Perception in Immersive Environments

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Abstract

Immersive environment (virtual reality) systems provide a unique way for researchers to perform experiments in completely controlled environments. Virtual environments enable researchers to create experiments that would not be easily created in the real world due to physical limitations. This paper will discuss some of the problems facing immersive systems and explore how they might be resolved. It will specifically focus on a research project that I worked on for the University of Utah's Treadport—a locomotive interface for virtual worlds. We created two experiments to see how people adjust to and perceive virtual environments. In the first experiment, the Treadport was used to try to duplicate a previously completed real world recalibration experiment in a virtual environment. The second experiment was designed to be a new way to measure compression in virtual worlds.

Introduction

Motivation

As the equipment for immersive, virtual environments becomes more economical, it is important to understand how people perceive computer-generated environments. For researchers, virtual reality systems provide a world that is completely controllable. In order for these systems to be a viable replacement for real world experiments, they must be able to at least convey accurate visual information. In some cases, running experiments in a virtual world might be cheaper, safer and more controllable than running the same experiment in the real world. For example, objects in a virtual world can easily be made to defy the laws of nature, a feat which is impossible in the real world.

Problems facing immersive environments

One fundamental problem facing immersive environments is that people perceive virtual worlds to be smaller than they really are. Although one might think that improving the quality of computer graphics would lead to more accurate human perception in virtual environments, recent research at the University of Utah suggests that the quality of graphics does not make a significant impact on a viewer's perception of the distance to an object [2]. This study measured the perceived distance of an object from a viewer with a triangular walking task. Subjects looked at the object and then walked blindfolded at an angle approximately 70 degrees to the right of the object. After walking a couple meters, subjects were told to turn, stop and then point at where they thought the object was. This process allowed the researchers to measure distance to the object the viewer perceived. In the real world, subjects accurately perceived the distance. The same experiment was repeated with a head-mounted display (HMD) displaying wire-frame, poor and photo-realistic graphics. Although increased visual realism slightly improved an accurate perception of distance, all three virtual worlds caused people to underestimate the distance to the object by approximately 50 percent.

Since the study indicates that visual information alone isn't enough to convey accurate size and depth, the influence of other senses such as sound and touch on perception of distance must also be explored. In addition, immersive environment systems rarely are able to make users feel like they are really inside the virtual environment instead of in the real world. This problem must also be addressed.

Recalibration

People react to their perception of their surroundings by adjusting their actions in a process called recalibration. In the real world, people have no problems recalibrating to new environments. For example, it doesn't take long to get used to walking against the wind on a windy day. Psychologists have done many experiments to try to understand how we use our perception to recalibrate to changing environments. One particular study by Rieser et al. at Vanderbilt University used a treadmill towed behind a tractor [1]. As a pretest, subjects looked at an object and then closed their eyes while they walked to where they thought the object was. In the recalibration phase of the experiment, subjects would walk on the treadmill while the tractor pulled them at a slower, faster or equivalent speed for approximately ten minutes. Immediately after this recalibration phase, subjects repeated the pretest procedure. The results showed that, during this posttest, people remembered the rate the world was moving by when they were walking on the treadmill. If the world moved by faster than the speed they were walking (biomechanically slower condition), they would not walk far enough during the posttest because they remembered that for each step they took, the world moves a greater distance.

Rieser's study also indicated that eye height is an important factor in the perception of speed. They noticed that the amounts of recalibration in the biomechanically faster and slower conditions were not symmetrical. The biomechanically slower condition resulted in less recalibration than the biomechanically faster condition as a result of the increased eye height of the subjects while walking on the treadmill. When the treadmill and tractor speeds were matched, subjects overshot on the posttest an average of seven percent. This result shows that people measure speed and distance in eye-height units. Therefore, it was important that the graphics in our experiments accurately displayed where the floor was and the height of the objects in the world.

The Treadport

The University of Utah's Treadport, a locomotive interface to computer rendered worlds, is an excellent device for duplicating Rieser's real world experiment in a virtual world. The Treadport is a large treadmill with three back-projected screens in front of it. Unlike a treadmill that moves at a constant speed, the Treadport senses how fast the user is walking forward or backward and the treadmill's belt adjusts its speed to keep the user in the center of the belt surface. The Treadport also simulates inertial forces with an actuator (the black bar behind the person in Figure 1) that is connected to the user's harness. Inertial forces are important because when the user starts walking, it takes a small amount of force to counteract the inertial force of their mass being at rest. Therefore, when users start walking from a standstill, the actuator simulates inertial forces by pulling them back slightly. It also simulates momentum by pushing them slightly forward when they are trying to slow down.

