Noname manuscript No.
(will be inserted by the editor)

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User experimentation: An Evaluation of Velocity Control Techniques in Immersive Virtual Environments

Received: date / Accepted: date

Abstract An effective velocity control technique can enhance sense of presence in an immersive virtual environment (VE) and allow the user to navigate the VE more easily. While many of the existing velocity control techniques are well designed, the techniques are often application-specific, making it difficult to compare their effectiveness. In this paper, we evaluate five known velocity control techniques using the same experimental settings. We compare the techniques based on the assumption that a good travel technique should be more "natural," thus allowing the user to focus more on the task in the VE. In other words, a good travel technique should be easy to learn and easy to use, should cause the user to have few collisions with the VE, should allow the user to complete tasks faster, and should promote better recollection of the environment afterwards. In our experiments, we ask twenty users to use each velocity control technique to navigate through virtual corridors while performing information-gathering tasks. In all cases, the users use *pointing* to indicate the direction of travel. We then measure the users' ability to recollect the information they see in the VE, as well as how much time they spend in the VE and how often they collide with the virtual walls. After each test, we use questionnaires to evaluate the ease of learning and ease of use of the velocity control technique, and the users' sense of presence in the environment. Each of the travel techniques is then evaluated based on the users' performances in the VE and the results of their questionnaires.

Keywords Virtual Reality · 3D Interaction · Velocity Control Technqiues

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1 Introduction

In a large-scale virtual environment, navigation techniques are commonly used to assist people in moving freely about the environment. Bowman et al.[5] classify navigation tasks into two sub-tasks: *traveling* and *wayfinding*. *Traveling* is regarded as the motor component of navigation and refers to the process of controlling the user's viewpoint motion in a VE. *Wayfinding* is considered as the cognitive component that uses additional guides such as maps or compasses to help the user find a path [11]. According to Bowman's classification [2] [5], *traveling* can further be broken down into three components: direction/target selection, velocity/acceleration selection, and input conditions. In this paper, we focus on velocity/acceleration selection, evaluating the performance of five different velocity control techniques.

Most VE applications only allow a user to travel at constant 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 explore the environment more efficiently. Although several techniques have been developed for efficient navigation of a large-scale VE while allowing variations in the user's velocity (for a survey of these techniques, see [20]), it is unclear how effective each velocity control technique is outside of its designed environment. In this paper, we evaluate five velocity control techniques (count-based, time-based, gesture-based, force-based, and speech-based techniques) in the same experimental environment. We test each velocity control technique in an immersive VE in which the user wears a tracked head-mounted display (HMD) and uses a 3D spatial input device (a flying mouse) for interaction. In all experiments, the flying mouse is used as a pointing device for indicating the direction of travel.

To determine the usefulness and efficiency of the velocity control techniques, we follow the testbed evaluation method [3] [7] [22] in which each technique is measured quantitatively and qualitatively. As quantitative measurements, the user's information-gathering ability, the number of times the user collides with the VE, and the amount of time the user spends in the environment are measured. Qualitatively, we examine a few quality factors [5] regarding ease of learning, ease of use, and presence [1].

In the following sections, we review some related research and existing velocity control techniques, followed by discussion of our experimental environments. Finally, we present our findings and rate each of the five velocity control techniques.

2 Prior Work

As computers and graphics cards become faster, the potential size of virtual environments also grows correspondingly. Traveling through these large virtual environments using conventional travel techniques that adopt constant velocity is becoming less and less feasible. Instead, researchers and designers are beginning to look toward using velocity control techniques to effectively traverse these large environments. However, controlling velocity in a 3D virtual environment is not simple [20] because most existing devices have been designed for use in 2D environments.

From the taxonomy of virtual travel techniques [2] [5], we understand that velocity control is one of the key components in motion control (travel). Mine [20] classifies five different methods to specify the speed of motion (constant speed, constant acceleration, hand (gesture) controlled, physical controls, and virtual controls) in order to understand the principles of velocity control techniques. Bowman et al. [5] list several velocity control metaphors in the taxonomy of virtual travel techniques.

