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Effects of Joystick Mapping and Field-of-View on Human Performance in Virtual Walkthroughs

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Abstract

Virtual environments are increasingly used to visit virtual mockups of proposed buildings or virtualized models of real sites or buildings. This paper presents the results of a human-machine interaction experiment aimed at measuring the effects of the real field-of-view (FOV) and of the use of a third joystick axis on human performance for navigation in virtual walkthroughs in a closed-space environment. The results indicate that neither the real FOV nor the third joystick axis significantly affect performance. There is however a perceived increase of immersion with the larger real FOV, and an added freedom of movement when a third axis of movement is mapped onto the joystick.

1. Introduction

A lot of research is currently done in the field of virtualized reality, which relates to the sensing and modeling of real 3D worlds, generally with the help of sensors [1]. The models obtained by such means are often visited in virtual walkthroughs for applications such as telepresence, virtual visits, or virtual museums. Because navigation in virtual environments is often difficult [13], an important aspect for public acceptance of those applications is the usability of the navigational interface [8, 9].

A good interface must be easy to learn, easy to use and provide good performance, i.e. allow fast and accurate navigation in the virtual environments. In the case of virtualized rooms and buildings, the usual navigation paradigm is the virtual walkthrough [2, 3]. The walkthrough allows users to move the viewpoint through the virtual environment, while also controlling its orientation. In contrast to flythroughs, users cannot move the viewpoint up or down unless transported by a virtual object like an elevator.

Many input devices such as mice, keyboards and joysticks are used to navigate in virtual walkthroughs. When rate control is used, elastic input devices such as joysticks are generally better suited to navigate in environments, especially during the learning phase [4]. Recently a flurry of three-axis joysticks has appeared in the market. Although this could be useful because it adds a third degree-of-freedom (DOF) to interact with flight simulators, the usefulness of a third DOF for virtual walkthroughs has not been demonstrated. We address this issue in this paper.

There are also different output devices to display the virtual environment, such as head-mounted displays (HMD), wall-based displays, and desktop monitors. These displays provide different FOVs to the user, which vary the degree of immersion within the world. It is known that generally a large FOV increases the immersion of the user [5, 10] and helps build a cognitive map of the world [12]. Although the effect of the FOV on human performance has been studied with HMDs [6], those use a 6 DOF control interface. This contrasts with desktop and wall-based displays where 2 or 3 DOF control interfaces are generally sufficient for virtual walkthroughs, thus reducing the cost and complexity of the system. It is then important to measure their effects on human performance.

This paper presents the results of an experiment in which we compared the effect of 2-axis and 3-axis joystick mappings as well as of the FOV on the navigational performance of human subjects for virtual walkthroughs.

2. Experiment

To study the effect of the number of joystick axes and of the FOV on navigation performance in virtual walkthroughs, we used a virtual world consisting of a maze made of a complex corridor (Figures 1 and 2), such as could be found in the catacombs or in a pyramid.

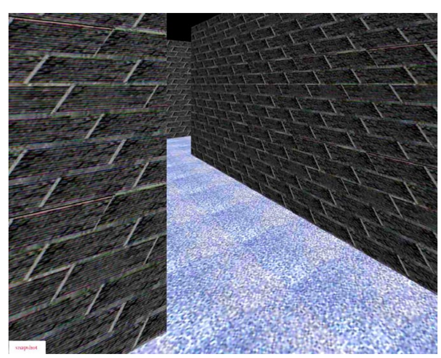

Figure 1. A view of the walkthrough environment

3. Experimental Method

The experiment was carried out in a controlled environment with the following conditions:

3.1. Subjects

In total, 16 volunteer subjects (11 males and 5 females) participated in the experiment. They were all right handed, computer literate, and had an age distribution of 18/59/30 (min/max/average). They all had perfect or corrected vision. Most of them had no or limited experience with joysticks.

3.2. Task

Users were instructed to navigate from the start point to the end point in the shortest time possible, while trying to avoid collisions with walls by navigating in the center of the corridor (Figure 2).

3.3. System

The displays used for the experiment were a desktop monitor and a wall-based display with respective horizontal dimensions of (0.50 m and 3.0 m). Both had a resolution of 1280 x1024 pixels, an update rate of 30 fps, a refresh rate of 60 Hz and a total response time smaller than 140 ms.

The *real FOV* is the angle subtended by the two ends of the screen when projected into the user's eye. The viewing distance of the users was 70 cm in the desktop configuration and 1.8 m in the wall configuration, thus giving *real horizontal FOVs* of 40° and 80° respectively.

The virtual corridor was 2 m wide with walls that were 3 m high. It had a total length of 100 m, with 20 turns (10 to the right and 10 to the left (see Figure 2)). The virtual (avatar) viewing height was 1.8 m, with a *virtual FOV* of 80° x 60° (H x V) for both the desktop and the wall-based configurations. The *virtual FOV* is the angle of the viewing-volume frustum used for the perspective projection [14].

