8-6-2010

A Study of the Effects of Immersion on Short-term Spatial Memory

Eric A. Johnson
johns141@purdue.edu

Follow this and additional works at: http://docs.lib.purdue.edu/techmasters

PURDUE UNIVERSITY
GRADUATE SCHOOL
Thesis/Dissertation Acceptance

This is to certify that the thesis/dissertation prepared

By Eric Arthur Johnson

Entitled A Study of the Effects of Immersion on Short-term Spatial Memory

For the degree of   Master of Science

Is approved by the final examining committee:

Professor Nicoletta Adamo-Villani
                    Chair

Professor LaVerne Abe Harris

Professor Bedrich Benes

To the best of my knowledge and as understood by the student in the *Research Integrity and Copyright Disclaimer (Graduate School Form 20)*, this thesis/dissertation adheres to the provisions of Purdue University's "Policy on Integrity in Research" and the use of copyrighted material.

Approved by Major Professor(s): __Nicoletta Adamo-Villani__

Approved by: James L. Mohler   7/26/10
                    Head of the Graduate Program   Date

PURDUE UNIVERSITY
GRADUATE SCHOOL

Research Integrity and Copyright Disclaimer

Title of Thesis/Dissertation:

 A Study of the Effects of Immersion on Short-term Spatial Memory

For the degree of Master of Science_____

I certify that in the preparation of this thesis, I have observed the provisions of *Purdue University Teaching, Research, and Outreach Policy on Research Misconduct (VIII.3.1)*, October 1, 2008.*

Further, I certify that this work is free of plagiarism and all materials appearing in this thesis/dissertation have been properly quoted and attributed.

I certify that all copyrighted material incorporated into this thesis/dissertation is in compliance with the United States' copyright law and that I have received written permission from the copyright owners for my use of their work, which is beyond the scope of the law. I agree to indemnify and save harmless Purdue University from any and all claims that may be asserted or that may arise from any copyright violation.

 Eric Johnson
_____
Printed Name and Signature of Candidate

 7/26/10
_____
Date (month/day/year)

*Located at http://www.purdue.edu/policies/pages/teach_res_outreach/viii_3_1.html

A STUDY OF THE EFFECTS OF IMMERSION

ON SHORT-TERM SPATIAL MEMORY

A Thesis

Submitted to the Faculty

of

Purdue University

by

Eric Arthur Johnson

In Partial Fulfillment of the

Requirements for the Degree

of

Master of Science

August 2010

Purdue University

West Lafayette, Indiana

To my wife, Carrie, for her unending support and caring actions during the past six years. Also to my friends and family who push me further than I could ever go alone.

ACKNOWLEDGMENTS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

DEFINITIONS

- Immersion: "the illusion of being in the projected world… surrounded by images and sound in a way which makes the participants believe that they are really there" (Roussou, 2001)

- Spatial Memory: the cognitive ability to recognize and understand relationships between objects in space.

- Fish Tank VR System: a virtual reality system that renders "a stereo image of a three dimensional (3D) scene viewed on a monitor using a perspective projection coupled to the head position of the observer." (Ware, 1993)

- Frames Per Second (FPS): The number of frames rendered in a real-time application over the period of one second.

ABSTRACT

Johnson, Eric Arthur. M.S., Purdue University, August, 2010. A Study of the Effects of Immersion on Short-term Spatial Memory. Major Professor: Nicoletta Adamo-Villani.

The goal of the study was to determine whether the level of immersion of a virtual environment has a significant effect on the user's short term spatial memory. Two previous virtual environment development projects are reviewed: the Muscatatuck Virtual Tour and the 21st Century World Future City (Adamo-Villani, et al. 2009, 2010)). These projects show the viability of producing a virtual environment and a partially immersive, low-cost virtual reality system ,i.e. a Fish-Tank system (The system was used for the purpose of the study). Previous research is analyzed to demonstrate the viability of using virtual reality as a testing tool for measuring the effects of immersion on cognitive processes. Results of the study show that there is a significant difference in spatial memory when the level of immersion changes.

CHAPTER 1. INTRODUCTION

This chapter presents a research question and hypothesis that will be tested during the course of this study. The scope of the study is outlined along with the limitations, delimitations, and assumptions. The significance of this study on the current body of knowledge of immersion and cognitive processes is presented as well.

1.1. Research Question

When navigating a complex virtual 3D environment, does the user's spatial memory improve with an increased level of immersion?

1.2. Hypothesis

H_1: Spatial memory is improved as immersion is increased.

1.3. Scope

The study presented by this paper focuses on the effects virtual reality systems and immersion have on cognitive processes, specifically spatial memory. Other cognitive processes like episodic memory may be affected but

were not tested during this study. In this study we compare non-immersive VE with partially immersive ones (i.e. VE with head tracking and stereoscopic rendering). Full immersion virtual reality systems were not used during the course of this study.

1.4. Significance

Virtual reality systems have become increasingly popular as the hardware and software needed to create such as systems are becoming more available and affordable. The use of new control devices and delivery methods in modern graphics applications are moving in a direction that embraces virtual reality concepts, like motion control and stereo rendering, and moves away from traditional computer setups (i.e. keyboard and mouse). Understanding the effects virtual reality and immersion have on cognitive processes could prove useful in development of effective virtual reality applications we will see in the future.

1.5. Assumptions

The assumptions for this study include:

- Participants have knowledge of basic computer commands and input devices (i.e. how to use a mouse and keyboard to navigate).

- The quantitative testing methods used to measure immersion are sufficient for this study.

- The virtual environments created for this study are sufficient for display and testing purposes.

- Participants have little to no knowledge of fish tank virtual reality systems.

- Standard T-Tests performed on the time taken to complete spatial memory tasks and improvement times will return valid results.

1.6. Delimitations

The delimitations for this study are listed and are addressed during discussion in Chapter 5:

- Comparison of different head tracking devices is not relevant to this study.

- Differences between participants (i.e. gender, age, etc.) are not a focus for this test. If major differences in results present themselves, they will be noted.

1.7. Limitations

The limitations for this study include:

- The virtual environment has been designed for a specific fish tank system and has not been tested on other immersive systems.

- The head tracking system used for the study has five degrees of freedom for tracking (position, roll, and pan) so "full" (six degrees of freedom) head tracking is not possible.

- Participants may become dizzy or disoriented during part of the testing, at which point the testing will stop.

- The pool in which the population sample was recruited does not represent the general population.

1.8. <u>Summary</u>

This paper presents a research question as it relates to the topic of virtual reality immersion and spatial memory. A hypothesis is formed from the research question; the hypothesis is tested using the methodology described in Chapter 3. The scope and significance of this study are presented, as well as the assumptions made by the study, delimitations, and limitations of the procedure.

CHAPTER 2. LITERATURE SUMMARY

The following literature review focuses on the topics related to virtual reality and spatial memory in order to better understand what goes into creating an immersive virtual reality system and its effects on a user. Previous work in virtual environment development is presented as well.

2.1. Previous Virtual Environment Development

Designing any virtual environment for use in a real-time application requires planning and organization in order to create the most efficient rendering system possible for the given deliverable specifications. The author has designed and developed two virtual environments for use in educational settings: Muscatatuck Virtual Tour (Adamo-Villani, et al. 2010) and 21st Century World Future City (Adamo-Villani, et al. 2009). One of the goals of these two projects was to increase the user's immersion in order for them to feel as if they were actually present in the locations.

The 21st Century World, shown in Figure 2.0, was developed to present information in an engaging way. Nanotechnology firms can upload information in the form of videos, audio, and images for users to interact with. This information is located in specific locations in the world. Current news is available at virtual

newsstands, while specific company information is available in a specific

building. The development of the city layout was influenced by what type of

information needed to be displayed for an exploring user. Trying to create a

virtual environment that was easy to navigate and learn led to multiple iterations

of the user interface and city layout.

Figure 2.1 Future City Real-time Virtual Environment

The goal of the city layout was to relate certain locations with certain

information. When a user wants to access a certain type of information, they

must know where to go in the world. Improving spatial memory of the user was

not a priority in the development of the 21st Century World, but it was a factor that

influenced design decisions (Adamo-Villani, et al. 2009).

The 21st Century World is being distributed through a webpage and can be displayed in a web browser. In order to keep the virtual world interactive, the rendering engine uses level of detail techniques to improve the frames per second when necessary. Computers that cannot run the application at a sufficient speed, would use fallback rendering techniques to compensate.

Lower resolution meshes and textures are replaced when necessary. Different height maps for terrain are loaded when a computer cannot support a large amount of detail. Using level of detail techniques like these allows the application to run on a wide variety of computers with consistency (Adamo-Villani, et al. 2009).

The Muscatatuck Virtual Tour, shown in Figure 2.1, was developed to document and preserve a historical site and present history information to the user. The layout of the buildings, trees, roads, and other miscellaneous objects was predetermined. One goal when developing this virtual environment was to give the user a feel for moving around the site and viewing it as it was before changes were made to the buildings and landscape. Increasing the level of immersion was an important factor for making the users feel as if they were at the site. Two versions of the virtual environment were developed. One would be distributed similarly to the 21st Century World over the Web. The other was developed for a single machine that took advantage of a Fishtank virtual reality system.

The same type of level of detail system was used in the rendering engine in order to keep the frames per second high enough for interactivity (Adamo-Villani, et al. 2010).

