Group 9 - Endless Corridor

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ABSTRACT

Maneuvering around in VR with your own feet is delightful, but requires more physical space than other locomotion techniques. To establish a work-around for this and to utilize the physical space available, we have implemented a solution in VR, where the user walks down a corridor-shaped environment, completing tasks. The application applies rotation gain to the user, such that they walk back and forth in a boxed-shaped real-world environment. A set of participants has been evaluating our application, and the results showed that they felt no noticeable difference between walking down a virtual corridor completing tasks with or without rotation gain applied.

1 INTRODUCTION

Many creative solutions have been proposed to solve the real-world limited space one might have when in virtual reality (VR). Solutions such as redirected walking (RDW), resetting, high/gain walking, and more. Each of these have their respective pros and cons, where RDW might provide a more realistic sense of walking than resetting, however comes at the cost of space.

We propose a solution we call Endless Corridor, that requires no more space than what one might have in their living room or bedroom, and provides a more realistic sense of walking than resetting and other techniques. This of course does not come for free, as this means that restrictions have to be put on other places, this being the game/ program in this case. We evaluate our solution by comparing it to real-world walking, in terms of performance and subjective measures.

The solution we propose is comprised of multiple techniques that allow for the exploration of larger virtual environments in limited real-world space, and therefore does not introduce any novel technology or technique. Our solution does however shift the cost of real-world space and the feeling of walking, to the application, which allows for immersive walking in a limited real-world space given a tailored VR experience.

2 RELATED WORK

Previous papers have discussed techniques for exploring larger virtual environments in limited real-world space. These papers discuss techniques that focus on RDW, Self-overlapping spaces, High-gain walking, Resetting, and more. Of these, we are interested in techniques that achieve this on physical space less than or equal to 6×6 meters [1], whilst the user does not notice. The following will show examples of techniques that try to achieve these or are interesting to our technique. The three techniques: Freeze-backup, freeze turn, and 2:1 turn [5], focus on making the user consciously reset their world-view.

While these techniques do work, it differs from our goal, as we would like to create a technique that does this without the user noticing. Fig. 1 shows the freeze turn technique from [5]. Another technique proposed, is the unlimited corridor technique [3]. This technique is a form of RDW, with a focus on making a corridor that does not end. This technique fulfills the requirement of being unnoticeable by the user. The problem with this technique, however, is the amount of space required. As seen in Fig. 2, we see that it requires a large structure for the technique to work.

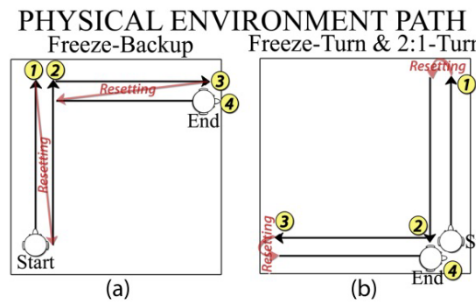

Figure 1: Freeze turn technique [5]

Figure 2: Unlimited Corridor [3]

3 ENDLESS CORRIDOR

Our solution takes the idea of aligning the virtual world with the real world whilst the player is occupied with a given task that requires them to rotate in place. As seen in Fig. 3, the idea is for them to:

1. Walk forward
2. Perform a task, gradually resetting the worldview
3. Walk forward (walk backward in real space)

The actual resetting could be done in multiple ways. The solution we chose for our technique works by having a rotation gain applied to the virtual view of the user. For our solution to work, it is required that the player has made a 180-degree turn, which is translated to a 360-degree turn in the virtual world, before

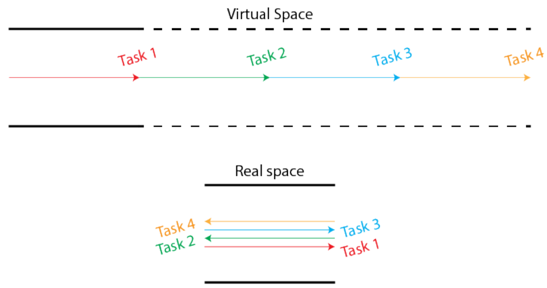

Figure 3: Mapping of the endless corridor from virtual space to real space

continuing forward. One could imagine that doing this translation directly with a rotation gain of 2, would be noticeable, and may induce motion sickness. This is why we need tasks that require a lot of turning, to gradually do this without the player noticing.

Our implementation has the virtual view turn by 39% more when turning right, meaning a rotation gain constant of 1.39 applied to the virtual view. We tested different variants of this constant before concluding that 39% worked out best. As the person rotates, the virtual space and real space start to become misaligned. The technique keeps track of the person's rotation in the real world. Once the rotation in the virtual world is aligned with the real world, as to have rotated the real world and virtual world with a difference of 180 degrees, the rotation gain is turned off.

