The VR Scooter: Wind and Tactile Feedback Improve User Performance

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ABSTRACT

We present an experiment using the VR scooter in an Immersive Virtual Environment (IVE). The scooter is used for traveling naturally and easily in large scale Virtual Environments. Vibrotactile tactors are mounted on the VR scooter to simulate motion speed, and a fan is used to simulate wind blowing when the VR scooter is in motion. We compared user performance (time to complete a task) with and without the tactors and fan, and we observed reduced time with these additions. While they were originally designed to make the experience more realistic and convincing, we found that they also improved user performance.

Keywords: I.3.7 Three-Dimensional Graphics and Realism - Virtual reality

Additional Keywords: Navigation Device, Multimodal Sensory

1   INTRODUCTION

We present a new input device, the VR scooter, for easily and naturally traveling in large Immersive Virtual

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Environments (IVEs). We analyze the human factors issues in designing a navigation interface incorporated with the VR scooter, which provides multiple degrees of freedom. The VR scooter is based on a real world metaphor, the scooter. We believe it is "natural" to use because most people can utilize skills they gained in the real world and apply them in IVEs naturally, and that includes riding a scooter, a bicycle, a motorcycle, a car, etc. Limitations and future improvements are also presented. The VR scooter was first introduced in [13]; here we present our experimental results along with further development of the scooter.

Designing a 3D traveling technique is difficult in general. The traveling technique should be effective, easy to learn, and user friendly. Usually, the implementation of a traveling technique requires at least an input device. The input device should be natural to the user to use and also easy, so that the user does not have to remember to perform a specific coded gesture to change the speed of flight or to switch modes between drive and fly, for example. The interface becomes more complex when the traveling technique provides multiple degrees of freedom. To implement an effective and user friendly traveling technique, depends primarily on the input device; the device that instructs the computer of the user's intent.

Large scale Immersive Virtual Environments (IVEs) are common in current research. One of the major problems in large scale IVEs, however, is traveling. Because most people know how to ride a bicycle, riding the VR scooter does not require much additional training, which makes the VR scooter a user-friendly device. Novice users may need some training since the device offers features that are not found in conventional scooters, such as flying, vertical movements, speed increase/decrease, etc.

We find traveling in Virtual Environments using the VR scooter requires minimal training; users can learn how to use the device within minutes. Force feedback is provided by a set of tactors that are attached on the VR scooter for enhanced realism. A fan in front of the user simulates forward wind blowing while the scooter is in motion. A spring attached on

the steering component of the VR scooter also provides force feedback to the user.

Haptic feedback has been used for years in Virtual Environments to draw the user's attention at a particular point of interest [21], to provide collision information and provide a sense of touch [8], and in general to improve spatial awareness [2] [17].

We present empirical results to support the use of vibrotactile cues as a means of improving user performance on a spatial task, more specifically in traveling in a Virtual Environment. We find that the utilization of a fan and vibrotactile devices to simulated wind blowing and vehicle vibration respectively, based on the speed of travel not only makes user experience more convincing, but it also helps the users achieve navigational tasks with more accuracy.

2   BACKGROUND

In navigation or traveling techniques the user does not need to have all 6 degrees of freedom available at the same time, as opposed in a manipulation technique [23]. However, the user should be able to switch modes to select different degrees of freedom; the easier and more naturally the user can perform the selection, the better interface [33].

For example, VRML enabled browsers allow the user to switch modes of navigation (walk, fly, pan, etc). This is implemented by allowing the user to control the navigation technique by mapping the 2 degrees of freedom of the mouse onto various translations and rotations. The same mouse movements can produce different results based on the selected mode; the mode selection is done by selecting a button at the side of a VRML enabled browser. This mode switching, however, is very confusing to even expert users. That is why it is common to find yourself in an awkward orientation within the Virtual Environment and that is why there is an 'align' button on these browsers to align the orientation of the view with the ground. While it is difficult to use a traveling technique that provides all 6 degrees of freedom to the user simultaneously, a better approach is to provide a few degrees of freedom to the user and also allow the user to select the degrees of freedom by switching traveling modes. If the switching mechanism is difficult to master, then we run into the problem we face with VRML enabled browsers as it was described above.

