Force-based Velocity Control Technique in Immersive V.E.

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Abstract

Virtual traveling technique in virtual environment (VE) is one of the interaction techniques. It aids user to travel freely in VE. Even though there are a lot of virtual traveling techniques, all is only based on the way of specifying the target position. In this paper, we proposed new travel technique called Forve which are allowed to specify the desired velocity and acceleration of travel. We evaluate its usefulness by conducting quality factors analysis. Subjects are required to travel through virtual corridors until reaching the end of the corridor. All subjects use various velocity control techniques while using the pointing technique for specifying the target position. Results indicate that the force-based technique is more efficient for specifying velocity and acceleration in VE.

CR Categories: I.3.6 [Computer Graphics] : Methodology and Techniques – Interaction Techniques; I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism – Virtual Reality

Keywords: Virtual Reality, 3D interaction technique, Virtual travel technique.

1 Introduction

As the technology of display and graphics systems have been developed, virtual environments (VEs) applications have become in common use outside the research laboratory [Martin 1996]. Although most of VE applications require the object manipulation more frequently, efficient viewpoint motion control does not exist enough to apply for interacting in a large-scale environment. Travel is one of the navigation techniques to maximize user's comfort and productivity in VE. Although they are useful and efficient in VE, most of travel techniques should specify the target position or moving direction. But user can have difficulties when he specifies the direction or position in a large-scale virtual environment. To reduce this problem, the strategy to allow users to select velocity / acceleration is indispensable in VE travel technique. Our work attempts to modify the existing velocity control techniques, and make them to be more useful techniques which can be easily applicable to a large-scale environment as well as reduce user's discomfort.

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In order to develop new traveling technique, we set limit of our application domain into the following area. First, we use the new technique in immersive virtual environment, in which user wears head tracked and head-mounted displays, and uses 3D spatial input device called the flying mouse for interaction. Second, in our study the first-person viewing system is considered. User can navigate VE depending on camera viewing point whose position can be acquired from head-tracking system attached on user's head. Finally, we are interested in the way to control velocity/acceleration easily and efficiently rather than the way to travel.

We compare new technique with previous techniques. To show its usefulness and efficiency, we perform the quality factors analysis regarding speed, accuracy, ease of learning, ease of use and so on [Bowman at al. 1997]. From a point of view of human-computer interaction, it is essential to consider usability, acquisition and comfort (e.g. user-centric performance measures [Poupyrev et al. 1997]). Especially immersion is the most important. Therefore we perform experimental qualitative analyses for evaluating various techniques.

In the following section, we review previous related researches about travel techniques. In Section 3, our newly proposed techniques are explained. Experimental framework and results are described in later section. Our conclusion will be followed.

2 Previous work

2.1 Viewpoint motion control

Viewpoint motion control called travel is a technique by which user can navigate through virtual or 3D environment. A lot of 3D games adopt the viewpoint motion control, but they use 2D input devices as a velocity control system.

Lots of researchers have issued the results about viewpoint motion control in immersive 3D environment. Ware et al. define new metaphors such as the "flying", "eyeball-in-hand", and "scene-in-hand" [Ware and Osborne 1990][Ware and Jessome 1998]. Pausch and et al. suggest new navigation and locomotion control called a "World-in-Miniature" [Pausch at al. 1995]. While user can navigate immersive VE via flight technique, spatial awareness problem take place. Bowman and et al. evaluate spatial awareness in absolute and relative motion control by adopting velocity/acceleration schemes. And he categorized existing viewpoint movement controls to obtain taxonomy of virtual travel techniques focusing on different views and structures. The taxonomy consists of three parts such as Direction/Target and Velocity/Acceleration Selection and Input Conditions [Bowman at al 1997]. Also he generated new travel taxonomy depending on fundamental differences of interaction techniques [Bowman 1999].