Figure 2.2 Muscatatuck Virtual Tour Environment

2.2. <u>Virtual Reality Systems</u>

Virtual reality as it relates to the topic of immersion has been a subject of interest over the past two decades. In many definitions of a virtual reality system, the word "immersion" is used to describe what the system does. Immersion can be described as "the illusion of being in the projected world … surrounded by images and sound in a way which makes the participants believe that they are really there" (Roussou, 2001, page?). A virtual reality system is designed to increase the sense of immersion a user experiences, and the goal of a virtual

reality system has not changed over the years. "Total immersion" is a term used to describe the "holy grail" of virtual reality. So far no studies have claimed to have reached "total immersion," or have had a user's senses be completely removed from the real world.

In order to create an immersive virtual reality environment, certain requirements of the system must be met. Brooks (1999) describes immersive virtual reality as an experience "in which the user is effectively immersed in a responsive virtual world. This implies user dynamic control of viewpoint." In order for a user have dynamic control over a viewpoint, the virtual environment can be rendered in real-time on a computer. There are also six characteristics associated with an immersive virtual reality system. They include head-referenced viewing, stereoscopic viewing, a full-scale virtual world, realistic interactions via gloves or similar devices, enhancements like auditory and haptic technology, and networked applications for shared experiences (Beier, 1999). Including all of these characteristics in a virtual reality system would create a fully immersive system. Removing one or more of these characteristics would create a partially immersive system. There are many different hardware and software combinations that can be used to create a virtual reality system. Because there are so many combinations, it is hard to categorize virtual reality systems into different groups. One possible breakdown is by display device. This results in three major categories:

- Projection Based VR systems
- Head Mounted Display (HMD) based VR systems

- Monitor-based desktop VR systems

    (Wen, et.al. 2006)

Projection based VR systems, otherwise known as C.A.V.E., surround the user with multiple large projection screens in the orientation of a cube. Multiple projectors are used to render views into the virtual environment on the projection screens. This effectively surrounds a user on all or most sides with views of the environment. Motion tracking systems are used in conjunction with the display system. There are several advantages of using a projection based system for virtual reality applications. Multiple sensors for a motion tracking system can be used in any setting, but because the interaction space is predefined in projection based systems, the tracking setup can be calibrated specifically for that space. This leads to more accurate motion tracking systems. Surrounding the user with displays allows for the potential of implementing all of the requirements for creating a fully immersive environment. The disadvantages of using these systems are the size and cost. C.A.V.E. systems need to be large enough to completely surround a user, as well as house multiple projectors and tracking sensors. The large number of screens and projectors also raises the cost of purchase and maintenance of these systems as well as decreases portability.

Head mounted display VR systems are similar in nature to C.A.V.E. systems in that they surround a user with viewports into the world. HMD systems are more compact that C.A.V.E. systems since there is no need for multiple large displays. Everything the user views is through a small screen mounted a short distance from the user's eyes. Because the display moves with the user,

accurate motion tracking systems must be used in order to orient the view on the display according to user motion. Head mounted displays are specialized hardware used specifically for virtual reality and are more expensive and less portable than typical computer hardware.

Monitor based desktop VR systems are the simplest of the categories. A virtual reality system based on a monitor display is called a fish tank system. A fish tank system can be defined as a virtual reality system that renders "a stereo image of a three dimensional (3D) scene viewed on a monitor using a perspective projection coupled to the head position of the observer" (Ware, 1993). The requirements for creating a fish tank virtual reality system coincide with creating a partially immersive system described above. The display device is a standard computer monitor that can render stereo images, and only one motion tracking sensor is required. Because the user is always facing a stationary display device, some of the advantages that come with surrounding the user with the environment are lost. However, cost of purchase and maintenance is less than other systems since the hardware and software used to create fish-tank systems is readily available.

Motion tracking systems can vary as much as the display systems. The number of motion sensors in combination with the number and type of tracking points can affect accuracy. When using image based tracking, a camera captures the user and processes the image in order to find changes from one frame to the next. This can lead to inaccurate tracking in changing lighting conditions that affect the captured image. Infrared (IR) based tracking systems

eliminate some of the lighting requirements. By tracking IR LED's, an IR sensor can accurately locate a tracking point in a variety of lighting conditions. Large amounts of IR light, such as an in an outdoor environment, can lead to less accurate tracking, however.

In order to test how immersive a virtual reality system is, immersion can be measured quantitively. Paush et.al. (1997) performed multiple tests in the paper "Quantifying Immersion in Virtual Reality" that show increased levels of immersion when a virtual reality system was used as opposed to not. The tests also used time taken to complete a task as a testing method to measure various types of productivity. If the time taken to complete a memory task changes due to the level of immersion, it is a sufficient means of measuring the effects of immersion on the processes used to complete the task. Generally, the use of virtual reality systems will increase the level of immersion a user experiences when compared to not using a virtual reality system.

Based on the literature, a fish tank system is sufficient for use as a virtual reality system that will increase the level of immersion for the user. This type of system will be used for testing purposes in this study.

2.3. Recent Advances in Virtual Reality Technology

While virtual reality systems have been around for two decades, recent advances in rendering and tracking technology have jump started virtual reality development in the past five years.

In 2005, Nintendo released the Wii, the first commercially successful game console to use a tracking system as its main input device. The Wii uses and infrared sensor paired with infrared LEDs in order to track where a user is pointing a remote (Nintendo, 2010). The technology behind the Wii controller was further explored by Lee (2010) for use in a variety of applications, including head tracking.

In 2001, Nvidia released 3D drivers for their line of graphics cards. These drivers allowed the graphics card to render stereoscopic images to a display. The display and glasses hardware needed to run this system were not developed by Nvidia. In 2009, Nvidia released the Vision system that included a pair of active shutter glasses and a signal adaptor that could be plugged into a computer via USB. The Vision system is supported by updated graphics drivers and the expansion of 3D compatible display development (Nvidia, 2010).

In 2009, Microsoft announced a tracking system using a camera with two separate lenses called Natal. This system uses the two lenses to calculated depth in combination with motions tracking (Microsoft, 2010).

In 2010, Sony announced a controller for its Playstation 3 platform that uses a combination of a camera, controller, and tracking software. This in combination with stereoscopic rendering on the platform opens the doors for virtual and augmented reality applications to be developed on a large scale (Sony, 2010).

All of these systems were created with game interaction in mind. So far, many of the control schemes for the motion tracking systems involve using

gestures to represent commands. It is also possible to use the tracking systems to replicate human movement in a virtual environment. The type of hardware and software used in these examples has been around since the first fish-tank system, but cheaper production and higher resolution sensors as well as a larger adoption of new technology opens up the potential for creating virtual reality systems with portable products available to the general public.

2.4. <u>Spatial Memory</u>

Spatial memory is a cognitive process that allows a person to remember locations and relationships between objects in space, or the "ability to recognize and understand spatial relationships (both in 2D and 3D)" (Robertson, 1998). The use of this process allows someone to remember "where" something is in relation to some other object.

Virtual reality can be used to measure the use of spatial memory in a similar way it can be used to measure episodic memory. Episodic memory, or memory of a sequence of events, can be tested in a virtual reality system by having participants explore a virtual world, either actively or passively, and then asking questions about the experience (Plancher, 2008). In the study done by Plancher (2008), the users' experienced increased levels of immersion and had better scores on episodic memory tests. In this case recalling events was a sufficient testing method for measuring episodic memory tasks. In order to test spatial memory, the user can be asked to complete a task reliant on spatial memory after exploring a virtual environment.

Both Brooks et al. (1999) and Carassa et al. (2002) suggest that virtual reality can increase the use of episodic memory by the user. Carassa (2002) also states that participants who actively explore a virtual environment complete more memory tasks as opposed to passively exploring an environment. Carassa (2002) and Plancher (2008) both mention that spatial memory seemed to increase when using an immersive virtual reality system, however neither study used spatial memory as a variable and no testing specific to spatial memory was completed. This study addresses the lack of data related to the effects of immersion on spatial memory by testing the effects immersion has on spatial memory.

2.5. <u>Summary</u>

The literature provided describes virtual reality systems and their role in measuring cognitive processes. Virtual reality systems and increased immersion has been shown to be used as a testing method for measuring episodic memory. Those studies note the improvement of spatial memory while using virtual reality systems without giving conclusive statements. Based on the literature this study looks to test for conclusive evidence that spatial memory is affected by the level of immersion experienced by the user.

CHAPTER 3. METHODOLOGY

The following methodology is presented to answer the research question presented by this study through quantitative research techniques. The process of developing a Fishtank VR system is described. Experiment design and evaluation techniques are outlined. Previous development of virtual environments is discussed.

3.1. <u>Study Design</u>

This study uses a quantitative research approach with human subjects. Human subjects were asked to take part in one of two experiments (A or B). Both Experiment A and Experiment B have four tasks:

- *Task 1* has the subject navigate a virtual environment using a standard control scheme. The navigation is guided by a set of checkpoints strategically located around the environment.
- *Tasks 2 has the subject start at a predetermined location and navigate* to a goal object located elsewhere in the environment. The navigation is unguided.

- *Task 3* has the subject navigate a virtual environment replicating the same checkpoint system as *Task 1*.

- *Task 4* has the subject start at a predetermined location different from the start location in *Task 2*. The subject navigates to a goal object located elsewhere in the environment.

Subjects who participated in Experiment A (the control group) did not use the Fishtank VR system during the completion of the tasks. Subjects who participated in Experiment B used the Fishtank VR system during *the tasks.* The experiment a particular subject takes part in is decided at random without prejudice. In order to keep collected data consistent, the starting locations and goal objects for *Task 2* and *Task 4* are consistent across subjects. The data collected from both experiments was gathered and evaluated using statistical analysis in order to test the presented hypothesis.