Many velocity control techniques have been developed. Brogan et al. [9] use stationary bicycles to control the user's velocity. Couvillion et al. [10] create a pressure-sensitive mat and track the user's footsteps. Although these two techniques are both based on the natural locomotion of the user, the cost of construction makes them unfeasible for many applications. Another device used to control the speed of travel, Bungee Bat [21], is a 3D passive force feedback device, but it is restrictive in that the user has to use both hands and thus has not been used widely.

In this paper, we examine five velocity control techniques that can be applied to a wide range of virtual environments. The gesture-based technique [20] is introduced in Mine's 1995 report on virtual environment interaction techniques. The simple terms of discrete and continuous range of selection in velocity are used by Bowman et al. [6] in his taxonomy of travel techniques. Jeong et al. [13] present the force-based technique using force sensing resistors and show its efficiency by comparing with other techniques. Lee's speech-based technique [17] allows the user to control velocity using voice commands.

In virtual reality and HCI, subjective evaluation is a common method to determine the efficiency of a designed technique in comparison to others. For virtual environments, Bowman summarized three evaluation methods: testbed evaluation, sequential evaluation, and a combined approach [7]. Testbed evaluation [4] [7] is a method for evaluating interaction techniques in a formal experiment environment called a testbed. As opposed to the testbed evaluation, sequential evaluation is a user-centered evaluation method involving a user task analysis, heuristic evaluation, formative evaluation, and summative comparative evaluation [12]. A combined approach is a method integrating the two different evaluation methods [7]. Since user-centered approaches require knowledge of application context, we follow the testbed evaluation technique in our experiment.

3 Velocity Control Techniques

We examine five velocity control techniques:

- count-based (discrete selection [6]),
- time-based (continuous range selection [6]),
- gesture-based [20],
- force-based [13],
- speech-based [17].

In all five scenarios, *pointing* is used to indicate the direction of travel through the use of a 3D mouse (see section 4). *Pointing* is chosen because it is the most efficient direction control technique [5]. In all cases, users are only allowed to move forward (user's velocity $\overrightarrow{v}$ is always positive).

Count-based velocity control technique : Two buttons on the 3D mouse are used for increasing and decreasing the speed of travel. Initially the click count of each button (m and n) is set to zero. m and n are then incremented as the user clicks on their associated buttons. The velocity $\overrightarrow{v}$ is defined as:

$$\overrightarrow{v} = (m-n)\alpha \qquad \text{where } (m-n \geq 0) \tag{1}$$

We use a scale factor α to represent the ratio between distances in the VE and the real world. In our experiments, α is empirically set to 0.015 because this allows the user to travel approximately 0.075 meters per frame after 5 button clicks of speed increase. In our system where the frame rate is approximately 20 frames per second, 0.075 meters per frame translates to roughly 1.5 meters per second, which is the normal speed for people when walking in the real world [26].

Time-based velocity control technique : Instead of counting the button clicks, time-based velocity control measures the duration of a button press. When the button is held down, the velocity is continuously increased, and when the button is released, the velocity slowly decreases until it reaches to zero.

$$\overrightarrow{v_f} = \overrightarrow{v_{f-1}} \pm \left(\frac{\Delta t}{\beta}\right)$$
$$\Delta t : \text{elapsed time (milliseconds)} \tag{2}$$

$\overrightarrow{v_f}$ and $\overrightarrow{v_{f-1}}$ are both greater than or equal to 0 and represent the velocity of the current (f) and previous frame ($f-1$) respectively. Δt is the elapsed time between each rendered frame, and β represents a scale factor. Depending on whether or not the button is held down, the velocity of each frame is incremented or decremented by $\frac{\Delta t}{\beta}$ from the previous frame's velocity. In our experiments, we find that a value of 10 for β gives the user a good balance between being able to change velocity rapidly and retaining fine control of the velocity. By holding down the button for 1.5 seconds or so, the user can achieve the average walking speed in the real world of 1.5 meters per second.

Gesture-based velocity control technique : This technique allows the user to control the velocity based on the distance between the user's hand and head. The two most commonly used gesture-based velocity control techniques are *zone-based mapping* and *linear mapping* [20]. In our experiments, we adopted the *linear mapping* because of its intuitiveness and ease of use over *zone-based mapping* [20].