To overcome the difficulty of navigation in a large-scale virtual environment, landmarks based VE guidelines are proposed [Vinson 1999]. More efficiently support a natural and intuitive fashion, a foot-pedal prop is used as locomotion input device [Brogan 1998][Couvillion at al. 2001]. In [Paton and Ware 1994], a 3D passive force feedback device (Bbat) is used to control velocity while navigating the 3D environment. It is the first trial of using force to control velocity, but it has some restrictions such that user has to use their both hands so that it is not used easily to other applications.

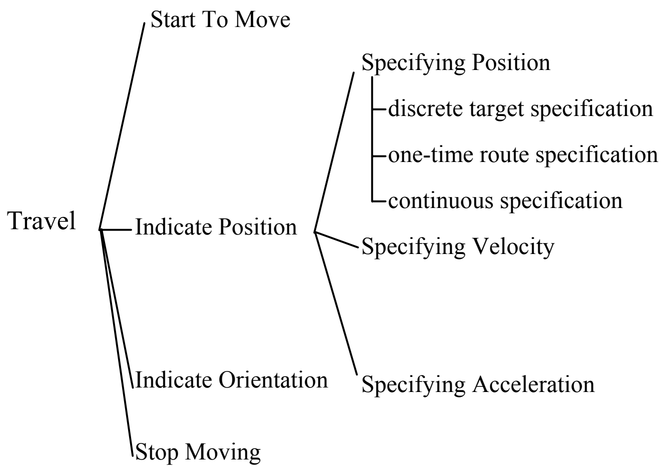

Figure 1. Taxonomy of virtual travel techniques [Bowman 1999]

A lot of researchers focused on using force feedback technology to enhance user performance in many tasks. But a few researches applied force field to immersive 3D travel technique. Although force feedback enhances the capabilities of virtual environment system, we only focused on sensing device in this paper.

2.2 Pressure sensors

Pressure sensors offer continuous control in one dimension. They can be combined into an isometric joystick or a spaceball. Further more pressure sensors are used in enriching interpersonal communication paradigm [Chang at al. 2002]. Common sensors are used in Human Computer Interface (HCI) to devise a new device or to get information from human. Also since pressure sensors are easily applicable and movable, they are useful.

3 Force-based velocity control technique

To navigate or travel in VE, a lot of previous techniques indicate the target position to reach a goal. As shown in Figure 1, travel techniques with indicating position can be classified into three different categories by three fundamental factors. They are position, velocity and acceleration. The techniques using position are efficient for navigating VE. If the VE is relatively huge, user can hardly reach the goal. Also, it can cause serious discomfort about spatial awareness. To reduce the problems and increase comfortableness, travel techniques should adopt velocity or acceleration control. There are some previous velocity control techniques such as discrete velocity control by counting button clicks, time-based control by measuring how long button is pressed and gesture-based control by dividing arm's reach into three velocity zone. Although most of them are broadly used, more effective technique is necessary.

We have designed a new technique by applying pressure sensor, commonly called force-sensing resistors (FSR's). It uses the electrical property of resistance to measure the force (or pressure). A force sensing resistor is made up of resistive film and digitizing contacts like conductors. The resistive material serves to make an electrical path between the two sets of conductors on the other film. When a force is applied to this sensor, a better connection is made between the contacts; therefore conductivity is increased. Conductivity is approximately a linear function of force ($F\alpha C$, $F\alpha 1/R$).

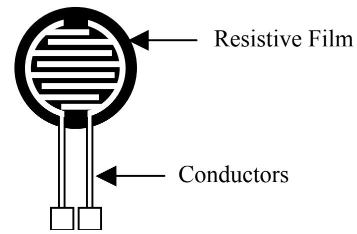

Figure 2. Diagram of a typical sensing resistor

The sensor is attached on 3D spatial input device with which user can increase velocity just by pressing it with one's forefinger. As user press, the conductivity of FSR's is increased, and then velocity of travel is accelerated.