The use of haptic cues in virtual reality systems can take on many forms as it is described in [14]. They can be used to:

- Provide a sense of touch between the user, most commonly his/her hands or fingers, and the virtual objects [8]; this also reduces human error rate [15].
- Improve the situational awareness of participants, providing hints of what may come up, and provide advice of where the user should go next (which part of the IVE should visit) [7].
- Alert users of visual information currently outside the field of view of a visual display, such as where other objects of interest reside within a Virtual Environment.
- Increase the overall realism by improving the user experience, making it closer to the experience being simulated, and thus providing a convincing environment closer to a hypothetical real environment.

There are many devices available commercially and also devices developed in research institutions that allow a user to travel in a VE. Some of these devices include simulators such as [3] [4] [28] [32]. The CMP-2100SR [4] is a simulator that resembles a car, with a rumble seat that provides vibration to the user, force feedback steering wheel, and an HMD. 3D manipulation, however, is difficult to perform because the user is strapped in his/her seat. In [26] researchers used a car-like device to study path steering. The users could feel the steering wheel and the pedals but there was no feedback from the device. In the CMP-2100 [3] the user can navigate using either a mouse-like device with buttons to indicate the direction and speed of travel. This device does not provide a natural way of navigation. The Xtream Sports [32] and the VR snowboard [28] are suitable devices for a particular type of game that requires a snowboard and are not suitable for general purpose VE navigation. The Cyber bike [5] consists of a conventional bicycle where the speed of travel depends on the speed the user pedals; this technique gives force feedback to the user that can travel only in places where he/she can stay attached to the ground (streets, hallways, etc). Other devices such as the ones in [24] and [19] are suitable for navigation in VEs where the user does not need many degrees of freedom.

Feedback is an important feature to make a traveling technique and device easy to use and master. In general, a device that provides force feedback can increase the level of immersion/realism a user experiences; the device does not turn left because there is a wall on the left, the device is vibrating because the user crashed into a building, etc. The Omni-directional treadmill [22] is an example where the user can physically walk on an Omni-directional treadmill while his/her center of mass is moved by the device at the center of the device. The user can walk or run in any direction, as in real life, and the treadmill moves the user at the center of the device. Other novel devices similar, at least partially, are the devices presented in [10], and [11]. The VMC [30] is a device where the user steps on different parts of a circular platform to indicate direction and speed of travel.

One feedback device that could easily be incorporated in a VE is a fan (or network of fans) that can simulate wind blowing depending on the speed and direction of travel [16] [27]. In [16] there is fragrant substance unit and the fan is used to primarily add fragrant substance to the artificial wind. This device also forces the user to provide additional effort to pedal on inclines by adding load to the pedals.

3   THE VR SCOOTER

The VR scooter consists of electrical switches built on it to close or open electrical circuits. The user, for example, could increase the speed of travel. The computer passively monitors the user's actions and turns on/off the appropriate relays to increase the rotational speed of the fan to simulate wind blowing. The vibration intensity of the vibrotactile tactors is also adjusted based on the scooter's velocity. The vibrotactile devices are used to simulated vibration and the engine's sound of the VR scooter while it is in motion. The vibration and wind blowing depends on the speed the VR scooter is traveling. Currently, the fan and the vibrotactile devices operate on three different speeds; the faster the user travels the more air the fan is blowing at the user and the more the tactile devices vibrate. The fan and the vibrotactile devices can be activated and deactivated based on user's actions, passively, to provide a more convincing experience. The switches can be queried by a computer when they are pressed or released by the user.

Most people can ride a bicycle, and this scooter-like device is built at least partly on this concept. Users do not have to remember awkward gestures or postures to issue commands to navigate or travel in a synthetic environment. They can simply

ride the VR scooter device in a similar way that they ride a conventional bicycle, scooter or motorcycle. Operations such as increasing/decreasing the speed of travel, switching on and off the virtual lights attached on the 3D model of the VR scooter, pressing the brakes, drive, or fly, etc., are simple to perform while users concentrate on the task they would like to perform instead of the actual mechanics of getting there and "making it happen". Figure 1 shows a picture of the VR scooter used in our experimentation.
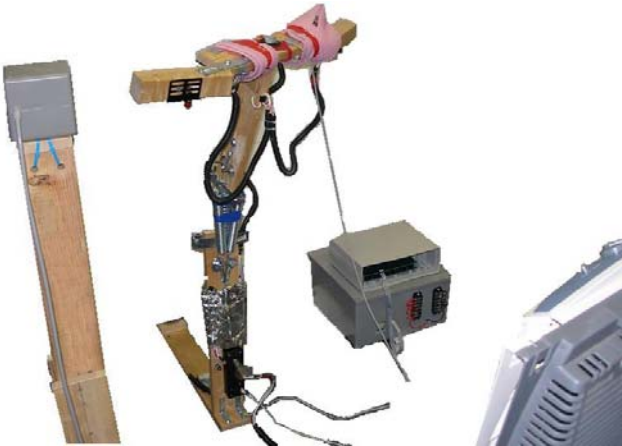