The Treadport has additional capabilities which were not used for our experiments. Because the Treadport's belt cannot slide sideways, turning is impossible to simulate realistically. When the user is not walking, turning is accomplished by turning in place. The world continues to spin until the user faces forward. While walking, the user can turn by walking to the right or left of the center of the Treadport and then moving back to the center of the Treadport to walk straight again. This method of turning is effective in large, outdoor worlds, but it is difficult to control in smaller indoor worlds. The Treadport uses the same mechanism that simulates inertial forces to simulate slopes. Users are pushed while they are walking downhill and pulled while walking uphill. Physically tilting the Treadport would be difficult to implement and would not be able to change the slope forces quickly.

Figure 1: University of Utah's Treadport

Experiments

As interns, three students from Mount Holyoke College and I helped design and implement the experiments and software at the University of Utah during the summer of 2002. The primary goals were to learn about the design of an effective experiment and to create an experiment that would be analogous to Rieser's real world tractor and treadmill experiment. The virtual world we created also allowed us to create a unique way to measure the compression of virtual worlds.

The results presented here are preliminary. Further experiments using our virtual environment are currently being conducted at the University of Utah.

Recalibration experiment

We created two different virtual models that resembled the hallways in the building where the Treadport is located. Both of these models were infinitely long so that we could have subjects walk down the hallway during the recalibration phase of the experiment without having to worry about turning. We created a geometrically sparse model (Figure 2) that is a simple “box” with textures on the walls, floor and ceiling to make it look like a hallway. We also made a geometrically complex hall (Figure 3) that has much more geometry in it (such as vending machines, trash cans, intersecting hallways and open double doors to walk through). The additional geometry in the complex model provides motion parallax information unavailable in the sparse hallway. Motion parallax is relative motion that is perceived during movement. Distant objects appear to move more slowly than closer ones because a large amount of movement is needed for a distant object to move across an observer’s field of view and only a small amount of movement is needed for a nearby object to move across the field of view. For example, while driving, distant mountains appear to move slower than nearby street signs. While walking in the virtual hallway and looking down an intersecting hallway, one can see nearby objects move faster than distant ones.

Figure 2: Simple hallway

We measured the amount of recalibration by performing a series of tests on the subjects in the real hallway before and after walking on the Treadport. They looked at a red disk on the floor in front of them. Next, they walked blindfolded until they believed that they were standing on the disk. This process was done several times with the target at different distances. By comparing how far they were from the disks before and after walking on the Treadport, one can determine how much recalibration occurred.

Figure 3: Complex hallway

This experiment differs from Rieser's experiment in a two ways. First, the subjects in the virtual world can walk at any speed they want to and they can change their speed whenever they want. Unlike in the real world, it is very easy to adjust the speed with which the virtual world moves by. We simply multiplied the Treadport's velocity information from the real world to determine the rate at which the virtual world should move. Second, unlike the towed treadmill, the Treadport simulates inertial forces correctly. It would be very difficult to create a mechanism that accurately simulated the inertial forces of a towed treadmill. Such a mechanism would have to cancel out inertial forces resulting from the tractor's change of speed and simulate the forces resulting from the subject's change in speed. Inertial forces are important to consider because people might interpret their physical effort in addition to visual information in estimating their walking speed.

We ran this experiment on several people with a large difference between the biomechanical walking speed and the virtual world speed. The results indicated that it is possible to cause some recalibration with the Treadport. However, many more experiments are needed to determine how much recalibration occurs, if it is symmetric for the biomechanically faster and slower conditions and if geometric complexity affects recalibration.

Gain adjustment experiment

After the infinitely long hallway was implemented, we created another experiment to determine how fast people want the virtual world to move while they are walking. To do this, the subjects walked holding a small box with two buttons on it. These buttons adjusted the gain, or speed differential, between the walking speed and the world's speed. One button increased the speed the world moved and the other button decreased it. By starting subjects at different speeds and having them adjust the gain, we were able to determine how compressed they perceive the world to be. Because people perceive computer graphics to be compressed, we guessed that people would want to have the hall move slower than it should. However, the subject could not be allowed to take a long time to find the speed that they liked because there is a chance that the subject could get recalibrated to an initial, incorrect speed. As a result, a time limit of about 15 seconds was placed on the subject.

After a couple experiments, it was clear that subjects found it difficult to adjust the gain in the given amount of time. As a result, this experiment will be modified slightly in order to allow the subjects to feel comfortable with their selection of estimated speed.

Implementation of the virtual environments

The University of Utah did not have an indoor virtual environment that would be suitable for a recalibration experiment. Therefore, we needed to create realistic hallway models and a program that could display the hallway models efficiently. We used an existing model of a hallway and a template of code for Treadport applications as a starting point for our project.

To make the subjects believe that the hallway was infinitely long while also conserving video memory and CPU cycles, we used fading preview images at the end of the rendered hallway. Instead of rendering the very distant portions of the hallway, we only rendered the first 80 to 160 meters of the hallway and then put a flat preview image of the rest of the hallway at the end. When the user went past the 80 meter mark, old geometry was removed from behind the user, 80 meters of new geometry was added behind the preview image and the preview image slowly faded away. Figure 4 shows what the preview images would look like if they were white. The closest image with the number one on it is approximately 80 meters away. The next preview image is 80 meters behind the first. Once the implementation was complete, it was almost impossible to see where the preview images started. This method worked very well because users could not turn and were forced to walk in the middle of the hallway. If the users were not in the hallway's center, the preview images would immediately appear to be flat.