The *real FOV* is one of the two independent variables studied in this experiment, since the *virtual FOV* is the same in all the conditions.

The navigational interface was a 3-axis joystick (SideWinder Precision Pro from Microsoft), using two different mappings: the standard 2-axis mapping to control the yaw and forward/backward movement of the user, and a 3-axis mapping, to add a third degree of freedom to the user, which was a lateral movement (Figure 3).

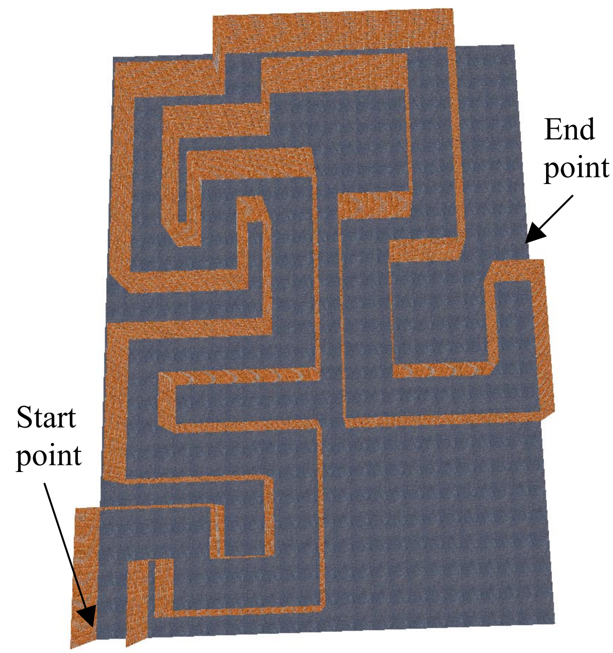

Figure 2. Bird's eye view of the maze

Both navigational interfaces used rate control to move within the maze. The translations were controlled with a linear function gain and a maximum speed of 5 m/s, while the rotations used a cubic function gain and a maximum speed of 90°/s. The speed values and function gains used here were found, in a pilot study, to optimize the performance.

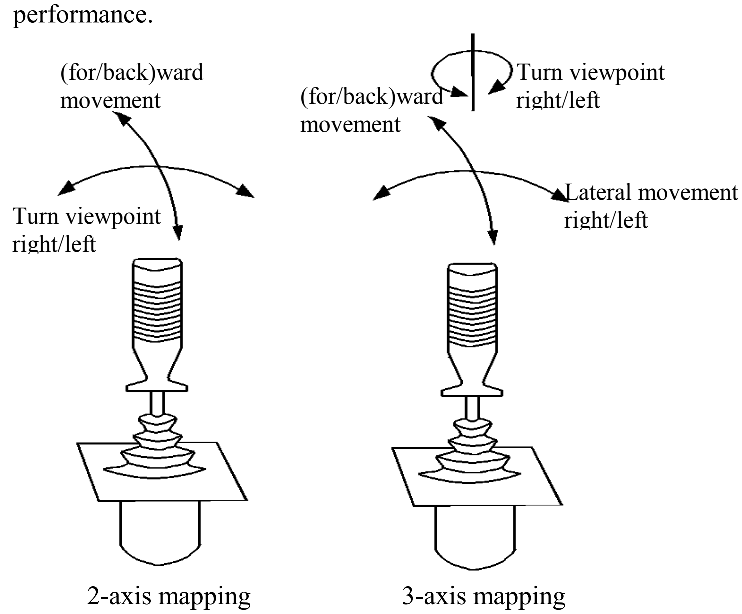

Figure 3. Illustration of joystick mappings

3.4. Design

The independent variables were the real FOV and the joystick mapping, while the dependent variable was the completion time. We used a 2x2, within-subject design with repeated measures and used a balanced order to avoid the effect of practice on the results; producing four conditions, each combining a real FOV with a joystick mapping. For each of the four conditions, the subjects had one practice trial followed by 3 main trials, for a total of 12 main trials.

3.5. Procedure

Once the subjects had read the instructions and completed a consent form, they were seated in front of the respective screens and told to begin the experiment. Subjects were allowed to ask questions at anytime during the experiment but were otherwise left alone until the end of the trials.

Each trial was preceded by an audiovisual countdown of three seconds and for each condition, the users had one practice followed by three main replications, in order to lower the effect of practice on the performance. Finally, the trials ended automatically when the subjects reached the end point.

Once all the trials were completed, they were asked about their level of satisfaction with the joystick interfaces and about their preference for the small or large FOV. Finally, all their comments about the experiment were to help provide insights about the results.

4. Results

The results of the experiment are divided in two groups: the quantitative results and the qualitative results.