Figure 1. The VR scooter

The VR scooter was designed to make the virtual reality experience more realistic for several reasons. For example, users perform operations with more effort, as in real life. A user has to physically bend down to go below a bridge instead of pressing the left mouse button for example. A user can feel the speed of travel via the fan that provides an air stream as it blows at the user and via vibration by the vibrotactile devices that both depend of the speed of travel; the faster the user travels the more air and vibration he/she feels. When the user presses the brakes that stop the motion of the VR scooter, the fan and the vibrotactile devices get deactivated to simulate that the vehicle stopped moving. In addition, a user physically experiences (e.g., feels) the VR scooter because, for instance, he/she can hold on to it. When flying, for example, a user feels the force of the steering wheel (e.g., because of a spring that is attached to the steering device). Thus, the VR scooter is not only a 3-D object/model in a virtual environment, but it is also a real object that the user can touch and feel. The user can turn the steering device to take turns as on a conventional bicycle. Moreover, a user can pull up or tilt down the steering device to specify the direction of flight; this is achieved via the spring attached to the steering mechanism. Figure 2 is an illustration of the VR scooter, the hardware components used in our experimentation, the placement of the 3D sensors and the vibrotactile devices, and the connectivity between the VR scooter and the host computer.

All the switches are attached on the steering mechanism of the VR scooter where the user can push them easily with minimal hand movement. According to [29], the torso is not the best body part for vibrotactile feedback, where hands and legs are. Since we wanted to minimize user tethering, we attached the vibrotactile devices on the scooter instead of on the user. Two of tactile devices were attached on the handles of the steering mechanism, and one on the base of the VR

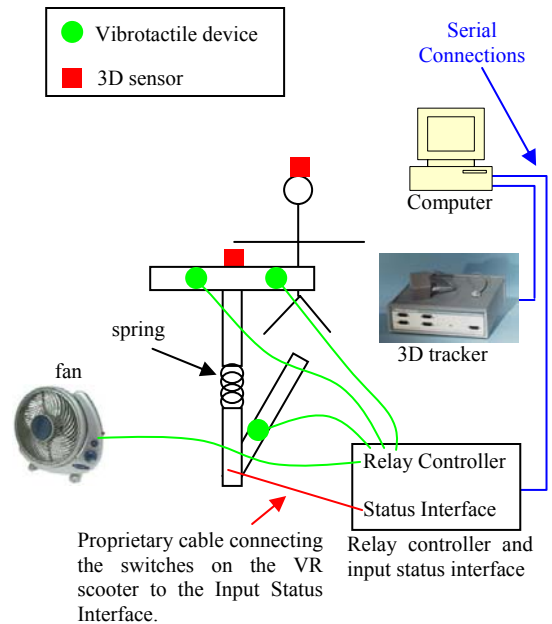scooter on which the user places one of his/her legs for stability.

Figure 2. Components of the VR scooter

4 METHOD

4.1 Hardware

We conducted this study in the Virtual Reality Laboratory at the University of Georgia, at the department of Computer Science. We used a Gateway PC running windows XP professional with 1G of main memory. The PC was equipped with a Radeon 9800 video card which was driving the Head Mounted Display (HMD). We had two HMDs: (a) a stereo Virtual Reality V6 HMD from Virtual Research Systems, Inc. and (b) i-glasses from i-O Display Systems. We chose to use the i-glasses because of its smaller size and less weight compared to the V6 HMD. For 3D tracking we used a Polhemus FastRak, tracking the user's head, and the VR scooter.