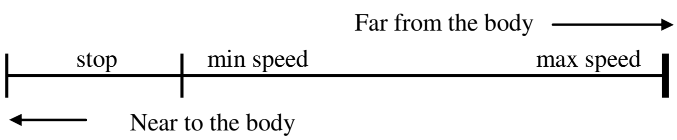

Fig. 1 Gesture-based velocity control technique using a linear mapping

In *linear mapping*, the user's hand location is linearly mapped to the reachable space in front of the user, thus allowing the user to control the velocity based on the placement of the hand (Figure 1). For additional control, a "stopping zone" is added such that the user can instantly set the velocity to 0 by placing the hand close to the body.

$$\overrightarrow{v} = (normalized(d_{tc}))\delta$$
$$d_{tc} : \text{distance from the head position to the user's hand in tracking coordinates} \quad (3)$$

Due to people's different arm-reach lengths and body sizes, we normalize d_{tc} to accommodate their physical differences. The value δ is then applied to change the scale of speed. In our experiment, δ is empirically set to 4.0 so that the maximum velocity for a user is 4 meters per second.

Force-based velocity control technique : This technique allows the user to control velocity based on how hard the user pushes down on a button. The button is made with a force-sensing resistor (FSR), which has the electrical property of resistance to measure force (or pressure). In general, a FSR is made of resistive film and digitizing contacts like conductors. When greater force is applied to an FSR, a better connection is made between the contacts, resulting in better conductivity [25].

In our experiment, an FSR is attached to a spatial mouse. To give the user the illusion of feedback, we add two layers of foam tape on top of the FSR to give it a "squishy" feel. By pressing down on the foam-padded FSR, the user increases the velocity of travel. Removing pressure from the FSR sets the user's velocity back to 0.

$$\overrightarrow{v} = F_s\lambda$$
$$F_s : \text{known measured force } (0 \leq F_s \leq 190) \quad (4)$$

λ is empirically set to 0.001, which sets the maximum velocity of the user to 4 meters per second.

Speech-based velocity control technique : In this technique, the speed of travel is set discretely based on the recognition of different utterances. In our experiment, the user can choose from 6 different velocities by speaking the word "stop, " "very slow," "slow," "go," "fast," or "very fast." We use Microsoft SAPI 5.0 as the speech recognizer in conjunction with context-based recognition for increased accuracy. To test the accuracy of the recognition, we ask 10 users to speak each word 20 times. We find that the user's speech is correctly identified about 98.0% of the time (in average 19.6 ± 2.4 words are correct).

$$\overrightarrow{v} = l\psi$$
$$l : \text{velocity step } (l = 0 \ldots 5) \quad (5)$$

Each velocity step has pre-defined speed values (see figure 2). In our experiment, ψ is set to be 0.04, which allows the user to travel at 4 meters per second under the "very fast" mode.

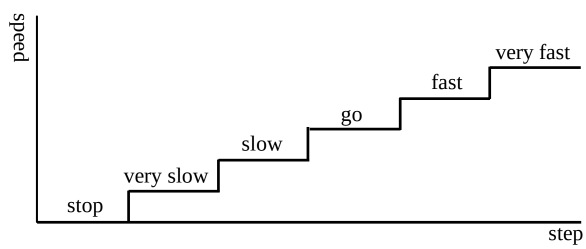

Fig. 2 Speech-based velocity steps

4 Experimental Environment

Since velocity control techniques are generally developed in different VE applications, it is important for our evaluation to be done as a testbed [3]. With each technique evaluated in the same experimental settings, we can then distinguish the differences among the techniques and find the strengths and weaknesses of each technique. This section describes our environmental settings including the devices used in the experiment.

4.1 Hardware Environment

A 3D spatial input device (a flying mouse) is used to indicate the direction of travel. The 3D mouse is created using a commercial joystick similar to the i3stick [8]. The pistol grip on the joystick is separated from the stationary base, and a magnetic tracker is attached to the bottom of the grip for tracking the position and orientation of the device in the virtual environments (Figure 3).

Fig. 3 Spatial mouse with attached FSR (1) and receiver (2).