This study design eliminates external variables that could contaminate the resulting data within the scope of the project. Lighting conditions remained constant throughout the testing procedure. All subjects experienced the same testing module under the same conditions while allowing the level of immersion to be manipulated by the testing administrator during the required portion of Experiment B.

3.2. Variables

Multiple variables were measured in order to identify the differences in spatial memory task completion as it is affected by immersion. They are as follows:

- Time – The time taken to complete *Task 2* and *Task 4* for each subject.

- Improvement Rate – The time taken to complete *Task 4* divided by time taken to complete *Task 2* for each subject.

- Immersion – The level of immersion is labeled as either non-immersive or immersive depending on the use of the Fishtank VR system.

- Frames Per Second (FPS) – 30 FPS minimum/ 60 FPS ideal (per eye for Experiment B)

- Gender – Male or female.

- VR Experience – Five point Likert scale including Very Experienced, Experienced, Undecided, Inexperienced, Very Inexperienced.

Evaluation of time taken and improvement rates of subjects show whether or not the level of immersion has a significant effect. Gender and VR Experience data is used for discussion purposes. Frames per second is used to show the testing environment runs at an acceptable speed in order to maintain real-time interaction.

The external variables listed below are identified in order to eliminate their influence as much as possible during the testing procedure:

- Room lighting – could interfere with the head tracking system or distract the subject.

- External Noise – could be a distraction to the subject.

- Glitches – if there are technical glitches like freezes during a subject's testing session, the data could be contaminated.

- Subject comfort – if the subject is testing in an uncomfortable position or the head tracking hardware does not fit, it could be a distraction.

3.3. Subjects

44 participants (age 18-26) were tested for this study. Each subject participated in one of the two experiments described above. The subjects were recruited students at a collegiate level. No subjects have color blindness, blindness, or other visual impairments. Subjects include both males and females (Figure 3.1) with various levels of virtual reality experience (Figure 3.2).

3.4. Virtual Environments

The development of multiple virtual environments took place in order to ensure a sufficient testing environment for this study could be created. The two virtual environments created were the Muscatatuck Virtual Tour, which the testing module is based off of, and the Future City virtual environment. The testing module was created using the same tools and procedures laid out by these two development cycles.

testing module was created using the same tools and procedures laid out by these two development cycles.

The Muscatatuck Virtual Tour was created in order to give users the experience of exploring and learning about a historical site as it was before the site was converted into an urban training facility for the Indiana National Guard. The site holds many art deco style buildings and a unique layout of roads that called for showing a large range of detail to the user. Multiple cameras were used to achieve this goal, including a first person controlled camera, a guided camera with limited user control, and a fly through camera with no user control. In order to be able to show all of the detail of the environment to the user while still giving them the feeling of exploring, the first person camera was developed as the main camera. This viewpoint replicates human movement and height in order to give the feeling that the user is really there. The testing module adopted this viewpoint due to the style of control. The environment was creating using custom building models, road and sidewalk models, and other detail meshes. A nature painting system was used to add foliage and trees to the environment, and a cubemap in conjunction with transparent billboards were used to create the sky and clouds.

The Future City virtual environment was created to share information with the user about nanotechnologies role in the future world. The environment and camera systems were built similarly to the Muscatatuck Virtual Tour. Custom buildings and detail meshes were used to populate the environment, however specific locations of objects and buildings were not guided like the real world site used in the Muscatatuck Virtual Tour. There was only one camera system in the

first person perspective, however the camera could jump from one static position to another in order to focus on specific objects. This works as a combination of the first person camera and the guided camera used in the Muscatatuck Virtual Tour. Real-time cube maps were used to create reflections in bodies of water. The sky was rendered as a static skybox.

In both virtual environments a graphic user interface (GUI) was used in order to give the user direction and make available commands. These GUIs were developed specifically for each environment and for each situation a user would run into when navigating. In order to keep the testing module controls as simple as possible, the GUI system was limited to only two buttons since the number of interactable objects and cameras was reduced.

3.5. Stimuli

.

The fish tank system includes a personal computer, a display monitor, head tracking, and stereoscopic rendering, and stereoscopic shutter glasses . The display monitor used is a Samsung 120 Hz monitor, the Nvidia Vision system is used to display stereoscopic images, and the head tracking hardware is a custom layout of infrared LEDs attached to the stereoscopic glasses and an infrared sensor. The personal computer is a Dell Studio PC with an Nvidia Geforce 255 graphics card capable of rendering stereoscopic images. This system will be used to display the virtual environment for all participants.

The virtual environment is designed specifically for the fish tank system. Multiple 3D buildings are displayed on a terrain with varying height. Foliage is rendered around the perimeter of the scene as well is in-between buildings. Roads and pathways are also present. Buildings are identified as different landmarks (i.e. hospital, school, etc.) and other types of structures will be placed among the landscape. The sky will be rendered using a 'sky sphere' and animated billboards of clouds. The moving clouds will help increase immersion without allowing the user to use them as stationary landmarks.

The head tracking software is a combination of open source hardware drivers for a Nintendo Wii Remote (Wii, 2010) and a tracking algorithm written in the application logic engine. The tracking algorithm converts two screen space transforms captured by the IR camera into camera transform information in the virtual environment that replicates human movement. This is achieved by following certain rules that are inherent to single monitor VR systems:

- If the subjects rotate their head left, right, up, or down while facing the monitor, the view of the display device is lost.
- If the subjects move the position of their head relative to the display device up, down, left, or right, the subjects must turn their head to a certain degree in order to face the display device.

Blending camera transformations when the IR camera loses track of the user keeps the view from snapping to a position which could be jarring to the viewer.

The testing module was developed using a DirectX graphics engine and runs locally on the personal computer described above as a self contained executable. The development of the testing software followed the guidelines described by Nvidia (2008) so no hardware programs cause unwanted artifacts or graphical glitches.

Fishtank Headtracking VR System
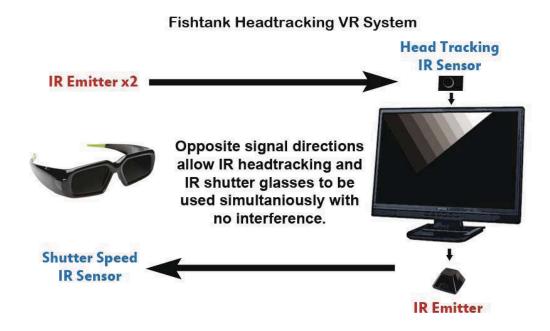
Figure 3.1 Headtracking Hardware Setup

The headtracking hardware setup is shown in Figure 3.0. Two IR emitters and two IR sensors are used for separate tasks. In order to eliminate interference from one sensor/emitter pair to another, the hardware was placed so signals would travel in opposite directions. The IR emitter sending the stereoscopic information to the glasses is located by the computer monitor, while the emitter sending head tracking information is located on the glasses. This setup was reliable in many different lighting conditions with no sign of signal interference.

3.6. <u>Procedure</u>

Before a subject participated in an experiment, one of the two experiments described above was chosen at random. The user was then asked to complete a short survey in order to record general subject data. The subject was then asked to sit down in front of the testing environment. The user was given the opportunity to become familiar with the control scheme used in the rest of the experiment by moving around a pretest environment consisting of primitive shapes. The subjects could start *Task 1* when they were comfortable with the control scheme. The following rules are defined for the subject at the start of *Task 1*:

- Follow the command in the upper left portion of the screen.
- When asked to stand still, do not use the movement keys. Only use the look controls.
- When asked to move to the next checkmark, use the movement keys and look controls to do so.

The subject then navigates through the environment in a guided fashion. Once *Task 1* is complete, the view of the testing environment is blocked and the starting position for *Task 2* is set. The following rules are defined for the subject before *Task 2* starts:

- A picture of an object will be shown.

- Navigate to the object.

- When in range of the object, click the "Found It!" button.

When the user was ready, they click a start button. The environment was again shown along with a still picture of the goal object, and a timer was started. The user navigates to the goal object. A "Found It!" button was displayed when the subject moves in range of the goal object. The subject clicks the "Found It!" button and the timer was stopped. Figure 3.2 shows the testing environment with a testing checkpoint and goal objects present.

Figure 3.2 Checkpoint and Goal Objects

The subject was then reset to the pretest environment where subjects in Experiment A are asked to wait for the next task to begin. Subjects in

Experiment B are asked to put on the stereoscopic shutter glasses with head tracking.

Task 3 replicates *Task 1* except subjects in Experiment B can use head tracking in addition to the standard control scheme. *Task 4* replicates *Task 3* except the starting location and goal object are changed.

The testing session will take a maximum of 30 minutes to complete. The pretest survey will take no longer than five minutes. *Task 1* and *Task 3* are estimated to take seven minutes and thirty seconds each to complete. *Task 2* and *Task 4* take less two minutes each to complete. The remaining time was dependent on the subjects comfort with the control scheme. The data collected by the testing module was recorded in a secure manner after a subject completes all of the tasks.

3.7. Analysis

The data collected for this study was compiled and analyzed in order to search for any significant effect of immersion on the subjects' spatial memory The time taken to complete Task 2 and Task 4 across Experiment A and Experiment B was calculated from the two tasks along with the improvement time. The resulting information gathered from the data analysis was tested for significant differences using standard T-Tests. Gender and experience information about the subjects was analyzed for the purpose of discussion; however, conclusive data was not retrieved due to the small sample size.