4 Experiments

To travel in VE, user must indicate or steer the direction of travel. The discussion is not focusing on steering techniques in this work; therefore evaluating and comparing task among different velocity control techniques is performed using the same steering technique. In our experiment, we adopt the pointing technique as steering the direction because it is relatively advantageous and follows relative viewpoint motion control [Bowman at al. 1997].

With the pointing steering travel technique, we evaluate and compare several velocity control techniques listed as below under the same experimental setting.

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

A VFX-3D (HMD) is used attached with Polhemus Insidetrack trackers and a 3D spatial mouse. The virtual environment is built using the Simple Virtual Environment (SVE) toolkit [Georgia Tech. 1997], and rendered on a desktop computer (dual CPU) with graphic accelerator.

Before participating in the experiment, subjects experienced experimental trials to learn how to use the techniques. In the trials, some explanation is given because none of subjects has the experience of virtual environment.

4.1 Method

Twenty-two student volunteers participate in the experiment. All subjects have basic knowledge about virtual reality, but no experience. Four velocity control techniques are tested for evaluating performance.

We have designed several different virtual corridors as virtual environments. Subjects travel through the corridor using one of four velocity control techniques in different virtual corridors. The environment consists of 10 sections. Each section has only one word and randomly positioned on the walls, ceilings and floors.

Figure 3 shows a word positioned on the right side wall. In the experiments, subjects must find their goal such as gathering information and searching for an exit. After the experiment, subjects answer the gathered information.

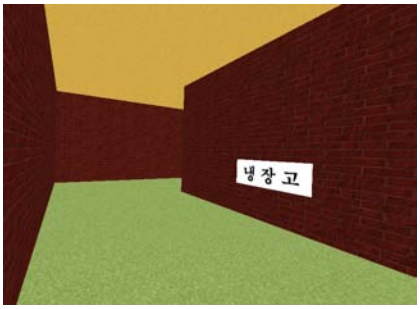

Figure 3. Interior view of virtual corridor and information attached on the wall

One of the virtual corridors is selected randomly before participating the experiment; therefore subjects may travel in different environments for their own experiment. The selected environment is excluded at once for the next selection not to be chosen it again.

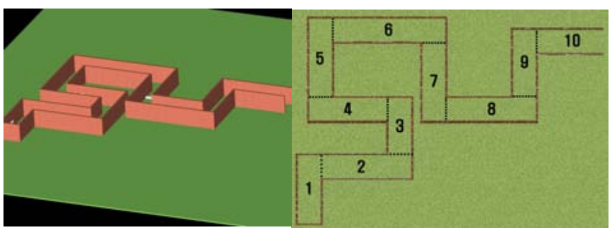

Figure 4. Exterior view of virtual corridor and map divided into 10 sections

Subjects use 3D spatial mouse to specify their ways. 3D spatial mouse is designed with a commodity component like I^3Stick [Brederson 1999]. In discrete velocity control, subjects click left mouse button to accelerate the speed and decelerate by clicking right mouse button. In time-based velocity control the velocity is measured how long the button is pressed. Depending on the time interval, speed is accelerated or not. Another velocity control technique operates by recognizing subject's hand gesture. The space consists of three zones such as decelerate, constant and accelerate. Mine used velocity zones to control speed [Mine 1995]. If subject stretch forward his hand which belongs to the accelerate zone, the speed grows exponentially depending upon the rate of acceleration. When subject gets close his hand to his body, system maintains constant speed or decelerate speed depending on the zone where his hand positions. Typically it uses linear mappings between hand position and its speed.

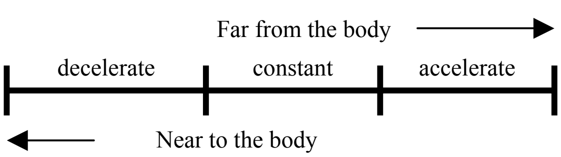

Figure 5. Hand controlled velocity zones

The last velocity control technique we suggest is the Forve. As we mentioned previous section, it is designed using force-sensing resistors (FSR's) attached on 3D spatial mouse. Whenever subject applies force to FSR's using his forefinger, speed grows approximately proportional to its conductivity. We adopt force-sensor values to application with one-to-one mapping.