The VR scooter was attached to the "Relay Controller and Input Status Interface" box as shown in figure 2. This box contained two cards in it. The first card is a relay controller (RC) card that can activate and deactivate relays. The second card is the input status interface (ISI) card that detects button presses and releases; these are the switches attached on the VR scooter (these are the AR-16 and STA-16 cards respectively with an expansion card hardware devices from [12]). For example, the user riding the VR scooter can increase/decrease the speed of travel by pressing the "speed increase" button. The software driver that we wrote polls the ISI, increments the speed of travel in the Virtual Environment and turns the appropriate relays on or off to reflect the speed change. These relays are attached to the speed controller of the fan and the vibrotactile devices, making the fan spin faster/slower and the tactors vibrate faster/slower. For the vibrotactile devices, we purchased a $20 12VDC HOMEDICS 5-motor back-massager and we used its motors and its vibration intensity controller.

4.2   Software

For software we used Java3D. The Virtual Environment was designed using VRML Beans 2.0, which saves the world in VRML 2.0 format. The produced VRML file was then loaded into Java3D using the Xj3D's VRML loader, which builds a scene graph in Java3D.   Our virtual reality environment consists of an open area with trees, roads, buildings and fountains, as shown in figure 3.

Figure 4 shows the entire map used in the experimentation. The subjects were to travel on the roads (shown with blue color in figure 4) and fly over the obstacles, such as water fountains (shown at the center in figure 3). The red areas are ceilings and the subjects were supposed to go below the ceilings. The beginning point is shown at the bottom right corner in figure 4, and the end point is at the center of the map. The gray areas are walls that prevent the user in seeing what is on the other side and also help them stay on the road by defining the path that should be followed.
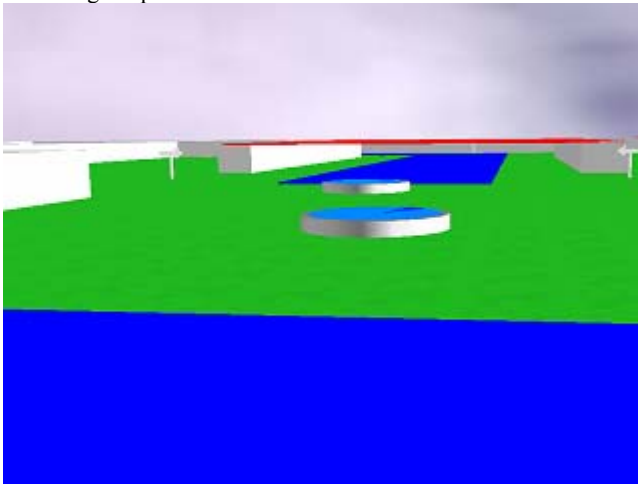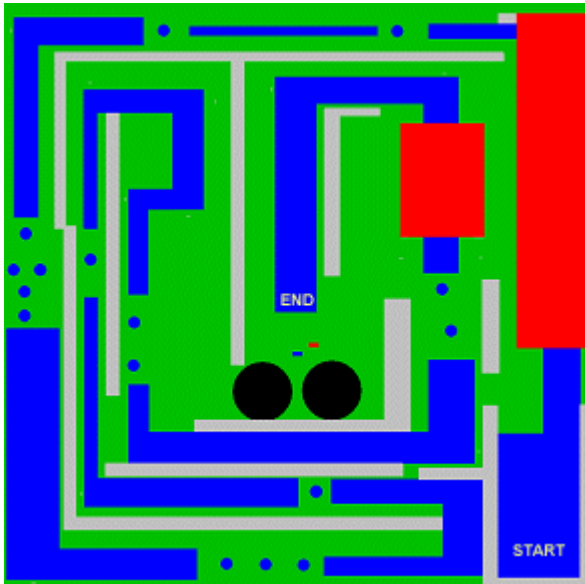

Figure 3. : Snapshot of the Virtual Environment

Figure 4.   Map of the VE

4.3   Participants

Thirteen subjects volunteered to participate in the experiment. One subject reported motion sickness and we had to interrupt the experiment and remove him as a participant; he didn't want to try again. The subjects were undergraduate, graduate and staff members of our department. Their average age was 23. Nine subjects had no prior experience with VR while two subjects had some insignificant experience: they had used a VR system once in the past. One subject used a VR system several times in the past and was familiar with the devices utilized. Twelve subjects successfully completed the experiment.

