An Evaluation of Techniques for Controlling the Speed of Travel in Immersive V.E.

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Abstract

While traveling in immersive virtual environments (VEs), a number of navigation techniques are used to enhance one's sense of presence. Velocity control is commonly used to increase interactivity; with an effective velocity control technique, people can easily navigate a large-scale virtual environment. In this paper, five commonly used velocity control techniques are evaluated. In our experiment, twenty subjects use each velocity control technique to travel through various virtual corridors. In all cases, the participants use Pointing [1] to indicate direction of travel. Each user is requested to perform an information-gathering task to measure their ability to remember specific words and their locations in the environment. Additionally, we evaluate each technique by con-ducting qualitative analysis and measure the sense of presence using the Steed-Usoh-Slater (SUS) presence questionnaires.

Keywords: Virtual Reality, Interaction Techniques, Velocity control techniques.

1. Introduction

In a large-scale virtual environment, navigation techniques are commonly used to assist people in moving freely about the environment. In general, many VE applications adopt a continuous velocity. However, when traveling in a large-scale virtual environment, it is often useful to be able to change one's velocity in order to more efficiently explore the environment. Although most of existing techniques are useful and efficient for controlling speed, some are inappropriate for navigating in a 3D virtual environment. Furthermore, most of the designed techniques have been evaluated and formalized in a same experimental setting. Therefore, we evaluate in the same experimental environment five commonly used velocity control techniques: discrete, time-based, gesture-based, force-based, and speech-based.

To determine the usefulness and efficiency of each technique, we perform a quality factors analysis regarding speed, accuracy, ease of learning, ease of use, etc. [2]. In thinking about human-computer interaction, it is essential to consider usability, acquisition, and comfort (e.g., user-centric performance measures [10] and simulator sick-ness questionnaires (SSQ) [6]). However, immersion is the most important factor. Therefore, the techniques are evaluated in terms of this by experimental qualitative analysis. The Steed-Usoh-Slater (SUS) presence questionnaires are used to measure the sense of presence [11].

2. Previous Work

In order to overcome the difficulty of navigating VE, several methods have been proposed. Step-WIM is designed similarly to a map-based traveling method [9]. Using the step-WIM, the user can navigate by quickly stepping into another place in the world using a map shown on the floor. To support a natural and intuitive interaction, a foot-pedal prop is used as the locomotion input device [3]. However, the foot-pedal prop is expensive. Another device used to control the speed of travel, Bbat, is a 3D passive force feedback device [4]. However, this has a restriction such that the user has to use both hands and thus has not been used widely. As an alternative to force feedback devices, force sensing resistors (FSRs) have been proposed [5].

3. Techniques and experiments

Five different velocity control techniques are tested:

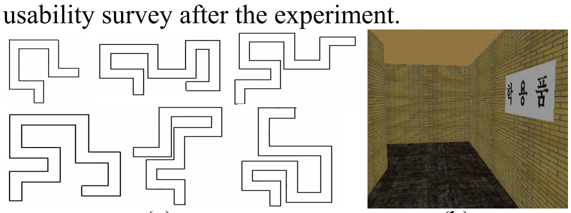
- Discrete velocity control technique
- Time-based velocity control technique
- Gesture-based velocity control technique
- Force-based velocity control technique (Forve)
- Speech-based velocity control technique

Discrete velocity control technique uses two buttons: one for increasing the speed and the other for decreasing it. Instead of counting the button clicks, time-based velocity control measures how long the button is pressed.

Gesture-based velocity control operates by measuring the distance between the user's hand and head position [8]. Force-based velocity control uses a force-sensing resistor (FSR) sensor to control the speed. When force is applied to this sensor, traveler's speed is increased or decreased [5]. Finally speech-based velocity control uses speech recognition technology. The speed of travel is increased or decreased momentarily with the recognition of different utterances.

In the experiment, a spatial mouse (3D mouse) is used to indicate or steer toward the direction of travel. A VFX-3D (HMD) is used with Polhemus Insidetrack trackers. A trial environment and five experimental environments are designed using the Simple Virtual Environment (SVE) toolkit [7].

Twenty student volunteers, seventeen males and three females, participated in the experiment. During the experiment, both the completion time and the frequency of collisions are monitored. Ten words are positioned randomly in one of the places such as wall, ceiling or floor. All subjects are requested to write down their memorized words and the words' locations and also take a usability survey after the experiment.



(a) (b)

Figure 1. Outline of a trial environment (top-left) and five different experimental environments (a) and interior view of the virtual corridor and information (the word "stationary" in Korean) attached on the wall (b)

4. Result and Discussion

4.1. Evaluation

The user's ability is evaluated in terms of completion time, number of correct words, location accuracy, and surface accuracy. The overall score can be described as $(3a+2b+c)/t$, where t = total time spent, a = the number of correct combination of word, location, and surface, b = the number of answers in which two variables are correct and c = the number of answers in which only one variable is correct.

Table 1. Mean and Standard Deviations of time spent in seconds (maximum time limit is 180 seconds)

	Discrete	Time-based	Gesture-based	Force-based	Speech-based	Total
Mean	132.1	133.2	133.5	113.5	143.8	131.2
Std	38.3	33.9	28.0	29.5	31.5	33.3

The left image in figure 2 shows that time-based and gesture-based velocity control techniques are superior to other techniques in information gathering. In contrast, the right image shows that force-based velocity control technique performs best when considering time spent. This indicates that most of subjects spend relatively more time when using time-based or gesture-based velocity control techniques.