4.1. Quantitative results

Figure 4 illustrates the results for the four conditions. An analysis of variance (ANOVA) with the pseudo-F test shows no significant effect of the real FOV (RFOV) on the completion time, ($F_{1,15}$ = 1.223, p>0.05). It also shows no significant difference for the completion time between the two joysticks ($F_{1,15}$ = 0.388, p>0.05).

Also, no significant interaction has been found between the different variables. The ANOVA, however, shows that completion time is significantly reduced with practice. ($F_{2,30}$ = 11.465, p<0.05).

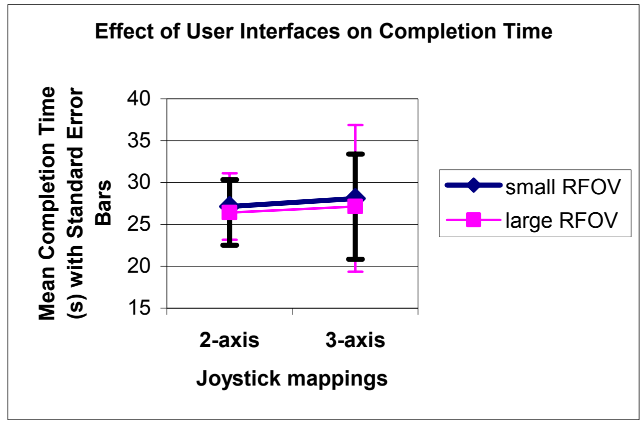

Figure 4. Completion time for the four conditions

Figure 5 below illustrates the effect of practice on the completion time.

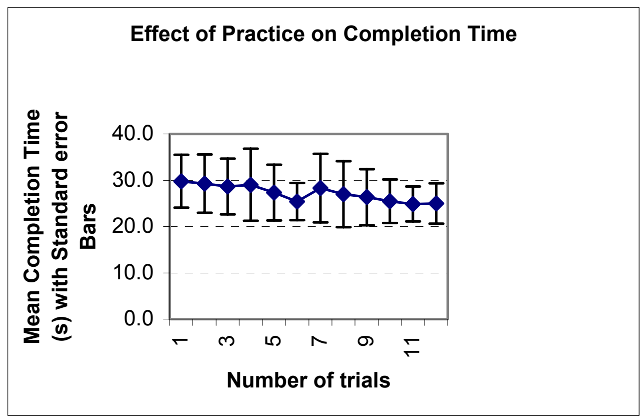

Figure 5. Effect of practice on completion time

The curve generally follows the power law of practice [7] except for the small transitions between each group of three trials where subjects switched from one condition to the other. The bump is particularly visible between the 6th and the seventh trial, where the subjects switched from one FOV to the other.

4.2. Qualitative results

Figure 6 shows the results of the subjective ratings at the end of the trials, where subjects were asked to rate on a scale from 1 to 5, the control interface on the ease of use, the fatigue, the precision and the performance.

Comments from the subjects indicate that they think the 3-axis joystick has better potential to increase the performance after a period of training, especially because the third axis allows lateral movements. The qualitative results, however, indicate no significant differences between the two joystick mappings.

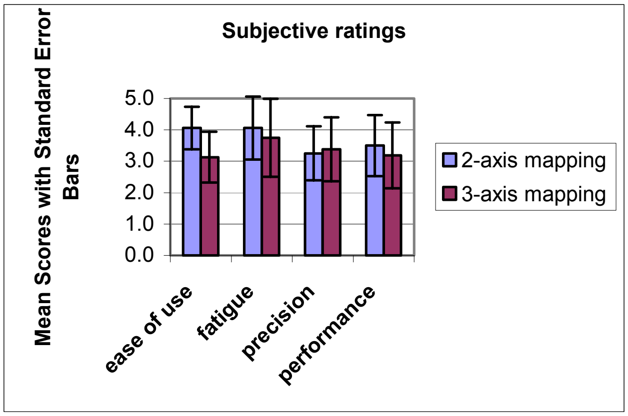

Figure 6. Subjective ratings of the mappings

Finally, all the subjects indicated that the larger FOV increased their feeling of immersion in the virtual environment.

5. Discussion

No significant difference in performance were found between the joystick's 2 and 3-axis mappings, thus indicating that the use of a third axis doesn't hamper performance, while allowing an additional degree of freedom and thus more complex movements.

The results also indicate that for a fixed virtual FOV, a change of the real FOV doesn't affect the performance although a larger real FOV increases the level of immersion. This result is consistent with real world experience where people in a movie theater can see the same movie but from different distances (and thus different real FOVs) even if these do not exactly match the virtual FOV of the camera, a phenomena called robustness of visual perspective [11]. We have now demonstrated that this robustness also holds true for navigational performance in virtual walkthroughs.

6. Acknowledgements

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