CHAPTER 4. RESULTS AND ANALYSIS
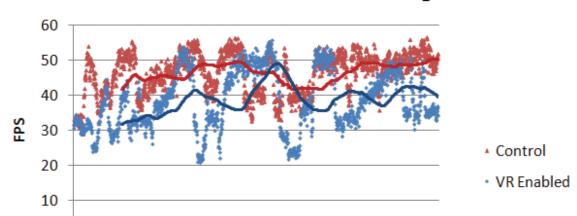
The data collected during the procedure described in Chapter 3 was analyzed and is presented below.

4.1. Testing Module Frames Per Second

The frames per second (FPS) calculated while navigating the testing module was recorded and analyzed. Figure 4.1 shows the frames per second data over the period of 1500 with and without the VR system enabled. The FPS are calculated at each frame to show the FPS at that instant. The average FPS during the testing sessions remains over the minimum average allowed by this study at 30 FPS. Table 4.x shows the statistical data gathered.

Table 4.1 FPS Across Experiments

	Average (FPS)	Min (FPS)	Max (FPS)	STDV (FPS)
Control	46.15	28.75	56.31	5
VR Enabled	60	60	60	5

Figure 4.1 Graph of Frames Per Second during testing sessions.

4.2. Time Comparison

The time taken to complete Task 2 and Task 4 was recorded in order to measure the subjects' ability to complete spatial memory tasks. Table 4.2 and Table 4.3 show the statistical data gathered from analyzing the time comparison data. Time taken to complete Task 4 is shorter than time taken to complete Task 2 in each case. This is expected based on the study design. The high standard deviation shows the data is scattered loosely around the mean, however Experiment B shows a more stable data set.

Figure 4.2 and Figure 4.3 show the task completion times of individual subjects in Experiment A and B. In general the completion times for those

participating in Experiment B were faster than those participating in Experiment
A.

Table 4.2 *Experiment A Task Completion Time*

	Average (s)	STDV (s)	CI 90% (s)
Task 2	26.23	16.73	7.10
Task 4	20.48	9.60	4.07

Table 4.3 *Experiment B Task Completion Time*

	Average (s)	STDV (s)	CI 90% (s)
Task 2	20.90	10.11	4.30
Task 4	15.93	5.23	2.22
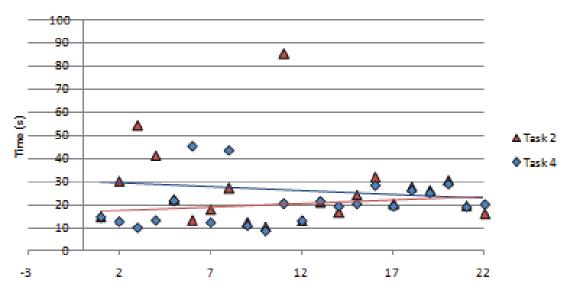
Figure 4.2 Graph of Experiment A Task Completion Time
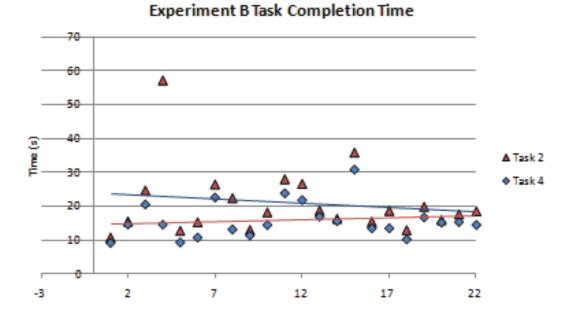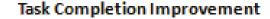
Figure 4.3 Graph of Experiment B Task Completion Time

4.3. Task Improvement

Task completion improvement is used to measure how much subjects improved their ability to perform during Task 4 after having equal time navigating the testing module. Time taken to complete Task 4 is subtracted from the time taken to complete Task 2. There is a positive relationship between the time taken and the level of improvement. Negative task completion improvement time shows that a subject's ability to complete the task worsened.

Task Completion Improvement
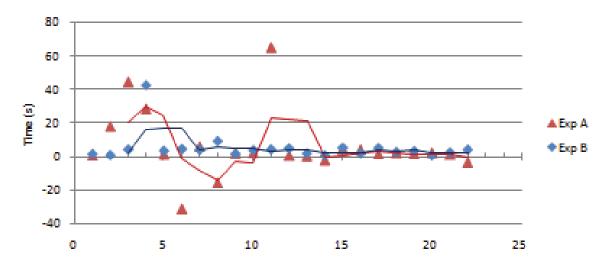
Figure 4.4 Graph of Task Completion Improvement

There are five subjects that performed worse during Task 4 than in Task 2 in Experiment A. All subjects in Experiment B improved from Task 2 to Task 4. Table 4.4 shows the statistical data pertaining to task completion improvement across both experiments. The average improvement for Experiment A is lower than the average improvement for Experiment B. The standard deviations for both are high, however Experiment B's standard deviation suggest less variance in the data compared to Experiment A.

Table 4.4 Improvement Time Statistics

	Average (s)	STDV (s)	CI 90% (s)
Exp A	5.75	19.45	8.26
Exp B	4.96	8.63	3.66

4.4. <u>Correlation</u>

A sample correlation coefficient was calculated across both experiments for Task 4 and task improvement times with relation to the level of immersion. Table 4.5 shows the resulting correlation coefficients for the data. There is a negative correlation between the time taken to complete Task 4 and the level of immersion. The correlations calculated for this sample population are statistically weak. These statistics were used as an estimate for the population correlation, however the results are inconclusive and can only be noted.

Table 4.5 *Correlation Coefficients*

	Cofficient (r)
Task 2	-0.198
Task 4	-0.441
Improvement	-0.033

4.5. <u>Significance</u>

A standard T-Test was performed on both the raw and modified data in order to find a significant difference between data collected in Experiment A and Experiment B. The data collected on both Task 2 and Task 4 as well as Improvement Times were used to test the hypothesis presented. Table 4.6 shows the resulting data from the test across both data sets.

Table 4.6 *T Test Results*

	Result (p)
Task2	0.0467
Task 4	0.0497
Improvement	0.4319

Using an alpha value of 0.05, the resulting p values show that there is a statistically significant difference between data collected from Experiment A and Experiment B when focusing on Task 2 times. The Task 4 results show a significant difference after the subjects have been navigating the environment for around 20 minutes.

4.6. Gender Comparison

Out of the sample population consisting of thirty subjects, six were female and twenty two were male. Two subjects chose not to respond. Figure 4.6 shows the percentages of gender distribution. While the subjects' gender was not a factor when deciding what experiment they would take part in, the distribution of males and females was equal across both experiments. There were also 3 non across both experiments.
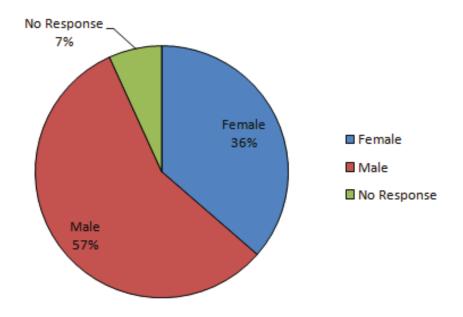
Figure 4.5 Gender distribution across Experiment A and B

The average completion time for Task 4 for females was 19.68 seconds while the males average completion time was 17.64 seconds. Table 4.7 shows the average completion times for males and females in their respective experiments.

Table 4.7 *Average Completion Time(s) Task 4 Across Gender*

	Male	Female
VR	13.74	23.21
Non VR	16.83	25.97

The average improvement time in seconds from Task 2 to Task 4 for females was 17.72 seconds while the males' improvement time was 7.54

seconds. Table 4.8 shows the average improvement times for males and females in their respective experiments.

Table 4.8 *Average Improvement Time(s) Across Gender*

	Male	Female
VR	8.82	24.45
Non VR	5.55	16.86

In this sample population, female subjects showed greater improvement than male subjects in task completion from Task 2 to Task 4. Males had faster times when completing Task 2 and Task 4 than females.

4.7. Subject Experience

Subjects were asked to rate their previous experience with virtual reality systems from "Very Inexperienced" to "Very Experienced". Out of the thirty subjects, two stated they were very inexperienced, eleven stated they were inexperienced, three stated they were experienced, four stated they were very experienced, and three did not respond. Figure 4.6 and Figure 4.7 show the distribution of subjects in each experiment related to previous experience in virtual reality.
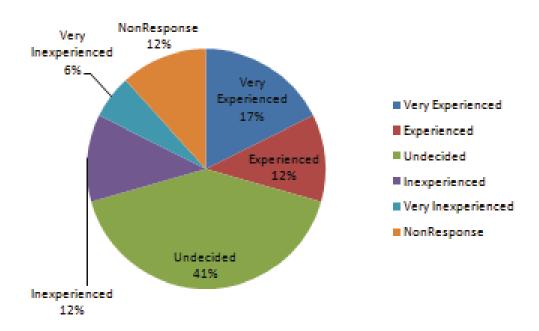
Figure 4.6 Graph of Subject Experience Experiment A

The subjects who participated in Experiment A in general had more previous experience with virtual reality systems. The distribution of experienced subjects to inexperienced subjects was not equal across both experiments.
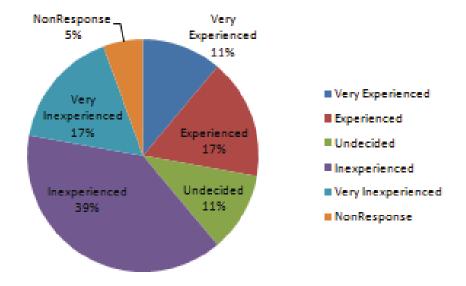
Figure 4.7 Graph of Subject Experience Experiment B

Table 4.9 shows the statistical data from to Task 4 and improvement times related to experience. The data does not show a strong relationship between experience and the ability to perform spatial memory tasks. Figure 4.9 shows the breakdown of experience related to gender.