Figure 5.   Illustration of the devices

4.4   Experimental Setting

Figure 5 is an illustration of the devices used in the experiment. The subjects used the VR program by standing next to the Polhemus transmitter, which was placed on a wooden base, about 3.5 feet from the ground. We removed most of the furniture and equipment in the physical area used by the subjects in order to prevent distraction and signal distortion.
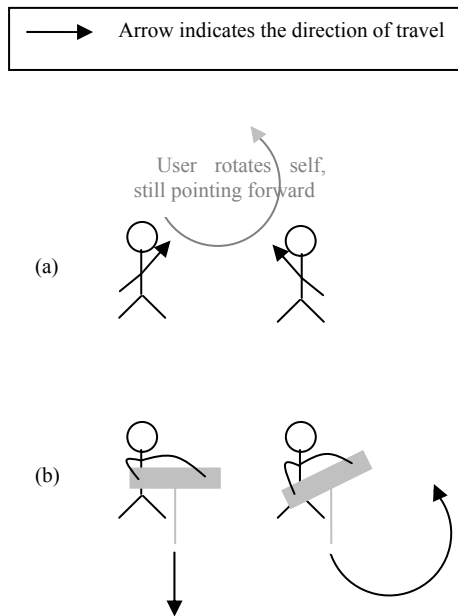
Figure 6. Pointing vs vehicle-based traveling techniques

4.5 Traveling technique

Traveling techniques implemented using gestures, postures or a pointing device [18] held by the person traveling in a Virtual Environment are different from a traveling technique where a vehicle is used for the implementation. A person pointing at [6] (or looking at, or leaning at [9]) the direction of travel can rotate himself/herself 180 degrees to travel in the opposite direction. Vehicle-based traveling techniques, however, may restrict the user from rotating himself/herself in the opposite direction; the user may not be able to physically pick up the vehicle and rotate it. In a vehicle-based traveling technique there is normally a steering mechanism that allows the user to turn it and as a result the user and the vehicle make a turn in the virtual environment as shown in figure 6.

As shown in figure 6(a), the user rotates himself/herself and keeps pointing forward to travel forward with respect to its self. In a vehicle-based implementation, shown in figure 6(b), the user rotates/tilts the steering mechanism to achieve the same result. However, if the user keeps the steering mechanism rotated, the user will make a full circle and come back to his/her original orientation. Driving with a vehicle-based device is ease (making turns around the vertical axis). However, flying (having the freedom to perform rotations around all axis simultaneously) is not easy and can easily disorient the users; they may find themselves upside down in the virtual environment. That is why car games are easier to master than flight simulator games. The initial and default scooter's traveling mode was "driving". The user could switch to "flying" mode by pressing a button located on the left side of the steering mechanism. While this button was pressed, the user was in the "flying" mode and upon its release the system switched back to the default "driving" mode.

4.6 Procedure

The subjects had a short training session, about 10 minutes, to familiarize them with the HMD, Polhemus and the scooter's controls. First, the experimenter introduced the devices and explained their functionality. Then the subjects used the devices to practice and familiarize themselves with the scooter. The subjects were given 10 minutes to practice and become familiar with the traveling technique and the buttons on the VR scooter; the environment used for this practice was different from the one used in the trials.

All subjects used both versions of the environment, with and without the fan and vibrators; we refer to these as "VR enhanced" and "VR plain" respectively. The order of the two was counterbalanced to eliminate differences in fatigue and learning. The order in which the subjects used the VR plain and VR enhanced versions of the program did not indicate an important effect on the performance: 10 out of the 12 subjects performed better in VR enhanced. There was a 5 to 10 minute break between the two trials. A simple collision avoidance mechanism prevented the users from going below the ground level.

At the end of the experiment we asked the subjects to respond to the following statement on a 5-point Likert scale (1. strongly disagree .... 5. strongly agree) in order to check if the training achieved its goal: "The training session familiarized me with using the VR scooter." The responses show that they were sufficiently familiarized with the VR scooter (Mean=4.75; Standard deviation=0.45).

After the training and the practice session, the subjects were asked to travel through the VE from the start point to the end point (with and without the fans and tactors; VR enhanced and VR plain respectively), as fast as possible. They were supposed to fly over the obstacles and land on the road on the other side of the obstacle(s). The road segment was interrupted, followed by the obstacle(s). This made it easy to understand that they were supposed to only stay on the "blue road". The subjects were told not to hit or go though any objects in the VE. These included the fountains, walls, roofs, and buildings. The subjects were also told not to fly high over the roads, instead, there were to stay on the road and only fly when the road was interrupted followed by an obstacle. The subjects told us when they were ready and we gave them a verbal signal to proceed in beginning their task. The experiment was terminated when the subjects reached the end point. In the analysis, we used the elapsed time from start to finish as the performance measure.

