Analyzing the Trade-off between Selection and Navigation in VR

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ABSTRACT

Navigation and selection are critical in very large virtual environments, such as a model of a whole city. In practice, many VR applications require both of these modalities to work together. We compare different combinations of two navigation and two selection methods in VR on selection tasks involving distant targets in a user study. The aim of our work is to discover the trade-off between navigation and selection techniques and to identify which combination leads to better interaction performance in large virtual environments. The results showed that users could complete the task faster with the fly/drive method and traveled less, compared to the teleportation method. Additionally, raycasting exhibited a better performance in terms of time and (less) distance traveled, however, it significantly increased the error rate for the selection of targets.

CCS CONCEPTS

• **Human-centered computing** → Human computer interaction (HCI); Interaction paradigms; Virtual reality; Human computer interaction (HCI); Interaction techniques; Pointing; Interaction design; Empirical studies in interaction design.

KEYWORDS

Navigation, Selection, Virtual Reality, Interaction Design

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1 INTRODUCTION

Large and complex virtual environments (VEs) are becoming more common. To make the interaction with such VEs faster and easier, many selection and navigation techniques have been proposed. We are thus interested to know how the combination of navigation and selection techniques affect user performance considering task completion time, error rate, and distance traveled. We designed a study to investigate the combination of either one of two chosen selection techniques with one of two navigation techniques. We chose our selection techniques (Ray-casting and Virtual hand) based on surveys which classified VR selection techniques based on their action space [5, 9, 10]. As the navigation techniques, we selected the two most commonly used methods: Teleportation and Fly/Drive. We analyzed the tradeoffs between the combinations of these techniques.

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2 RELATED WORK

While many studies have introduced or evaluated either selection or navigation techniques [1, 2], to the best of our knowledge, no study has addressed the effect of the combination of these two interaction modalities to identify the trade-off between them. VR studies typically compare navigation and selection separately [2–4]. However, most VR applications rely on offering both navigation and selection methods to enable users to perform all needed tasks [1].

We selected our two selection techniques based on the results of surveys [5, 9, 10]. They classified VR selection techniques and used the action space (infinite/arm-scale) to categorize them. We chose the most well-known object selection techniques from these studies: Ray-casting (infinite) and Virtual hand (arms-scale). Many selection techniques are variants of these two techniques. For example, Flashlight [6] is a variant of ray-casting and Go-Go [7] is a variant of the virtual-hand method. We selected these two fairly generic techniques to compare methods within different action spaces, while at the same time affording familiar selection methods with good performance. Among numerous candidate navigation techniques, we choose teleportation and fly/drive. In a comparison with three other ones, fly/drive was identified as the best navigation method in a recent study [8]. Teleportation was also identified as being superior in another study [2]. Thus, we selected these two methods to combine with the selection techniques.

3 METHOD

3.1 Stimuli and Apparatus

We experienced many restrictions on data gathering due to the COVID-19 pandemic during the study. Five participants, two male and three female, were recruited for the study (ages 24 to 30). Since we compare each participant with themselves through a within group experimental design, it was not necessary for participants to have previous experience in VEs.

We used an HTC Vive as the head mounted display (HMD) to present the VE to the participants. The VE that we used to investigate our research questions was designed in Unity3D. During the experiment, participants could see a single cluster of objects in the VR environment from their viewpoint. Participants were placed at a specific distance to the target and their goal was to select a highlighted small sphere within a cluster using the available navigation and selection methods. The size of clusters and the initial distance to the target for each task were chosen from 9 different trials (3 target sizes × 3 target distances). In each condition of the experiment, participants repeated the same task 5 times for each of the 9 trials, for a total of 45 repetitions. In each task, the cluster was

Figure 1: 3D clusters and target objects in different viewpoint. Left: how the environment looked at the start position. Right: selection of the target (yellow ball) using raycasting mode.