The user wears a VFX-3D head mounted display (HMD) with a Polhemus Insidetrack tracker on top. This allows us to track the position and orientation of the user's head.

4.2 Virtual Environment

A trial environment and five experimental environments are designed using the Simple Virtual Environment (SVE) toolkit [16], and rendered on a desktop computer. Since most researchers use virtual corridors or similar environments for testing travel techniques or finding important knowledge [2] [11] [15] [18], all environments in our experiment are designed as virtual corridors.

Five virtual corridors are created. Each corridor (except for the trial corridor) contains 10 divided sections (Figure 4). In each section, a word is positioned randomly on either the left wall, right wall, ceiling, or floor (Figure 5). The corridors are designed to contain 10 words because most people can retain about five to nine pieces of information at one time [14] [19].

The walls in the virtual corridors are not penetrable. When a user collides with a wall, the user is prevented from moving past it. Since collision is a factor in our quantitative analysis, and yet most users in a VE are not generally aware of the fact that they are colliding or in contact with a wall, we play a recorded message ('You hit the wall") when a collision occurs.

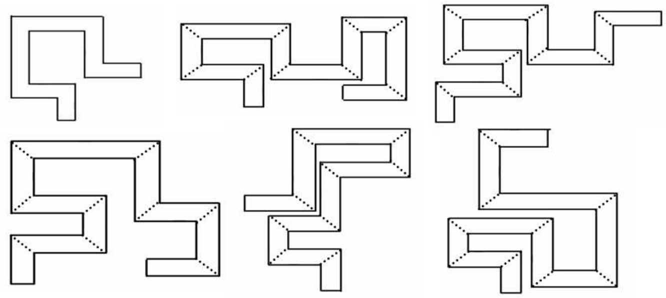

Fig. 4 Outline of a trial environment (top-left) and five different experimental environments. The dash-lines represent the virtually divided sections in the experimental environments.

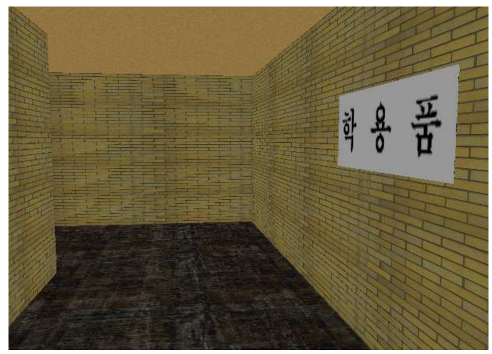

Fig. 5 Interior view of the virtual corridor and information (the word "stationary" in Korean) attached on the wall

4.3 Words in the Environments

All the words used in the virtual environments are chosen carefully. We start with 75 commonly used nouns such as "keyboard", "stationary", "refrigerator", etc. and separate them into 5 groups of 15 words (one group for each virtual corridor). Ten volunteers are then asked to look at each group and memorize the 15 words within 10 seconds. After the volunteers recite the words that they memorized, we discard the words that are the easiest or the most difficult to remember.

Our original assumption is that everyday words are easier to remember. However, we find that the volunteers are better at memorizing technical or infrequently used words. Furthermore, several subjects recited words that are synonyms of the original words (for example, "freezer" instead of "refrigerator"). By filtering out these words using the memory test described above, we reduce the ambiguity when scoring the users' information gathering ability in the VE.

5 Experiment

As mentioned previously, *pointing* is used because it is comparatively advantageous to other *wayfinding* techniques, and it follows relative viewpoint motion control [5]. By combining *pointing* and a velocity control technique, users can navigate a VE by indicating the direction that they want to move toward while controlling the velocity at which they would travel.

Twenty student volunteers (seventeen males and three females) participate in the experiment. Each user tests all 5 velocity control techniques in a random order, and receives the five virtual corridors in random order as well. Prior to the experiment, the users are required to familiarize themselves with each velocity control technique in the trial corridor.

The users are requested to use the randomly selected velocity control technique and navigate to the end of the virtual corridor within 180 seconds while memorizing words and the locations of the words as they appear in the corridors. Each user's completion time and duration of collisions are recorded during their experiments. After an experiment is completed, the user is asked to write down the words seen in the virtual corridors as well as the corresponding section numbers and their positions (whether the word appeared on the left or right wall, ceiling, or floor). Steed-Usoh-Slater presence questionnaires [27] and abstract performance evaluations [4] are also filled out by each user after each experiment in order to measure the qualitative aspect of the user's performance.