Figure 6. Force-sensing resistor's attached on 3D spatial mouse

We take a survey to measure performance right after subject finishes experimental travel. Before participating in the experiment, subjects practice and learn the tasks in trial environment. While doing the experiment, both completion time (the spent time) and the frequency of collisions are saved into the data file. Frame rate of immersive 3D environment are maintained above 10 frames per second.

4.2 Results and Discussion

Although speed or task completion time is the primary consideration when evaluating new tasks in virtual environments, we should consider and measure more factors such as accuracy, efficiency, presence, user-centric performance and more abstract performance values [Bowman at al. 1997] [Poupyrev et al. 1997] [Bowman 1998]. In our experiment, we evaluate information gathering depending on the completion time, accuracy, presence, user-centric performance and abstract performance values. If the interaction technique does not produce good usability, it can cause fatigue, dizziness and nausea. Following the user centered design paradigm in human-computer interaction, we also considered abstract performance values such as ease of use, ease of learning and user comfort to measure performance.

4.2.1 Evaluation

Speed or time is the important factor to measure human performance while using the new technique. But in travel technique, we should consider the user's ability about how much he or she gathered information during travel and accuracy.

The user's ability in our experiment evaluated in terms of several variables: time, numbers of correct words and their locations to measure user's ability. Subjects are asked to indicate words and their locations on the map of the virtual corridor. The formula is (3a+2b+c)/t, where t=time spent in the corridor in seconds, a = the number of correct pairs of word and its location, b= the number of correct words and c=the number of correct locations. We call (3a+2b+c)/t overall score. The maximum time allowed in the experiment was 180 seconds.

By a standard single-factor ANOVA, we find that the overall score differences in different velocity control techniques are significant ($p < 0.05$). Figure 7 summarizes the average values of overall scores. This figure shows that force-based velocity control method gets the highest overall score. The mean of time spent in the corridor is about 40 seconds.

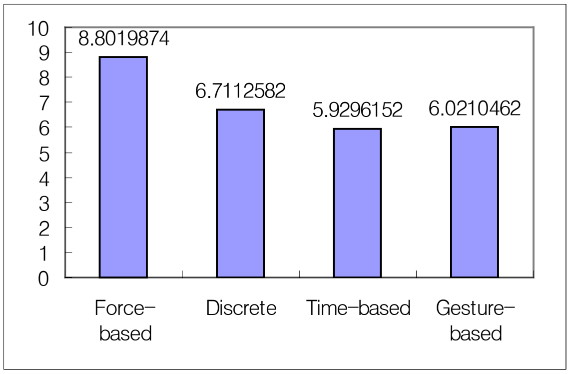

Figure 7. Average values of overall score

We also perform an analysis on the accuracies of different velocity control techniques. Accuracy is measured in terms of the number of collisions to the walls. The higher the number, the lower the accuracy. If the given technique is more natural and convenient than using 2D interaction devices, subjects easily reach the goal with a smaller number of collisions. In the experiment, the system counts the frequencies of collisions occurred.

Table 1. Averages of collision counts ($p < 0.01$)

	Discrete	Time-based	Gesture-based	Force-based
Inaccuracy	153.4	263.05	73.65	75.5

By ANOVA analysis, it is found that gesture-based and force-based velocity control techniques show no significant difference. We also find time-based method records the largest number of collisions.

Another interest is the sense of presence in the virtual environment. We ask people to measure a sense of presence. The indication value is between 1 and 100 where 100 is the highest sense of presence. Average sense of presence is 64.7.

4.2.2 Characteristics of the Technique

We evaluate overall interaction techniques following the paradigm on the user-centric performance measures [Poupyrev et al. 1997] [Bowman 1998]. Subjects rate fatigue of finger and arm, dizziness and nausea on their subjective measures. The subjects are asked to rate them between 1 and 7 where 7 is the highest. We summarize the averages of these measurements on four techniques in Figure 8.