Table 4.9 *Average Time Data Related to Experience*

	Task 2 (s)	Task 4 (s)	Improvement (s)
Very Experienced	15.49	14.84	8.50
Experienced	10.23	9.44	0.52
Undecided	18.92	16.84	2.89
Inexperienced	20.12	18.72	13.85
Very Inexperienced	18.23	17.11	5.38
No Response	11.74	10.08	7.32
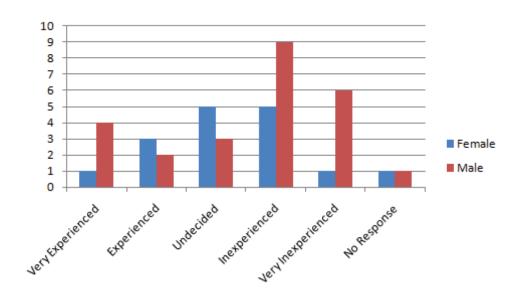
Figure 4.8 Graph of Subject Experience and Gender

4.8. <u>Summary</u>

This chapter presented the data gathered through the procedure described in Chapter 3. The data was analyzed using standard statistical analysis and T Tests. Information related to the level of immersion and spatial memory is summarized so it can relate to the hypothesis. Subject data was compiled and analyzed to show trends within the sample population. The statistical analysis is sufficient for a study with a small population pool of college students with the number of subjects presented.

CHAPTER 5. DISCUSSION AND CONCLUSION

This chapter summarizes the results of the study. Limitations of the study are discussed and future work is proposed to expand the knowledge base related to this area.

5.1. Immersion and Spatial Memory

In testing the hypothesis presented by this study, three variables were analyzed using a standard T-Test. The time taken to complete Task 2 and Task 4 was tested in order to find a significant difference between subjects who experience a higher level of immersion by using the VR system and those that did not after having equal time navigating the testing environment. The analyzed data shows that the difference in time taken to complete Task 2 between subjects in Experiment A and Experiment B was significant. The same test taken for Task 4 between subjects in Experiment A and Experiment B shows the difference was also significant.

The improvement time from Task 2 to Task 4 was tested in order to find a significant difference between the subjects' in Experiment A and Experiment B while taken into account the influence Task 2 had on the subjects' spatial

memory. The analyzed data shows that the difference in improvement times from Experiment A to Experiment B is also significant.

The data collected and analyzed for Task 2, Task 4, and improvement times of this study supports the hypothesis. In this study with the subjects presented, a higher level of immersion does have a significant effect on the spatial memory of the subject. The data does show a weak positive correlation between immersion and spatial memory. Correlation does not show causation; therefore, it cannot be said that spatial memory is directly impacted by immersion based on the data collected, but it is still possible a relationship exists.

5.2. Intractable System

The testing module was created based on the Muscatatuck Virtual Tour project (Adamo-Villani, et al. 2010). The tour was built with strict requirements for distribution formats including displaying in a Web browser and as a standalone executable, thus the control scheme, rendering system, and Level of Detail (LOD) system were in place. In order to create a stable testing module for the purposes of this study, many of the features were stripped out of the full tour. This ensures the interface and other content like pictures and audio did not affect the testing module during a testing session. The meshes and textures used in the full tour were used in the testing module. Therefore, the results of this study pertain only to the testing module and not the full tour. Were the same tasks performed while using the full tour as the virtual environment, external variables would likely influence the measured data.

The most important statistic directly related to the testing module is the frames per second (FPS) at which the module was running. The data collected shows that the average FPS while navigating the testing module with the virtual reality system enabled and disabled remained above 30 FPS. While there were some instances when the FPS on a particular frame dipped below 30 FPS, the impact on the overall interactivity is minimal. When calculating the FPS while the virtual reality system is enabled, the value is calculated for each eye for each frame. Therefore, the testing module rendered fast enough that the speed of rendering had no impact on the usability of the module.

The head tracking system that was created for the Muscatatuck Virtual Tour was used with the testing module to complete the Fishtank VR system. Because this system has the subject wear a pair of active shutter glasses, there was some concern as to possible discomfort as a distraction. Users were told to ask to stop the testing procedure if there was any discomfort from wearing the glasses. Out of the 15 subjects who wore the glasses, there were no requests to stop the test or any complaints about comfort during the test.

5.3. Subjects

The data gathered on subjects who participated in this study showed some interesting results. Females performed worse during Task 4 than males, but improved from Task 2 to Task 4 more than males. Because of the small sample size and the distribution of males and females, there is no conclusive data showing that females will perform worse at spatial memory tasks than

males. The same applies to female subjects' ability to learn testing procedures any differently than male subjects.

The previous experience of the subjects is not evenly distributed across both experiments. Experiment A had more experienced subjects than Experiment B. Since the subjects in Experiment A had a slower average time of completion in Task 4 and smaller average improvement times, it can be suggested that previous experience with VR systems may not have a larger influence on spatial memory than the level of immersion.

5.4. Limitation Discussion

This study uses subjects recruited at a collegiate level over the age of 18 who have general knowledge of standard computer input devices. Because the pool of subjects does not represent the general population in relation of age and computer experience, this study does not estimate the significance of immersion's affects on spatial memory for the general population.

The environment use for the testing module includes complex meshes and textures in order to facilitate an immersive environment based on reality. This environment is used in combination with the Fishtank VR system to create a complex virtual reality environment. The effects of the Fishtank VR system on immersion without using a realistic virtual environment is not considered. Only two levels of immersion are used. The quantitative level of immersion is not calculated for this study because only a difference in immersion levels is needed. Therefore the data collected for the study can only be used to show the effects of

general differences in immersion levels experienced by subjects on spatial memory.

5.5. <u>Future Research</u>

Due to the limitations of this study as well as the ever advancing technology in virtual reality systems and 3D graphics, there are many possible avenues to continue this research. A study involving a more diverse sample population would give a better estimate of the effects of immersion on the general population. Age difference, computer experience, and physical ability are all variables that were unable to collect conclusive data or were outside the scope of this study, but would be good variables to collect with a greater number of subjects. Using a greater number of subjects will give a better view of the general population and, with a proper study design, can account for physical and mental differences between subjects.

This study only used one type of virtual reality system for testing purposes. Testing subjects on multiple types of virtual reality systems will give a better idea of how multiple levels of immersion affect spatial memory. Knowing what type of virtual reality system is best used to affect spatial memory in a subject could be valuable information during the design stage of virtual environment development.

This study focused on the use of head tracking technology in order to replicate human movement in the virtual environment. Using head and motion tracking as a means to control aspects of the virtual environment through the use

of gestures was outside the scope of this study; however these different techniques for control could be tested in order to find the best use for increasing immersion for the subject.

As hardware and software technology used to create virtual environments and virtual reality systems improve, this study can be repeated to show what affect those improvements have on spatial memory. Assuming immersion in virtual environments will increase in the future, the affects of virtual reality systems on cognitive processes may change. Knowing this information will be important in understanding the affects of virtual environments and virtual reality systems on the human brain.

The topics discussed here for future research are avenues for improving the study presented in this paper by expanding the scope across larger and more diverse subjects and testing stimuli. This study could be used as a starting point for finding relationships between immersion and other cognitive processes.

REFERENCES

REFERENCES

Adamo-Villani, N., Johnson, E. 2010. Virtual Heritage Applications: the 3D tour of

　　MSHHD. *International Conference on Computer Science and Information*

　　Technology. http://www.waset.org.

Adamo-Villani, N, Johnson, E., Penrod, T. 2009. Virtual reality on the web: the

　　21st Century World project. *MICTE 2009.*

　　http://www.formatex.org/micte2009/book/622-626.pdf.

Beier, K.-P. 1999 Virtual Reality: A Short Introduction, *University of Michigan:*

　　Virtual Reality Laboratory, http://www-vrl.umich.edu/intro/index.html.

Brooks, B.M., Attree, E.A., Rose, F.D., Clifford, B.R. and Leadbetter, A.G. 1999.

　　The specificity of memory enhancement during interaction with a virtual

　　environment. *Memory, 7*, 65-78.

Carassa, A., Geminiani, G., Morganti, F. And Varotto, D. 2002. Active and

　　passive spatial learning in a complex virtual environment: the effect of the

　　efficient exploration. *Cognitive Processing – International Quarterly of*

　　Cognitive Sciences, 3-4, 65-81.

Lee, J.C. 2010. Johnny Chung Lee Projects Wii. Retrieved April 10, 2010, from

　　http://johnnylee.net/projects/wii.

Microsoft. 2010. Xbox.com Project Natal. Retrieved April 10, 2010, from

http://www.xbox.com/en-US/live/projectnatal/

Nintendo. 2010. Wii at Nintendo. Retrieved April 10, 2010, from

http://www.nintendo.com/wii.

Nvidia. 2010. Nvidia Vision Main Page. Retrieved April 10, 2010, from

http://www.nvidia.com/object/3d_vision_main.html.

Plancher, G., Nicolas, S., and Piolino, P. 2008. Virtual reality as a tool for

assessing episodic memory. In *Proceedings of the 2008 ACM Symposium*

on Virtual Reality Software and Technology (Bordeaux, France, October

27 - 29, 2008). VRST '08. ACM, New York, NY, 179-182.