6 Quantitative Evaluation

Three quantitative measurements are used in our experiment. First, we examine the time-to-completion for each user using each velocity control technique. Second, we evaluate how much information people can gather in the environment. Lastly, the number of the collisions and the duration of collisions (in frames) are examined.

6.1 Time-to-Completion Analysis

In the experiment, all subjects are requested to reach the end of the virtual corridors using each of the velocity control techniques. The maximum time spent has been set to 180 seconds. We record the start and end time of each experiment and compute the average time spent in the VE. If the subject stays more than 180 seconds in the environment, the system will be terminated and total time spent in the experiment will be recorded as 180 seconds. On average, users spend approximately 131 seconds in the VE. Even though there is no statistically significant difference, Table 1 further shows that users spend the least time when using the force-based technique. Simply we think that the force-based technique requires the least amount of effort from the user to manipulate, thus allowing the user to navigate the corridors more easily.

Table 1 Mean and Standard Deviations of time spent in seconds while using each technique

	Count-based	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

6.2 Information Gathering Ability Analysis

After each experiment, the users are asked to answer questions about which words they saw, in which sections the words were, and on which surface (ceiling, floor, left or right wall) the words were placed. As mentioned above, no user is allowed to spend more than 180 seconds for each experiment because spending more time in the VE would increase the users' information gathering ability.

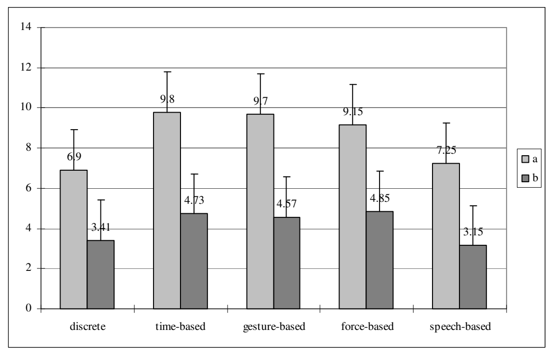

Fig. 6 Mean values of overall score without (a) and with (b) dividing by time spent in minutes

The user's ability is evaluated in terms of number of correct words, location accuracy, and surface accuracy. The overall score can be described as (3a+2b+c), where a = the number of correct combinations 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 [13]. Figure 6(a) shows the mean values of gathered information and the overall score. The result suggests that time-based and gesture-based velocity control techniques are superior to other techniques in information gathering. However, if we take the users' completion time into consideration and change the scoring function to (3a+2b+c)/t where t = the amount of time spent in the VE [13] (Figure 6(b)), we see that force-based velocity control technique outperforms the others, and users spend more time relative to how much information they can gather when using the time-based or gesture-based technique. It also shows that the amount of time a user spends in the VE has a direct affect on the user's information gathering ability.

By a standard single-factor ANOVA, we find that the differences between the velocity control techniques' overall scores are significant ($R^2 = 0.14, F(1,5) = 4.08, p = 0.004$)

6.3 Collision Analysis

A study by Profitt and Gilden [23] shows that people use only one dimension of information when making decisions in a dynamic environment. If more than one dimension of information exists in the decision making process, people tend to make more mistakes. Our experiment presents the user with two dimensions of information - wayfinding and velocity control - and we measure the number of collisions and the average duration of collisions as the “mistakes” made by the user in the dynamic VE. Based on the study by Profitt and Gilden, we hypothesize that the more natural and convenient the velocity control technique is, the fewer and shorter (in duration) the collisions would be; whereas if the velocity control technique is difficult to use, the user would have a harder time making correct judgements in the dynamic VE and cause more collisions.