Maya, a software package for 3D modeling, was used to create 20 meter hallway segments. These segments could be rendered four different ways. They could be

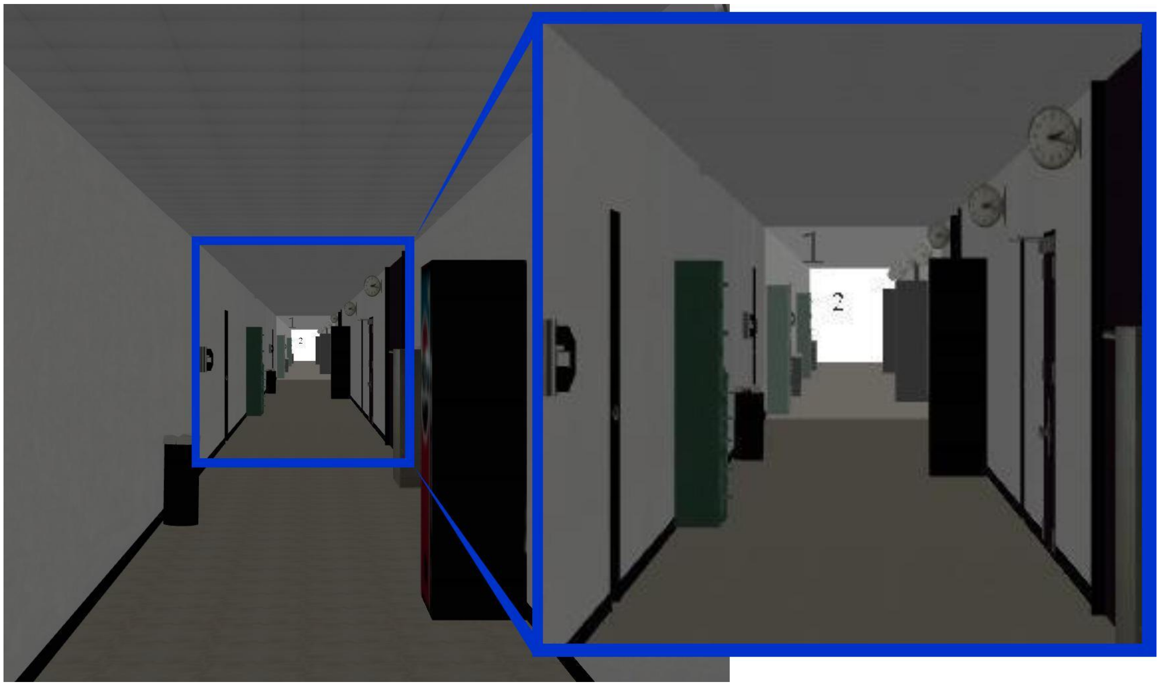

Figure 4: A fading preview image

displayed forward, backward (rotated around 180 degrees), inverted (left and right walls swapped) and both inverted and backward. This increased the feeling of randomness while walking down the hallway and also conserved memory. We wanted randomness so the user wouldn't get bored walking down the same sections of hallway repeatedly. For example, Figure 4 looks unnatural as a result of the same segment being repeated (there are many vending machines on the right wall). The hallway in Figure 3 is much more realistic.

In order to provide a random combination of hallway segments and their orientations but still be able to have created a set of preview images in advance, we created seven groups of 80 meter hallway segments for the simple and complex halls. Each group had an preview image associated with it. Any one 20 meter segment was a part of several groups of hallways and could be in different orientations for each group. When the user walks down the hall, the groups are shown in a random order. Grouping hallway segments provided sufficient randomness for the user but required only a limited number of preview images.

We used WorldToolKit, a development system built on OpenGL in C, to handle the fading preview images as well as import and display the Maya models. The graphics were rendered on a four processor SGI Onyx2 system with two rendering pipelines. We were able to render all three high-resolution screens at approximately 25 frames per second. There are plans to replace the SGI machine with a cluster of Linux machines. This upgrade should significantly increase the frame rate of all Treadport applications.

Conclusion

A large amount of research needs to be done before we can fully understand what information humans use in the perception of virtual environments. To create an effective immersive environment, it is important to focus on how people perceive computer graphics—not just on the graphics alone.

Once perfected, immersive environments and locomotive interfaces such as the Treadport will be useful tools for research that is not financially or technically feasible in the real world. Besides research applications, Treadport-like systems have many applications for simulation, education and recreation. Dangerous environments can be effectively simulated for training, and designers can use simulation to interact with an expensive prototype. Virtual worlds open many possibilities for education and might also provide a new recreational tool for exercise and entertainment. With more research, immersive environment systems have the potential to become more effective, useful and practical for a variety of applications.

References

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