4 Evaluation

The purpose of the experiments is ultimately to figure out if there are any noticeable differences between completing the tasks using either technique, this difference referring to performance and subjective user notability. We do this by measuring the performance of each user when completing the tasks given to them, and by giving them a survey to answer. To clarify for our solution, we have set up the following hypotheses and variables:

- H_0: There is no noticeable difference between walking down a virtual corridor completing tasks with and without rotation gain applied.
- H_1: There is a noticeable difference between walking down a virtual corridor completing tasks with and without rotation gain applied.
- Independent variables: Endless Corridor technique
- Dependent variables: Noticeability, Immersion, VR sickness, Task completion time

4.1 Experiment Design

We decided to go with a within-subject design experiment, as this better fits with the number of available participants.

The space given for the experiment is 7.30×3.30 meters wide, meaning the space given for the Endless Corridor technique is 3.65×3.30. The VR HMD used for this experiment is the Oculus Quest 2 which has a $1832x1920$ display resolution per eye, with a refresh rate of 72 Hz and a 89° field of view.

4.2 Participants

We experimented with 11 participants (10 male, 1 female) aged between 20-25 years old. Two participants used glasses. Most of the participants had little VR experience.

4.3 Performance Metrics and Surveys

For measuring the performance of the participants at each given task, we decided to measure the task completion time [4].

Given the rest of our dependent variables, we pose the following questions for the survey based on the Likert scale:

1. Did you feel that the movements in the VR matched movements in the physical space during the VR experience? [3] (1:Strongly disagree, 7: Strongly agree)
2. How often did you feel that the movements in the VR matched the movements in the physical space during the VR experience? [3] (1: Never, 7: Very frequently)
3. Did you feel any type of motion sickness throughout the experiment? (1:Strongly disagree, 7: Strongly agree)

The questions are based on measuring the rest of the dependent variables.

4.4 Experiment Procedure

Participants are split into two groups for counterbalancing. As our experiment is designed to be within-subject, all participants will have to be tested on both conditions, namely the Real Corridor and the Endless Corridor. Group 1 will have the order be 1. Real Corridor, 2. Endless Corridor, whilst Group 2 has order 1. Endless Corridor, 2. Real Corridor. The groups are decided by participant number, meaning the first person we test on will be participant number 1, and the last participant number is 11. Participants 1, 2, 3, 4, 5, 10 are in Group 1, and participants 6, 7, 8, 9, 11 are in Group 2.

Depending on the group, they will either start with the Real Corridor or the Endless Corridor. Participants are welcomed and are asked to put on the HMD. They are then told to walk down a corridor-like environment by moving their character with the left thumb-stick, and complete two tasks along the corridor. The task used for the experiment is modeled in Fig. 4 The two tasks in the

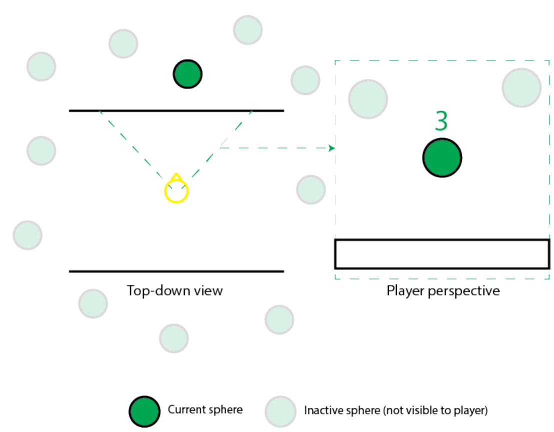

Figure 4: The task used for the actual implementation and experiment

experiment require the participant to look at spheres spawning in a set order. Looking at Fig. 4, the spheres spawn clockwise, starting from the east most sphere. The participants are tasked with looking at the current sphere for 3 seconds. Once 3 seconds have elapsed, the current sphere will disappear, whilst the next sphere will appear, prompting the participant to now look at this sphere. Using the left controller, the virtual rotation of the participant is constantly updated. We use this variable to decide when the task is complete. Once the participant has rotated a full 360 degrees in the virtual world, the task will stop, and prompt the user to continue down the platform. As the participant completes the second task, we remove their HMD and ask them to answer our survey. Once answered, we ask them to once again complete the task and answer the survey, however this time we load a build with the opposite technique of what they began with.

5 Results

After performing the user experiment, we collected the following data

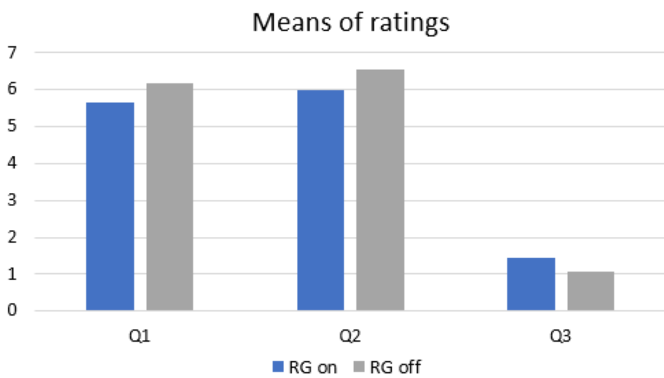

Figure 5: Means of ratings (RG: rotation gain, Q: question)