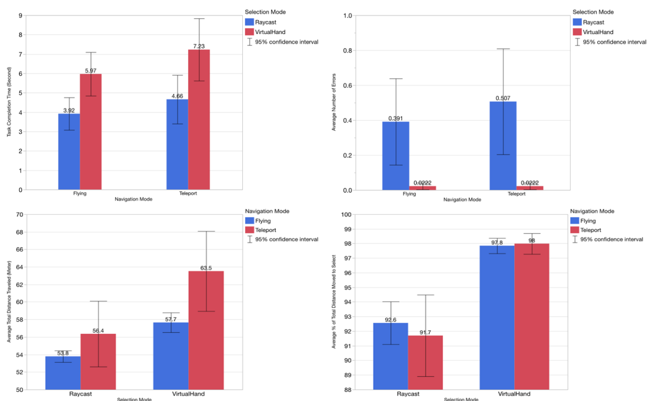

Figure 2: Results of the experiment. Top left: task completion time (s). Top right: number of errors. Bottom left: total distance traveled (meter). Bottom right: relative distance traveled (percentage of total distance to target).

placed sufficiently far away from initial position of the participant in the VE to make it impossible to select it directly. Figure 1 shows different viewpoints of the VE, 3D clusters and target objects.

3.2 Navigation and Selection Modes

For navigation, we implemented two typical techniques: teleportation and fly/drive. In the fly/drive mode, participants could change their movement direction and speed, while with teleportation they could jump to the position that they indicated using the ray pointer. For selecting targets, participants used either raycasting (which selects the first target along a pointer ray) or a virtual hand, where they can "grab" a target that the controller intersects. Figure 1 shows the appearance of the raycasting mode.

3.3 Experimental Design

The experiment used a 2 by 2 within-subject design, where each participant experienced all four of the conditions, which corresponds to the 4 combinations of both navigation and both selection methods. In each condition, participants had to perform nine trials, and each trial was repeated 5 time, for a total of 45 repetitions. Task completion time (in seconds) was measured from the moment that participants saw the target until they attempted to select it. Selection error was measured as the percentage of selection errors that participants made while attempting to select the target. A selection error occurred when the trigger button of the controller was pressed, but the ray or the virtual hand cursor did not intersect with the object. We recorded the total distance that participants navigated before the successful selection. Also, we defined the relative distance travelled as the percentage of the distance between the participants' original position and the position where they successfully selected a target divided by distance at which the target was initially presented.

4 RESULTS AND DISCUSSION

Following the within-subject design of the experiment, we used two-way repeated measure ANOVA to analyze the data. For the task completion time, the result of the ANOVA showed that the average of task completion time was significantly affected by the navigation method, $F(1, 4) = 14.19$, $p = .0196$, $\eta 2 = 0.78$, and the selection method, $F(1, 4) = 86.76$, $p = .0007$, $\eta 2 = 0.89$, but was not affected by the interaction of navigation and selection, $F(1, 4) = 2.08$, $p = .22$, $\eta 2 = 0.34$.

Considering the error rate, we found a main effect of selection method ($F(1, 4) = 20.23$, $p = .0108$, $\eta 2 = 0.83$); however, the main effect of navigation method ($F(1, 4) = 4.55$, $p = .099$, $\eta 2 = 0.53$) and the interaction of the two factors ($F(1, 4) = 5.47$, $p = .079$, $\eta 2 = 0.57$) were not significant.

Lastly, the results of an ANOVA identified main effects of navigation method ($p = .018$) and selection method ($p < .000$), without an interaction effect ($p = .23$), for total distance traveled. Also, the test showed a main effect of selection method ($p = .001$) but could not identify a main effect of navigation method ($p = .44$) nor an interaction ($p = .36$) for relative distance traveled. Figure 2 shows the results of the study.

Based on the results, task completion time was higher in the teleportation mode compared to fly/drive, and with the virtual hand mode compared to raycasting. The higher overall time with virtual hand was not unexpected since participants had to touch the target to select it, which means that they had to navigate longer to get closer to the target (relative to raycasting). However, the higher time with teleportation was surprising because participants could travel a substantial distance with just a click.

Our results show lower error rates for the virtual hand. The difference is substantial, since with raycasting participants made on average 40 selection errors in 90 trials, while they made on 2 selection errors in 90 trials with the virtual hand. This result supports the virtual hand method when precision is important.

The results for the total distance traveled showed that with teleportation, participants navigated more with the virtual hand than with raycasting. With raycasting, participants traveled about 92% of total distance (approximately 3.18 meters from target). With the virtual hand, this number was 98% (approximately 0.8 meters from target), which is only 6% higher. This indicates that although participants had the option to select targets from afar with raycasting, they still preferred to navigate to a point reasonably close to the target and to act within a fairly consistent range of distances.

In this study, we investigated the trade-offs of different combinations of selection and navigation methods in large VEs. In the future, we will extend our study to other techniques and towards identifying a best set of techniques for different selection and navigation tasks. In addition, we will compare the advantages and disadvantages of each method in more detail. We will also re-analyze all of our findings with data from more participants.

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