Randy Pausch , Dennis Proffitt , George Williams. 1997. Quantifying immersion

in virtual reality, *Proceedings of the 24th annual conference on Computer*

graphics and interactive techniques, p.13-18.

Robertson, G., Czerwinski, M. , Larson, K , Robbins, D.C. , Thiel, D , van
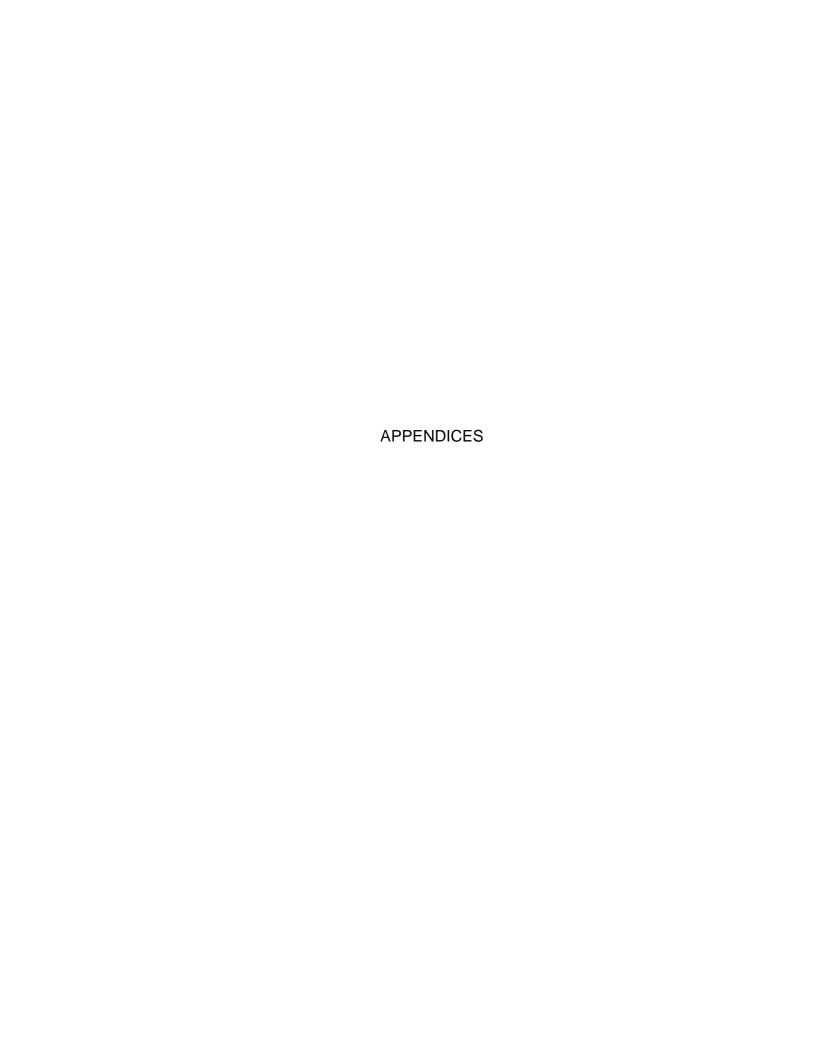
Dantzich, M. 1998. Data mountain: using spatial memory for document

management, *Proceedings of the 11th annual ACM symposium on User*

interface software and technology, p.153-162, November 01-04, San

Francisco, California, United States

Roussou, M. 2001. Immersive Interactive Virtual Reality in the Museum. In:

INTUITION Network of Excellence. http://www.intuition-

eunetwork.org/documents/papers/Culture%20History/mroussou_TiLE01_p

aper.pdf.

Sony. 2010. Playstation Move. Retrieved April 10, 2010, from

    http://us.playstation.com/ps3/playstation-move/index.htm.

Ware, C., Arthur, K., and Booth, K. 1993. Fish tank virtual reality. In *Proceedings*

    of CHI 93, ACM and IFIP, 37.42

Wen Qi , Russell M. Taylor, II , Christopher G. Healey , Jean-Bernard Martens.

    2006. A comparison of immersive HMD, fish tank VR and fish tank with

    haptics displays for volume visualization, *Proceedings of the 3rd*

    symposium on Applied perception in graphics and visualization, July 28-

    29, Boston,Massachusetts.

Wii Yourself! 2010. gl.tter's Native C++ WiiMote Library. Retrieved January 8,

    2010, from http://wiiyourself.gl.tter.org.

APPENDICES

Appendix A

Virtual Heritage Applications: The 3d Tour Of Mshhd

Nicoletta Adamo-Villani and Eric Johnson

Abstract— The paper analyzes the development of a digital heritage project that uses Virtual Reality (VR) as a documentation and communication tool for a variety of audiences. It also discusses general issues involved in creating virtual archaeology applications for the broad public. The objective of the project was to create an interactive tour of the Muscatatuck State Hospital Historic District (MSHHD) in Columbus, IN, USA. The virtual tour is deliverable on CD-ROM for distribution to schools, and on the web for the general public. In addition, the tour is designed for display in immersive devices for museum exhibits.

Keywords—Virtual Reality; 3D animation; Cultural Heritage; 3D for the web

CHAPTER 1. INTRODUCTION

In this paper we discuss the design and development of a 3D interactive virtual tour of the Muscatatuck State Hospital Historic District (MSHHD) in Columbus, IN, USA. MSHHD, founded in 1920 as the Indiana Farm Colony for Feeble-Minded Youth, includes buildings of historic value built in Deco, Moderne, Industrial, and Twentieth-Century Functional architectural style. The site is currently being transformed into an urban training facility for homeland security and natural disaster training and the plans for converting the area include major modifications to the district and its buildings. In 2006, The Indiana Army National Guard (INARNG) agreed to several mitigation stipulations for the adverse effect it will have on MSHHD. One stipulation was the creation of a photorealistic virtual tour to document and virtually preserve the historic area.

A team of Purdue University students and faculty was charged with the task of developing the tour. The team selected 3D animation and Virtual Reality (VR) as the technologies of choice. VR-based cultural heritage applications have gained popularity in recent years and some examples have been reported in the literature [1] [2]. Researchers argue that VR application for cultural heritage offer several benefits including an effective way of communicating the scientific results of historical investigations through photorealistic reconstructions of places and people that no longer exist, may not be easily experienced, or are threatened; intuitive visual representation of abstract concepts, systems and theories that would be difficult to communicate with diagrams, textual descriptions and static images; and enhanced viewer's engagement and motivation through high level of interactivity and "immersion". Immersion is defined as "the illusion of being in the projected world..... surrounded by images and sound in a way which makes the participants believe that they are really there" [3].

These reported strengths have motivated the choice of VR and 3D animation as the base technologies for the interactive application. The tour is deliverable on CD-ROM for distribution to schools, and on the web for the general public. In addition, it is designed for display in portable immersive devices for museum exhibits.

The paper is organized as follows. In section 2 we give an overview of virtual reality technology, we discuss the potential of VR as a tool for research, visualization, preservation and education in informal settings, and we report examples of VR- based cultural heritage applications. In section 3 we describe the Virtual Tour of MSHHD in detail. Specifically, this section includes historical information about the area, and detailed descriptions of the tour including visual content, interaction design and delivery formats/systems. Discussion of challenges and lessons learned are included in section 4.

CHAPTER 2. VR TECHNOLOGY AND CULTURAL HERITAGE

VR is a technology that allows users to

explore and manipulate computer-generated, three dimensional, interactive environments in real time [4]. VR is based on the theory that people do not experience reality directly, they receive a series of external stimuli which are interpreted by the brain as reality. "If a computer application can send the same external stimuli that the brain can interpret, then the simulated reality is potentially undistinguishable from reality" [5].

VR applications are gaining popularity primarily because they offer three main advantages: (a) representational fidelity; (b) immediacy of control and high level of active user participation; and (c) presence [6].

(a) Representational fidelity refers to the degree of realism of the rendered 3D objects and the degree of realism provided by temporal changes to these objects. (b) User control and high level of participation refer to the ability to look at objects from different points of view, giving the impression of smooth movement through the environment, and the ability to pick up, examine and modify objects within the virtual world [7]. (c) The feeling of presence, or immersion, occurs as a consequence of realism of representation and high degree of user control. It makes the VR environment intrinsically motivating and engaging by giving the users the illusion of really being part of the reconstructed world, and by allowing them to focus entirely on the task at hand. In addition, several studies have shown that VR applications can provide effective tools for learning in both formal and informal settings [8] [9] [10]. Two types of VR environments exist: desktop and immersive. The project described in the paper is an example of VR application that can be displayed on non-immersive and immersive systems.

Non-immersive virtual environments can be viewed on a regular PC with a standard monitor. Interaction with the virtual world can occur by conventional means such as keyboards, mice, trackballs, joysticks or may be enhanced by using 3D interaction devices such as a SpaceBall or DataGlove. Non-immersive VR has advantages in that it does not require special hardware, it can be delivered via web, and therefore can reach broad audiences.

Immersive VR applications are usually presented on single or multiple screens, or through a stereoscopic head-mounted display

unit. The user interacts with the 3D environment with specialized equipment such as a data glove, a wand or a 3D mouse. Sensors on the head unit and/or data glove track the user's movements/gestures and provide feedback that is used to revise the display, thus enabling smooth, real time interactivity. The use of immersive VR technology is a relatively recent trend that was originally limited to academic, military, and industrial research and development centers. Until recently, the high cost of VR displays and interaction devices coupled with difficulties in usability, operation and system maintenance have posed major barriers to the widespread use of the technology in schools and public spaces such as museums and cultural centers. Nevertheless, as the technology matures, immersive VR applications are entering multidisciplinary areas such as education, art, history, archaeology, and the humanities in general. Youngblut reports over forty VR-based learning applications [8] and Roussou describes about ten Virtual Environments designed for informal settings [9].

