 Post-experiment questionnaire

The average results of the post-experiment questionnaire were nearly identical between both groups of participants, those who knew the purpose of the experiment and those who did not. We interpreted the results with a point system, "Strongly disagree" counted as 1 point, "Disagree" counted as 2 points etc. According to the point system a completely neutral result should have 3 points average.

For question 1 Figure 6 the trend was slightly in favor of the environment shrinking, the average response was 3.25 points.

For question 2 Figure 7 the trend was greatly in favor of the virtual avatar growing in size, the average response was 4.15 points.

For question 3 Figure 8 the trend was somewhat positive in favor of the participants themselves growing in size, the average response was 3.65 points.

For question 4 the results of box visibility was already mentioned and can be reference here Figure 2.

For question 5 Figure 9 the trend was slightly negative in favor of the participants feeling nauseous, the average response was 2.75 points. A significant amount of people expressed "Agreed" to experiencing nausea which was anticipated, we attempted to minimize nauseating effects as much as possible.
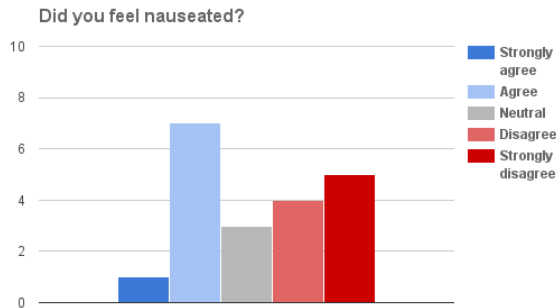
Did you feel nauseated?

Figure 9: *Participant nausea*

5   Conclusion

From the participant background data the team made some observations about the experiment results. The data strongly indicated that participant height did not affect how participants measured distance to and scale of virtual objects. 19 of 20 participants had no vision impairment or were short-sighted, there seemed to be no indication that being short-sighted influenced a participant's sense of scale. The only participant which was far-sighted had the highest deviation from the average number of steps to take towards the pier in question 3. The participant estimated the distance was between 15 and 20 steps, which was double the average. However, there is nothing conclusive about this correlation since the sample size was very small and only one participant was far-sighted. Further studies could take note of this and include eye sight measurements as a parameter. The data could not support that more hours spent playing games each week or that people had used HMDs before made them any less likely to feel nausea after participating in the experiment.

The results of the mid-experiment questions were not quite what was expected but still interesting to the team. Splitting participants into two groups and telling one group beforehand about the goal of the experiment proved more important than originally theorized.

The group that did not know what the goal was had 3 out of 10 participants describe their experience as "growing taller" and 1 described it as "growing bigger".

The group that did know the goal of the experiment had 4 out of 10 participants describe their experience as "growing taller" and 4 described it as "growing bigger".

This seems to indicate that suggesting to participants what they should be feeling affects the way they describe their experience. However, the data acquired from the post-experiment questionnaire indicates that there is no notable difference between participants' experiences, regardless of whether they knew the goal of the experiment or not.

6   Future works

The team has some ideas for future research to investigate this effect further.

The experiment was conducted without giving the avatar any virtual form, participants were essentially two floating cameras in the virtual world. Giving participants a visible virtual avatar as a frame of reference as it grows could make the effect more relatable for them.

In addition to that the team theorizes that the growth may have been too quick, causing participants to feel dramatic changes to their size, therefore simulating an elevator effect rather than a growing effect. This warrants further testing, the speed at which the participants grow could be considerably lowered to make the participants feel the growth effect more subtly.

References

[1] Kondratskiy, A. (2013). A Sense of Scale in VR. [online] Kholdstare.github.io. Available at: http://kholdstare.github.io/technical/2013/10/06/sense-of-scale-vr.html [Accessed 30 Apr. 2016].

Appendix

A   Questions

Background questions

1: Sex
2: Age
3: Height
4: Professional background / education
5: Vision impairment
6: How many hours each week do you spend playing video games?
7: Have you used a virtual reality headset before?

Questions asked during testing

Stage 1:
1: Do you see a lighthouse?
2: Can you see a yellow box anywhere?
3: How many steps does it take for you to reach the pier?
Stage 2:
4: Did something change just now?
5: Do you notice any change in the environment?
6: Can you see a purple box?
Stage 3:
7: How many steps does it take for you to reach the pier now?
8: Can you see a red box?
Stage 4.0 (Questions asked while the change in size between 3 and 4 is happening):
9: Do you feel like you are moving?
9.1: If yes: Could you describe what the movement feels like?
Stage 4:
10: How many steps does it take for you to reach the pier now?
11: What colored boxes can you see?

Post-experiment questions

1: Was the environment shrinking?
2: Was the player model growing?
3: Did you yourself feel like you were growing?
4: Did you see the following boxes?
4.1 - Yellow box
4.2 - Purple box
4.3 - Red box
4.4 - Black box
5: Did you feel nauseated?

B   Camera setup

The virtual world used in the experiment was created with the Unity game engine version 5.3.1 using the Cardboard Unity SDK version 0.6. The camera setup for the eyes came from Cardboard with modified distances between them and rotation around the up-axis(see Figure 1). The left and right eye both had a near plane of 0.3, far plane of 1000 and Field of view of 60. Left camera's projection matrix was:

$$\begin{pmatrix} 1.04625 & 0.00000 & 0.26897 & 0.00000 \\ 0.00000 & 0.87708 & 0.00000 & 0.00000 \\ 0.00000 & 0.00000 & -1.00060 & -0.60018 \\ 0.00000 & 0.00000 & -1.00000 & 0.00000 \end{pmatrix}$$

and right camera's projection matrix was:

$$\begin{pmatrix} 1.04625 & 0.00000 & -0.26897 & 0.00000 \\ 0.00000 & 0.87708 & 0.00000 & 0.00000 \\ 0.00000 & 0.00000 & -1.00060 & -0.60018 \\ 0.00000 & 0.00000 & -1.00000 & 0.00000 \end{pmatrix}$$

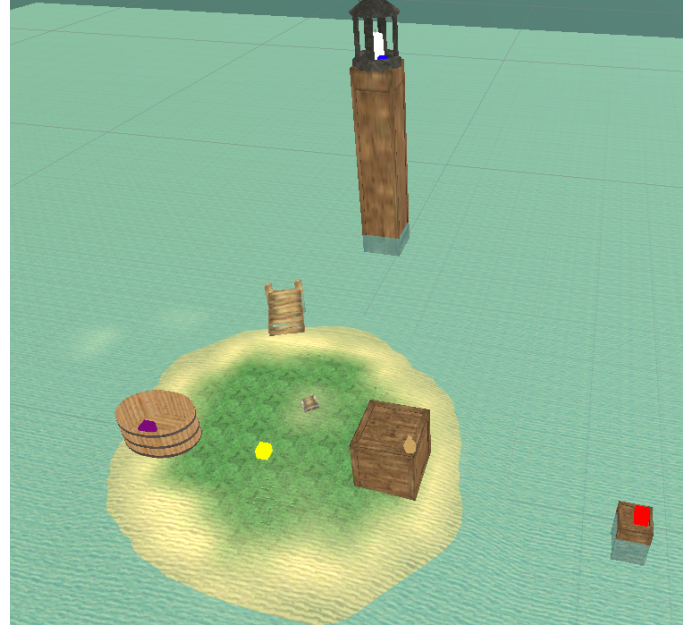The hardware used was a Samsung galaxy s6 smartphone in a Freefly VR headset.

Figure 10: *Bird's-eye view of the scene.*