As Figure 5 shows, the user ratings for the questions were in close proximity, whether rotation gain was turned on during the experiment vs. turned off. To examine the results further, we have performed a paired samples t-test on the gathered data. The t-test was performed as a two-tailed t-test, as some participants rated the experiment with rotation gain as more realistic. We chose a significance level of 95%. A t-test has been performed for each question, using the user ratings. Both the test runs with rotation gain applied, and without rotation gain have been used in each t-test. The t-tests gave us the following p-values

- Question 1: $p = 0,081$
- Question 2: $p = 0,095$
- Question 3: $p = 0,103$

For all the questions, we did not reject our H_0, since the p-value is higher than our significance. This means, that the experiment showed for all questions that it revealed no noticeable difference between using avatar rotation gain compared to normal rotation.

The average task completion time for the test run with rotation gain applied was 1 minute and 16 seconds. In the test run with no rotation gain, it was 1 minute and 4 seconds. We performed a two-tailed t-test on the completion time with a significance level of 95%. The t-test was performed in the same manner as the other t-tests. The null hypothesis remained the same as we were interested in comparing the task completion time across the two different iterations of the game. The t-test on task completion task was evaluated to the following p-value.

- Task Completion time: $p = 0,456$

We did not reject our null hypothesis with a p-value of $p = 0,456$, which indicated that the task completion task can be assumed identical with a t-test on 11 subjects with alpha at 5%. We limited the bias in what method the participants tried first by counterbalancing the order of tried technique, as half of the participants started out using rotation gain, and the other half started out using the unaltered version.

6 Discussion

We believe a between-subject design experiment, is better suited for the hypothesis we would like to test. This is since we would like to hide what we are testing on, namely the rotation gain. Due to the restricted amount of available participants, however, we believe a within-subject design experiment will provide us more insightful data, than what a between-subject design experiment would with this amount of participants. A larger amount of subjects would have provided more insightful data. There was only one subject that seemed to notice that something was a little off with the rotation gain experiment. With a larger sample size, we could have.

Looking at other papers that measure motion sickness, we noticed that Kennedy's Simulator Sickness Questionnaire (SSQ) [2] frequently appears. We would have liked to have used the same questionnaire, however, it seems that the paper is locked behind websites that require special access to read it. Therefore we had to come up with our own "primitive" way to measure motion sickness.

As mentioned before we rejected H_0 for all our questions. The primary goal was to make the user rotate 180°, without the user noticing the rotation gain. The performed t-test for this question proves that the users felt that the movements in the VR matched movements in the physical space during the VR experience.

Our implementation with rotation gain revolved around tracing how many degrees the user rotated. We didn't have access to any advanced hardware to track the rotation, therefore, we instead used the left controller. It is possible to track the angle of the joystick, therefore we made a counter using the angular change of the joystick to determine when the participant was calibrated. With calibration, we refer to the player having turned 180% degrees in the real-life from the original direction, while the participant still is looking in the original direction in the virtual space. Due to only using the controller and tracking its rotation, all the participants were asked to hold the joystick in a tight fixed position near their stomach. When the participants complied with this and kept it in a perfect angle and position, our test results were complete as designed. However, some of the participants didn't focus on keeping the joystick in a tight locked position resulting in a slightly imprecise calibration. We experimented with holding the left joystick in a box, but the inputs were slightly inaccurate when we did this. In a fully optimized setting, a vest or some other device could have been used to handle the angular change in the avatar along with the calibration in a more reliable way. We didn't use the headset to calibrate the movement because a person can move their head while their body is stationary. This would have led to either the experience being unnatural because we should tell the participants to only move their body and not their head or a very unreliable calibration due to exaggerated head movement. This is the reason why we used another device, in this case, the joystick, to have the sole purpose of tracking rotation.

While testing our software we had limited space, and therefore couldn't fully test the software in an open environment. This resulted in a bug where real walking inside the virtual space, resulted in the player position not moving, while the virtual player camera was following the player correctly in the virtual space. This bug did not occur while we used the joystick which led to us not discovering it before the day when other people should try or implementation. The bug proved a problem when we reached the task zone where we had to calibrate the player's orientation using the player position. Due to us using the player position in our code it resulted in a complex bug where the virtual camera would rotate around where it believed the player position was. This perceived player position was the spawning position when the game started. To accommodate for this unexpected bug, we drew a small tracking space for the participant, and the participants should then instead use the left joystick for the majority of their movement. This wasn't a problem in our findings as our primary focus was to observe whether the participants noticed their changing orientation while they were completing tasks. The most critical component was that the direction in which the participant would face matched with the expected direction. This did therefore not have a critical consequence for our findings but was a shortcoming of the original idea nonetheless.

7 Conclusion

From our experiment, we can hereby conclude, that there is no noticeable difference between walking down a virtual corridor completing tasks with and without rotation gain applied. The implementation of the given application seems to work appropriately, such that the user doesn't notice when rotation gain is applied to their HMD.

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