Finger fatigue can be caused when subjects press buttons and arm fatigue is related to long-term work involving continuous lifting of the arms. Some subjects report that even though gesture-based technique is efficient in controlling velocity, it produces arm fatigue. Also some subjects comment that discrete control technique is quite similar to 2D mouse in operation. Although 2D mouse is widely used in controlling 2D GUI (Graphical User Interface), too much pressing (clicking) operation can cause finger fatigue. Discrete control technique shows the similar result because it adopts pressing operation used in 2D mouse. As we can see in Figure 8, the techniques require more finger operations cause higher finger fatigue.

All subjects experience dizziness and nausea during the experiment. Two subjects quit the experiment before completion because of dizziness.

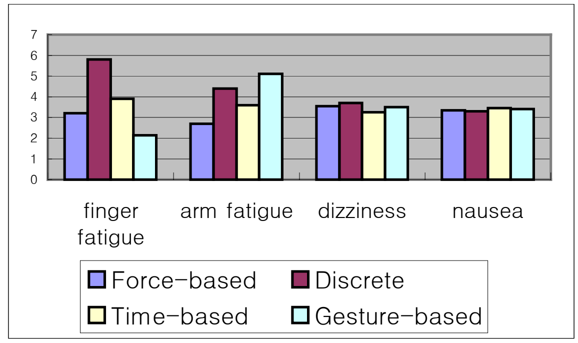

Figure 8. Average scores of user-centric performance.

We also ask the subjects to choose the most convenient, the most inconvenient, the most natural to use and the easiest to learn among four techniques.

In the experimental trials, a few subjects comment that discrete technique is the most efficient to control the speed because it adopts the same mechanism applied in normal 2D mouse. But the results in the experiment are somewhat different such that the gesture-based and force-based techniques show better results in terms of ease of learning, ease of use and comfort than the others. Even though the result show that gesture-based is better than the other techniques in terms of easiness of learning, it suffers from finger fatigue. The force-based technique is the best in terms of naturalness, convenience and easiness of learning among those techniques with lower fatigue.

Table 2. Measuring abstract performance values

	Ease of learning	Ease of use	Comfort
Discrete	2.75	3.5	3.35
Time-based	2.5	3.1	3.05
Gesture-based	2.3	2.65	2.75
Force-based	2.45	2.65	2.75

Some subjects complained about the inconvenience while using the force-based technique. These complaints are expected as the force-sensing resistors are attached on plastic plate of 3D spatial mouse so the technique does not produce force-feedback.

5 Conclusions

Although existing travel techniques are well suited for traveling in immersive virtual environment, more efficient travel techniques are necessary because most of existing travel techniques do not provide enough freedom of motion control in a large-scale environment. In this work, we propose a force-based velocity control technique using force-sensing resistors called Forve. We evaluate the performance comparing the proposed technique with other techniques. To show that the Forve is efficient and usable, we perform both quality factor and quantitative analysis. We find that gesture-based and force-based techniques are both useful in controlling speed, and since gesture-based technique causes arm-fatigue problem and force-based does not, force-based is the best choice of traveling techniques. Furthermore, when subjects use force-based technique, they gathered more information.

In this paper, we focus on how to specify velocity/ acceleration in traveling techniques. Also we evaluate our new technique when we adopt the pointing technique by which the traveling direction is decided. The techniques of specifying velocity are highly correlated with motion control techniques with which users can specify target position or their goal.

For the future work, to develop more generic techniques, we would like to apply our proposed technique to absolute motion controls such as gaze-directed or torso-oriented techniques. After that we would find more generic knowledge about traveling in a large-scale VE. As well as generalizing the knowledge, we will apply force-feedback devices to travel techniques in immersive VE and show the difference of using force-sensor or force-feedback device. Also we would apply the force-sensor to other fields, such as games because it has the useful characteristics of adoptability and applicability.

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