A. Examples of computer graphics applications for Cultural Heritage

Research in Computer Graphics (CG) and cultural heritage has shown considerable growth in recent years and several virtual heritage projects exist. Some applications focus on development of interactive virtual archaeology environments for educating the public about ancient civilizations. Other projects aim at accurate 3D reconstruction of historical artifacts for digital preservation through acquisition of digital data using computer graphics/computer vision techniques.

The first archaeology exhibit that made use of VR technology is "The Virtual Ancient Egypt" installation funded by Intel's Design Education and Arts (IDEA) program. The application presented users with a virtual recreation of the Temple of Horus, constructed at Edfu during the New Kingdom era in ancient Egypt. It was exhibited in networked form at the Guggenheim Museum in New York and at the Machine Culture exhibit of SIGGRAPH '93 [11].

More recent applications are the immersive installations at the Foundation of the Hellenic World (FHW) in Greece [12][13]. The VR exhibit "A Journey through Ancient Miletus"

allows participants to walk or fly over an accurate 3D reconstruction of the city of Miletus, experience the life of its people, examine architectural details from different perspectives, and get an understanding of the sense of scale, proportion and space used by the ancient Greeks.

Another interesting VR-based cultural heritage project is the "Mayan Civilization" exhibit held at the National Science Museum in Tokyo in 2003 [1]. The exhibit included a VR theater with a 4mx14m curved screen onto which 3 Hi-Vision equivalent images were projected, and a large-capacity graphics workstation utilized for image generation. The exhibit propelled the visitors on an immersive voyage of discovery through a virtually synthesized Copan acropolis.

One noticeable recent example is Digital Koguryo [14], a virtual heritage application that reconstructs the Koguryo mural tumulus, Anak No. 3, in Korea. The Anak No. 3 Tumulus is a large stone-built multichamber structure with mural paintings that illustrate the life and historical events of the Koguryo civilization. Digital Koguryo is a VR/multimedia-based museum exhibit designed to be educational and entertaining. Its goal is to help visitors learn about the culture and customs of Koguryo through an engaging interactive immersive environment.

Other intriguing examples of application of VR and AR (Augmented Reality) technologies to cultural heritage are the EPOCH's showcases [15]. One showcase is a virtual reconstruction of the nymphaeum of the ancient city of Sagalassos, Turkey. The pre-rendered 3D reconstruction of the nymphaeum is superimposed on the user's real view to generate the onsite reconstruction experience. Another showcase employs multilingual avatars to enhance the virtual visit of the German medieval town of Wolfenbüttel. The virtual town shows the application of several computer graphics technologies, such as: rapid modeling of repetitive components (i.e. buildings of no particular historic value in an urban context, or trees); avatars that act as tour guides to the visit or move autonomously as part of the reconstruction; and multilingual speech according to user's preferences.

An innovative application of VR and AR technologies to archaeology is the TimeLine installation at the Provincial Museum at Ename [16]. The interactive exhibit utilizes 3D reconstructions of an area measuring 3 by 3 km over a time span of 1000 years, is operated by a touch screen, and offers panoramic viewing of the selected era. Archaeological artifacts and historical objects exhibited in the museum are visually linked to the TimeLine reconstructions, providing visitors with precise information on the context in which the artifacts were found.

The Buddha project is a captivating example of CG applications that aim at accurate 3D reconstruction of historical artifacts for digital preservation [17]. The objective of the project is to digitally preserve cultural heritage objects that are deteriorating or being destroyed because of natural weathering, disasters and civil wars. Specifically, the Buddha project aims at preserving Japanese cultural heritage objects (often made of wood and paper) by obtaining digital data of these objects through computer vision techniques. Once these data have been acquired, the objects can be preserved permanently, and safely passed down to future generations. Similar projects that focus on the use of computer vision techniques for digital preservation of historical artifacts include Stanford's Michelangelo Project [18] and IBM's Pieta Project [19], to name a few.

CHAPTER 3. VIRTUAL MSHHD

3.1. MSHHD Historical Information

The Muscatatuck State Hospital Historic District was originally the Indiana Farm Colony for Feeble-Minded Youth, intended for males suffering from nearly every mental illness except epilepsy.

Founded in 1920, it was one facility in a system of eight in Indiana's mental health care system in the nineteenth and early twentieth centuries. The original colony covered an area of 1836 acres and included three farmhouses. It was identified as a home, and not a hospital or institution, and inmates earned their keep by working on the farm, and by raising crops and livestock in an effort to make the facility self-sustaining.

By 1933, after much argument and debate, the first female inhabitants were admitted to the colony. Separate quarters were constructed and maintained, and more "female oriented" work was added to the colony curriculum. In 1938 the colony received financial assistance from the Public Works Administration and widespread construction began. Several additions were made to the original facility including an Administration Building, a Medical Center, the Superintendent's Residence, the Power Plant, the School Building, a female dormitory, underground utilities, sewer lines, roads, and ditches. Architect/engineers W. C. McGuire and W. B. Shook of Indianapolis utilized Deco, Moderne, Industrial, and Twentieth-Century Functional architectural styles. These styles were not found in use in other state mental health facilities.

In the 1950s MSHHD shifted its mission from housing the developmentally disabled to developing individual programs to enhance personal development and its name was changed to the Muscatatuck State School and Training Center. Physical changes to the facility were made, including a decrease in acreage and the construction of new buildings to accommodate the shift in mission. By the 1980s, MSHHD encompassed 576 acres and included a summer camp area and a reservoir. Its new philosophy was that people who are developmentally disabled have the same civil and human rights as other citizens, including the right to live in the most normal and least restrictive environment possible.

In 2000, MSHHD was ordered closed due to the loss of Medicaid and other federal funding, the decrease in the number of patients, and rising maintenance costs. The final inhabitants left the facility in 2005. The property was then transferred to the INARNG to develop the MUTC (Muscatatuck Urban Training Center), an urban training facility for the war on terror, homeland security training, and natural disaster training. The plans for converting the site include major modifications to the buildings, designation of drop zones, construction of helicopter landing pads, construction of a 30-acre portable shantytown, 10-acre portable cemetery, and development of a mock port training facility. The conversion of the site into training camp is currently undergoing.

3.2. 3D Content

Sixty-four (64) buildings and six (6) historic features were identified at MUTC. The buildings date between 1924 and circa 1980. Of the 64 buildings, 34 are over 50 years of age and are considered contributing buildings within the MSHHD. In addition, all 6 features (4 tunnels and 2 drainage ditches) and the unique "butterfly" pattern of roads, not seen in any other Indiana mental health facility, are considered contributing elements to the historic district. The virtual tour includes 3D reconstructions of all thirty-four buildings, two tunnels, the road layout, vegetation, and bodies of water. Figure 1 shows an aerial view of the historic site and a photograph of one of the buildings of interest.

To get geometrical information about real 3D objects various techniques and devices could be utilized. Fully automated methods are not available yet and while most automated techniques involve limited user input, they require a substantial amount of interactive work to covert the resulting data into renderable structures [20]. Therefore, due to the lack of directly applicable automatic reconstruction techniques, the team made the decision to build all 3D models using commercial off-the-shelf modeling software (i.e., Autodesk Maya and 3D Studio MAX). To provide accuracy and realism, the 3D objects were developed from maps, architectural blueprints, photographs, drawings, and layout information, and were textured using procedural maps, digitally captured images, light maps, and ambient occlusion maps. Figure 2 shows the 3D reconstruction of the hospital building.
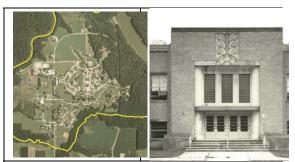

Fig 1. From the left: aerial view of MSHHD with clearly identifiable 'butterfly' pattern of roads; façade of school building with Art Deco architectural elements

The models were then exported from Maya and MAX to different formats for display on the

various delivery platforms. To achieve good visual quality, as well as high speed of response in a real-time environment, the models were optimized in different ways and the principle of Level of Detail (LOD) was implemented. LOD techniques were used extensively in the web-based version of the tour in order to lower the user's hardware requirements. The application detects the user's hardware configuration and the amount of detail displayed on models and textures dynamically changes depending on the user's computer system. The immersive system has limited dynamic LOD.

The terrain was created using a 2D height map. The resolution of this height map changes according to the LOD system. Cube maps were used to generate the sky and atmosphere as well as allow for reflections of 3D geometry on certain surfaces. How often and at what resolution the reflection cube map is rendered changes according to the LOD system.

C. Application development and delivery systems

Quest 3D [21] is the integrated development environment (IDE) that was chosen to develop the interactive 3D tour. The selection of this third party game engine was motivated by several considerations. Quest 3D allows for a relatively short development time- all of the coding is done using Visual Programming. Because it is a DirectX 9 game engine, it is supported by all DirectX 9 compliant graphics cards and operating systems. Lastly, Quest 3D supports a large number of delivery formats including web, executable, installer and windows screensaver. Although the user is required to download and install a plug-in in order to view the content, the size of the plug-in is relatively small and its installation is straight forward.
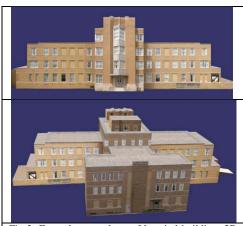

Fig 2. From the top: photo of hospital building; 3D model of hospital building (façade); 3D model of hospital building (back view).