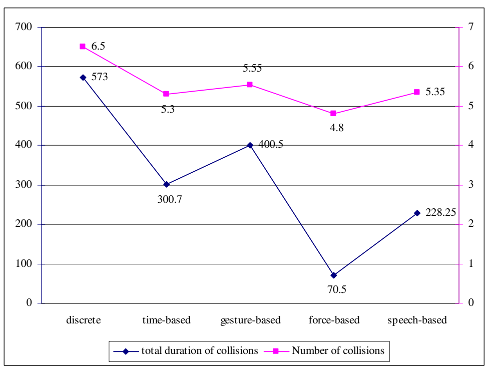

Fig. 7 The number of collision counts and the total duration of collisions (in frames).

Figure 7 shows the counted number of collisions and the average duration of collisions (in frames) using each velocity control technique. The number of collisions is incremented each time the subject hits the wall, and the duration of the collision (in frames) is recorded while user falls into the state of collision. We find that there is no significant difference on the number of collisions. But, the difference between each technique in considering the duration of collisions is significant ($p < 0.01$) by a standard single-factor ANOVA analysis ($R^2 = 0.3, F(1,5) = 10.59, p = 0.0001$).

Based on figure 7, we see that force-based velocity control technique is the most natural technique compared to the other four by a factor of three based on the duration of collisions. This is different from our original hypothesis that speech-based technique would be the most intuitive as it separates the task of traveling into hand manipulation and speech. The result suggests that such separation causes more distraction for the users as they divide their attention between different cognitive tasks.

7 Qualitative Evaluation

To evaluate qualitative performance of each velocity control technique, we examine sense of presence using the Steed-Usoh-Slater presence questionnaire [27]. Slater and Steed have demonstrated that the user’s sense of presence directly affects human-computer interaction in immersive VEs [24]. We also extend the abstract performance evaluation proposed by Bowman and Hodges [4] to include the measurement of user concentration when evaluating the user’s ability to perform tasks in a VE.

Table 2 shows that, on average, 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 indicating more people feel a deep sense of presence in the VE using these two techniques.

Table 2 Mean and Standard Deviations of SUS Questionnaire Scores (1. Low sense of presence ... 7. High sense of presence)

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

Abstract performance values are measured after a subject finishes all five experiments. The velocity control techniques are rated in order of preference (5=top choice, 4=second choice, etc.). Our abstract performance questionnaires not only measure ease of learning, ease of use, and user comfort as proposed by Bowman and Hodges [4], they also measure user concentration, which indicates how well the velocity control technique facilitates the user in concentrating on the information gathering task.

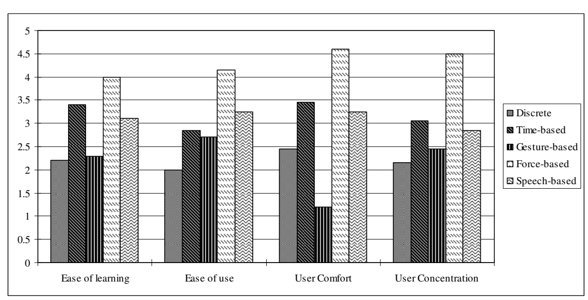

Fig. 8 Measuring abstract performance values. Highest number indicating the most efficient technqiue (5=top choice, 4=second choice, etc.)

Figure 8 shows the results of the abstract performance questionnaires. The results indicate that the force-based velocity control technique is better than the other techniques in all four measurements of the abstract performance values, while the time-based technique comes in as the second best option. The count-based technique appears to be the most difficult to learn, use, and concentrate on, and the gesture-based technique causes the most amount of user discomfort.

8 Conclusion

We summarize the results of our experiments in Table 3 in which each technique is broken down into its interaction type (Mapping), the major complaints of the technique (Weakness), how natural it is to use (Naturalness), how a user would interact with the device (Mechanism), and how quickly a user can change velocity using the technique (Sensitivity). Through the experiments, we find that the force-based velocity control technique is in general more efficient than the other four techniques when considering time spent, information gathering ability, amount of collision, sense of presence, ease of learning, ease of use, user comfort, and user concentration. Although the force-based technique appears to be efficient in all of our tests, we should note that the creation and construction of the force-sensing device is also the most time consuming.