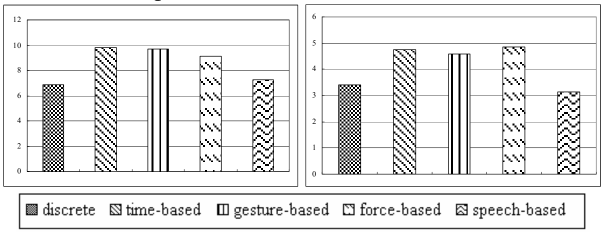


Figure 2. Mean values of overall score without dividing by time spent in minutes $p<0.01$ (left) and mean values of overall score $p=0.05$ (right)

We also perform an analysis of different velocity control techniques based on the number of collisions to the walls. A collision occurs when the subject hits the wall, and the duration of the collision (in frames) is also recorded. The total collision duration is significant ($p<0.01$) by a standard single-factor ANOVA analysis. The difference in total collision count is not significant.

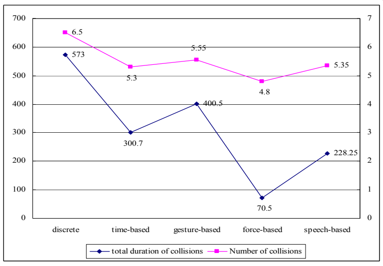


Figure 3. Number of collisions and total duration of collisions (in frames)

Another interesting result is the sense of presence. The sense of presence is measured after each experiment using the Steed-Usoh-Slater presence questionnaires [11].

Table 2. Mean and Standard Deviations of Questionnaire Scores

	Discrete	Time-based	Gesture-based	Force-based	Speech-based	Total
SUS Mean	*4.15±0.94*	4.65±0.93	4.58±0.81	4.62±1.03	4.53±0.95	4.51±0.93
SUS Count	0.60±1.04	0.80±1.32	0.85±1.18	1.15±1.42	1.20±1.32	0.92±1.26

There is no significant difference among the velocity control techniques. However, force-based and speech-based velocity control techniques have higher scores in SUS count.

4.2. Characteristics

Simulator sickness questionnaires (SSQ) is used in order to measure user fatigue and discomfort. Each question is classified into three columns (nausea, oculomotor discomfort, and disorientation), plus total severity [6]. The only significant score is oculomotor discomfort ($p<0.01$).

Table 3. Computation of SSQ scores across all participants

	Mean	*Standard Deviation*	*Low*	*High*	*Highest Possible Score*
Nausea	*31.48*	*27.87*	*0*	*114.48*	*200.34*
Oculomotor Discomfort	*40.55*	*23.36*	*0*	*90.96*	*159.18*
Disorientation	*50.80*	*40.21*	*0*	*153.12*	*292.32*
Total severity	*46.00*	*30.53*	*0*	*130.90*	*235.62*

Also all subjects are requested to rate velocity control techniques. Four different abstract performance values are measured such as ease of learning, ease of use, and user comfort, and user concentration.

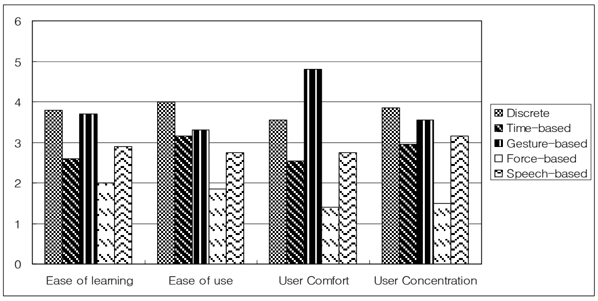


Figure 4. Measuring abstract performance values in order of preference (1=top choice, 2=second choice, etc.)

We found that force-based velocity control technique is the most efficient among the studied techniques. We also found that if a technique requires a lot of hand manipulations (i.e., a lot of button clicks) such as discrete velocity control technique, it causes the user discomfort. Although gesture-based velocity control technique is designed following a natural mapping with the user's actions, the results show that it is not the most ideal technique in terms of user comfort because user has to hold their arm up all the time to control the speed.

Overall, time-based velocity control technique displayed similar results to speech-based velocity control technique, although time-based is easier to learn and speech-based is easier to use. Both speech-based and gesture-based velocity control techniques are designed following a natural mapping to human actions. However, the result shows that gesture-based control is much more efficient than speech-based control for increasing or decreasing the speed of travel.

5. Conclusions

In this paper, five of the most commonly used velocity control techniques (discrete, time-based, gesture-based, force-based, and speech-based) were tested in immersive virtual environments. Several types of analysis were used to evaluate the performance of each velocity control technique.

Even though a velocity control technique might be well designed for controlling speed, other factors such as usability or comfort can affect the overall effectiveness and user experience. We hypothesized that a velocity control technique is efficient if it is designed following a natural mapping to human actions. However, in the case of gesture-based velocity control, subjects complained of arm and finger fatigue, and in the case of speech-based velocity control, they commented that recognizing the posted information is difficult while speaking commands.

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