Finally, the subjects filled out a survey containing questions about satisfaction with the interfaces and the level of immersion they presented to the user. The survey contained questions adapted from [31]; end-user satisfaction.

5 RESULTS

Our hypothesis was that in virtual environments subjects would perform better if the level of immersion is increased, which was achieved by the use of a fan and vibrotactile devices. We used a within-subject experimental design. Our independent variable was traveling type (using fan/vibrators and not using fan/vibrators). Our dependent variable was performance (time to complete the task; getting from the start to the finish point). Table 1 provides the descriptive statistics for our measurements. We tested the hypothesis by comparing the means of the pooled performance scores using one-way analysis of variance (ANOVA).

We incorporated a "scoring penalty" in our results when the subjects failed to obey the rules; going through a wall or

ceiling, hitting an obstacle, etc. Based on our estimated time to go back and correct each of these errors, we gave them a 15 second penalty if they failed to stay on the road, or if they hit a wall, a 30 second penalty if they failed to fly over an obstacle, and a 45 second penalty if they failed to go below a roof. We also gave them a 45 second penalty if their path of travel was high over the road.

We compared the result based on penalty given and without penalty. We found that there is no significant improvement in performance $(F(1,11)=0.49, p=0.498)$ when there was no "scoring penalty"; these results are shown in Table 1 on the row labeled "no penalty". However, not penalizing the subjects does not provide accurate results because the subjects could finish in shorter time by being less accurate and cutting corners collide with fountains, going through walls, etc. When we applied the scoring-penalty to our results we found that VR enhanced improves user performance $(F(1,11)=6.88, p=0.024)$. If we look closer at the results, we will realize that the subjects in VR enhanced are actually more accurate and careful in traveling with the VR scooter in a Virtual Environment. The subjects were obeying the rules more when they were using the VR enhanced environment and thus the scoring penalty was very low. This was also verified by the subjects' comments and the survey questions that we will describe later. Figure 7 shows the graphical representation of the means of pooled, VR plain and VR enhanced with and without applying the scoring penalty.

Finally, we were interested in exploring subject's satisfaction in VR enhanced and in VR plain. We asked subjects about ease of getting started, accuracy, and fatigue felt, and whether they found the fan/vibrators useful in VR systems. We were primarily interested in the user's reactions to VR enhanced, since this is a new combination of devices utilized. Table 2 shows the questions and subjects' responses.

Table 1. Performance measurements based on traveling type.

	VR plain		VR enhanced			
	M	SD	M	SD	F (1,11)	p
No penalty	397.17	128.46	374.17	158.60	0.49	0.498
With penalty	508.42	142.06	395.42	157.37	6.88	0.024

M and SD represent the mean and standard deviation respectively. F and p are from ANOVA analyses that compare the means of the answers in VR plain and VR enhanced. All questions were based on a 5-point Likert scale ranging from strongly disagree (1), to strongly agree (5).

Table 2. Survey questions and results.

	VR plain		VR enhanced			
Survey Questions	M	SD	M	SD	F (1,22)	p
It is realistic experience using the fan and vibrators	2.42	0.79	4.75	0.45	78.4	<0.001
The system is user friendly	3.92	0.79	4.00	0.60	0.08	0.77
The system is easy to use	3.17	1.11	4.17	0.58	7.62	0.011
It is ease to get started	4.17	0.58	4.42	0.67	0.96	0.34
The VR scooter's travelling technique is accurate	3.42	0.67	3.83	0.58	2.67	0.12
Fatigue felt while riding the VR scooter	2.42	0.996	2.42	0.996	0.0	1.0
I am satisfied with the performance of the application	4.08	0.67	4.33	0.65	0.86	0.36

M and SD represent the mean and standard deviation respectively. F and p are from ANOVA analyses that compare the means of the answers in VR plain and VR enhanced. All questions were based on a 5-point Likert scale ranging from strongly disagree (1), to strongly agree (5).
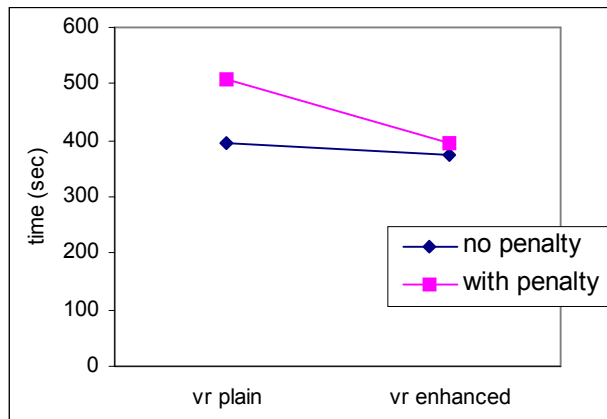
Figure 7. Mean time of performance with and without penalties.