The mechanism of using a time-based technique is similar to using a force-based technique in that the user is required to press and hold down a button to control velocity. Although the time-based technique receives high scores in information gathering tasks and all four of the quality factors, results indicate that user performance is slightly worse than when using the force-based technique. The main complaints about the time-based technique include finger fatigue after prolonged use and a lack of visual feedback on how long a button has been held down. Nonetheless, the fact that the time-based technique is much easier to implement than the force-based technique makes it a commendable choice.

The speech-based technique exhibits similar scores to the time-based technique in the qualitative evaluations, but receives a much lower score in time-to-completion and information gathering. As many users commented, it is difficult to recognize words in the VE while speaking commands to control velocity. The cognitive dissonance caused by performing two word-related tasks results in the overall low quantitative measurements on the users' performance. Moreover, the fact that speech recognition is not perfectly accurate occasionally forces the user to repeat commands, which further prolongs the time spent in the VE. However, the high scores in qualitative measurements suggest that using speech to control velocity is intuitive to the user, making this technique comfortable to use, easy to learn, and easy to use.

Since the gesture-based technique follows a natural mapping between velocity control and hand position, it is unexpected to see that most subjects rate this technique as the least comfortable to use, and one of the most difficult to learn and to use. Although it receives good scores in the information gathering tasks and is rated highly in sensitivity, all users complained of extreme arm fatigue after using the gesture-based technique in the VE, which drastically reduces the usefulness of this technique in most applications.

Arguably the least effective technique that we tested is the count-based technique. It receives low scores in all quantitative and qualitative measurements. Although the use of the technique resembles using a desktop mouse and therefore should be easy to learn, the users complained that while wearing a head-mounted display, they could not see where the two buttons are. Furthermore, the repeated clicking is tedious, tiring, and slow. All users commented on the fact that stopping is difficult, and after the experiment, they experienced finger fatigue.

9 Discussion and Future Work

As computer systems and graphics cards have become faster, virtual environments have also grown larger. To support traveling these large virtual environments efficiently, velocity control techniques are often required to assist the users. Several different velocity control techniques have been proposed and designed, but most of them are domain or application specific. To design a more generic and efficient technique, those existing techniques have to be evaluated in the same experimental settings in order to find their strengths and weaknesses. In this paper, five velocity control techniques (count-based, time-based, gesture-based, force-based, and speech-based) are tested in immersive virtual environments. To evaluate the performance of each velocity control technique, quantitative measurements such as time-to-completion, information gathering ability, and amount of collisions are taken into account, and qualitative measurements such as sense of presence and performance factors are also considered.

We originally hypothesized that if a velocity control technique follows a natural mapping to human actions, the technique will be intuitive to the user and therefore easy to use. However, from our experiments, we find that such natural mappings do not always result in good evaluations. The gesture-based technique suffers in the qualitative analysis in which users complained of arm fatigue. The speech-based technique causes cognitive dissonance during information gathering, and therefore receives low quantitative scores. Although the two techniques do not share the same weaknesses, the evidence is adequate to suggest that only considering a natural mapping to human actions in designing an efficient velocity control technique is simply not sufficient.

For future work, we would like to expand our experiments to include virtual environments other than virtual corridors. Many virtual environments today are not restricted to indoor environments, and we would like to design additional tests to examine if the findings in this project can be generalized to VEs of all types. Furthermore, through evaluating various velocity control techniques, we would like to find ways to extract the good design elements in each technique

Table 3 Summary of each techniques. Mapping depicts the type of interaction required by the user. Weakness summarizes the major complaints of the technique. Naturalness denotes whether or not the technique mimics a natural mapping to human actions. Mechanism shows how each technique is used, and sensitivity indicates if the user can quickly change the velocity using each technique.

	Mapping	Weakness	Naturalness	Mechanism	Sensitivity
Count-based	Discrete	Finger Fatigue	No	Pressing	Low
Time-based	Linear	Finger Fatigue	No	Pressing	Low
Gesture-based	Linear	Arm Fatigue	Yes	Gesturing	High
Force-based	Approximately Linear [25]	Difficult to Implement	No	Pressing	High
Speech-based	Discrete	Incorrect Recognition	Yes	Uttering	Low

and propose a more efficient and user-friendly technique of our own.

Acknowledgements The authors wish to thank Caroline Ziemkiewicz for her help on constructing and revising the drafts.

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