As the ANOVA results in the last two columns of table 2 indicate, subjects' satisfaction in VR plain and VR enhanced were not statistically different. However, in the first question in table 2 we see that the addition of the fan and the vibrotactile devices made their experience more realistic $(F(1,22)=78.4, p<0.001)$.

We further posed the subjects the following open-ended question: "Which version do you prefer: VR plain or VR enhanced and why". All twelve subjects specified that overall they prefer the VR enhanced. The subjects preferred the VR enhanced environment because it made their experience more convincing, and the environment "… comes to life" as it was quoted by several subjects. The subjects felt that it was difficult to figure out their speed of travel in VR plain. As a direct result, subjects who were traveling too fast and were to take a turn did not have enough time to react and either went though walls, on the grass or even failed to fly over an obstacle. However, subjects in the VR enhanced environment could feel the difference in wind blowing and vibration intensity and adjust their speed of travel so that they would have enough time to react to the environment and become more accurate; make turns without going through walls, activating the flying mode on time, etc.

Moreover, we asked all subjects if they find the utilization of fans and vibrotactile devices useful in Virtual Reality and particularly in scooter-based traveling techniques. The results suggest that the utilization of fans and vibrotactile devices are useful in Virtual Environments (mean=4.83, standard deviation=0.39) based on a 5-point Likert scale where 1 is strongly disagree and 5 is strongly agree.

6   FUTURE WORK

The subjects were encouraged to tell us any improvements or enhancements they would like to see in the future. They reported that they would like to feel, via vibration or sound, when the VR scooter is on the road; in a way simulating the rotation of the tires of a bicycle as it moves on the road. This is very useful when the subjects fly over an obstacle and land on the other side of the road. At times, it was hard to tell what was low enough to the ground.

The "Fly" button enables a subject to switch modes from drive to fly, while this button is pressed. Upon release, the user is switched back to the drive mode. Three out of twelve subjects would have preferred a toggle button instead of the push-button utilized.

While in the "fly" mode, the users could control all 3 rotations in space. Through out the subjects' comments we realized that only 2 rotations should be used in the "Fly" mode. While in the "fly" mode, one should be able to turn left and right, and tilt up and down. The rotation that seemed to disorient the subjects was the rotation around the Z axis, which is the axis going from the user through the screen; rotation performed on the x-y plain. This was reported by nine subjects. Disabling rotations around the Z axis would eliminate the problem of finding yourself upside down in the VE; this is useful and correct in flight simulations but in general purpose vehicle-based traveling techniques it simply seems to promote disorientation.

7   CONCLUSIONS

We built a device, the VR scooter (patent pending – UGARF case number: 1186), that is used in traveling in Virtual Environments naturally and easily. It is based on a real life metaphor, the bicycle or scooter, and users can master using the device within minutes since they can apply their skills gained from real life. We designed the VR scooter to create a more realistic experience for the user by utilizing a fan, or network of fans, that simulate wind blowing at the user, and vibrotactile devices that provide feedback to the user when the vehicle is in motion. The vibration and the wind blowing are adjustable and depend on the speed of travel.

While we designed the wind and vibration features of the scooter to try to increase the "realism" of the user's experience subjectively, we observed actual improved task performance measured objectively. Our findings suggest that the wind simulation and vibration could become a viable travel mechanism type in Virtual Environments.

Our satisfaction survey and interviews with the subjects after the experiment showed that they were much more satisfied with the experimentation when the fan and the vibrotactile devices were utilized as opposed to when there was no wind simulation and virtual engine vibration. They stated that they liked the idea of using the fan and the vibrotactile devices because the computer was passively monitoring their actions and responded to them, and also because they would feel their speed of travel while they were traveling or when they were not in motion.

8   ACKNOWLEDGMENTS

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