The 3D tour for portable immersive systems. The immersive version of the tour was created for a custom Fish Tank VR system. The immersive application and system will be used as a travelling exhibit and will be housed at the local historical society. The Fish Tank system consists of a Dell desktop PC, a 120Hz LCD monitor, an Essential Reality P5 glove with 6 degrees of tracking and bend sensors for each finger [22], a pair of wireless Nvidia Vision stereoscopic glasses [23], and a custom head-tracking system. The system is designed for a single user with the head tracker mounted on the stereoscopic glasses. Stereoscopic images of the 3D scenes are rendered to screen which helps create a sense of immersion. The user can use the P5 glove and a wireless controller to interact with the virtual tour. Other control options include using the wireless controller or using a standard mouse and keyboard setup. Multiple control options allow users to choose what is most comfortable for them; the availability of alternative controls creates a backup if hardware malfunctions occur. The head tracking system tracks five degrees of freedom (XYZ position, pan, and roll). Only one user can experience the full immersion provided by the system at a time because only one head tracker is active at a time. A second configuration can also be used in which head tracking is abandoned to allow a large audience to experience a semi-immersive tour. The rendered scene can be projected in front of a large audience in stereoscopic while one person interacts with the system. This setup is comparable to watching a stereoscopic movie in a theatre.

Software for the immersive system was developed specifically for the hardware. This allowed for debugging to occur on the machine the final product would be delivered on. Graphics techniques like dynamic weather, reflections, modern fragment/vertex programs, and hardware accelerated nature painting could all be tested and refined based on the specific hardware configuration.

The 3D Tour for the web/CD. The online virtual tour exists within a website that presents historical information about the area. The 3D tour is rendered inside the browser window using a web player plug-in specific to the graphics engine used for development (i.e. Quest 3D). Users are required to download the plug-in and install it on their computer the first time they visit the web 3D tour. The 3D tour will load automatically on subsequent visits to the website. A standard mouse and keyboard setup is used as the default control option; however users may also use a gamepad. The web 3D tour was tested on a variety of computers with different hardware/software configurations. In particular, low-end computers without dedicated graphics cards were used to test real-time performance and the dynamic LOD system.

D. The viewer's experience

Before starting the tour the participant has the option to choose between a "Quick Tour" and a "Detailed Tour". Each tour presents a different level of information about the facility and its history. The "Quick Tour" is a narrated story (with closed captions) written at a 4th grade level; the "Detailed Tour" presents in-depth information with references, and gives the user access to digital copies of original text documents and images.

Viewers begin the virtual tour of MSHHD by selecting one of two possible start locations. While all 34 buildings can be explored from the outside, only 6 are 'active', i.e. they can be entered. Upon approaching or entering a building, information about its history, functions and previous inhabitants can be displayed in a variety of media formats such a text, images and narration. When viewing the tour on a standard PC or on the Fish-Tank system users navigate the environment with mouse, keyboard, and/or gamepad/glove configurations.

Participants have the option to 'walk' through the environment or 'fly' to any location. If the 'walk' option is chosen, a terrain following constraint limits the subjects to only a specific plane. In other words, subjects can only 'walk' on the paths instead of being able to 'fly' freely through the virtual site. While the user is in 'walk' mode, there are three main actions: move, look, and interact. Moving 'pushes' the camera around the environment, while looking 'rotates' the camera. While in 'fly' mode, the user does not have direct control over the view, but rather controls the camera in order to take certain actions. While in this mode there is only one main action: interact. The user can click on a building and the camera automatically frames the building and displays appropriate information. The user can then take a step back, or interact with a door on the building and the camera will take appropriate actions to show the interior.

Head tracking is available in both viewing modes. In the 'walk' mode, head tracking can be turned on at all times in order to let the user inspect objects as the would in the real world. In the 'fly' mode, head tracking can only be turned on when the camera is not executing an action. Figure 3 shows 4 screenshots of the interactive tour for the WWW.

Fig. 3 Four screenshots of the web 3D tour

CHAPTER 4. DISCUSSION AND CONCLUSION

In this paper we have discussed the development of the 3D interactive tour of MSHHD. The VR tour is deliverable via World Wide Web and on CD; additionally, an immersive version of the tour has been developed for display on portable immersive devices, i.e. Fish Tank systems. A main challenge posed by the project was the requirement of web delivery. Due to diversity of network connections and computer performance, efficient representation of virtual objects is a fundamental factor for web presentations. Virtual scenes are always a simplification of reality and this is particularly true for web-based VR presentations which have to balance between visual quality/accuracy and rendering/data download speed. Several solutions were adopted to overcome the quality/performance trade-off challenge, including optimization techniques for converting 3D models to web-based format, Level of Detail (LOD), and normal maps, a technique for simulating complex geometric detail without adding extra geometry. In addition, extensive testing of the web application on a variety of computer systems was carried out in order to ensure client hardware can run the 3D tour at interactive rates.

Another challenge posed by the project was the need to deliver a low-cost immersive portable system for displaying the tour in museums. The system and user interface needed to be easy to use and maintain by users with little or no technical knowledge. After considering many hardware configurations, the team built an immersive portable fish tank system that is affordable, fairly intuitive to use and maintain while, at the same time, is capable of delivering a compelling immersive experience. The system consists of a standard PC with four additional pieces of hardware; the head tracker and stereoscopic glasses were combined into a single unit to limit the number of extra devices the user needs to deal with (the system is described in section III.C). In order to start the interactive tour only two steps are required, after the system has been turned on. We are confident that this combination of software+hardware will allow for easy training of end users. Evaluation of the hardware system and software user interface with target subjects is currently ongoing. Evaluation results will be reported in a future publication.

REFERENCES

[1] M. Hirose. Virtual Reality Technology and Museum Exhibit. *The International Journal of Virtual Reality*, 5(2), 2006, pp. 31-36.

[2] M. Roussou, and D. Efraimoglou. High-end Interactive Media in the Museum. *Computer Graphics*, ACM SIGGRAPH, 1999, pp. 59-62.

[3] M. Roussou. Immersive Interactive Virtual Reality in the Museum. In: *INTUITION Network of Excellence.* HTTP://WWW.INTUITION-EUNETWORK.ORG/DOCUMENTS/PAPERS/CULTURE%20HISTORY/MROUSSOU_TILE01_PAPER.PDF , 2001(Accessed on 28 November 2009)

[4] W.S. Sherman, and A.B. Craig. *Understanding Virtual Reality*. Morgan Kaufmann, San Francisco, CA, 2003.

[5] A.S. Akins. Virtual Reality and the Physically Disabled: Speculations of the Future. In: *Proc. of Virtual Reality and Persons with Disabilities Conference*, California State University, Northridge, 1992.

[6] J. Hedberg, and S. Alexander. Virtual Reality in Education: Defining Researchable Issues. *Educational Media International*, 31, 1994, pp. 214-220.

[7] B. Dalgarno, J. Hedberg, and B. Harper. The contribution of 3D environments to conceptual understanding. In: *Proc. of ASCILITE 2002*, New Zealand, 2002.

[8] C.Youngblut. Educational Uses of Virtual Reality Technology. In: *VR in the Schools - coe.ecu.edu*, 3(1), 1997.

[9] M. Roussou, E. Kavalieratou, and M. Doulgeridis. Children Designers in the Museum: Applying Participatory Design for the Development of an Art Education Program. In: *Proc. of the 6th International Conference on*

Interaction Design and Children, June 6-8, 2007, Aalborg, Denmark, pp. 77-80.

[10] NCAC (National Center on Accessing the General Curriculum) Virtual Reality/Computer Simulations. Curriculum Enhancement. U.S. Office of Special Education Programs, 2003.

[11] Interacting with "Machine Culture". *IEEE Computer Graphics and Applications*, September/October 1993, 13(5), pp. 4-8.

[12] M. Roussou. Immersive Interactive Virtual Reality and Informal Education. In: *Proc. of User Interfaces for All: Interactive Learning Environments for Children*, Athens, February 2000.

[13] A. Gaitatzes, D. Christopoulos, A. Voulgari, and M. Roussou. Hellenic Cultural Heritage through Immersive Virtual Archaeology. In: *Proc. of VSMM 2000 - 6th International Conference on Virtual Systems and MultiMedia*, Japan, 2000.

[14] K.S. Park, Y. Cho, and S. Park. Lessons Learned from Designing a Virtual Heritage Entertainment Application for Interactive Education.. *ICEC 2006, LNCS 4161*, pp. 233 – 238, 2006

[15] F. Niccolucci. Technologies for the public understanding of the past: EPOCH's contricution. *ICHIM 05 - Digital Culture & Heritage / Patrimoine & Culture Numérique*, Paris, 2005.

[16] Daniel Pletinckx. Ename Center for Public Archaeology and Heritage Presentation, Ename, Belgium. *Proc. of CAA 2009,* VA, 2009.

[17] Ikeuchi, K., Nakazawa, A., Hasegawa, K, Ohishi, T., The Great Buddha Project: Modeling Cultural Heritage for VR Systems through Observation, In *Proc. of International Symposium on Mixed and Augmented Realit,* 2003.

[18] M. Levoy. "The digital Michelangelo project," *SIGGRAPH 2000*, New Orleans, 2000.

[19] J. Wasserman, *Michelangelo's Florence Pieta*, Princeton University Press, 2003.

[20] J. Zara. Virtual Reality and Cultural Heritage on the Web. *Proceedings of the 7th International Conference on Computer Graphics and Artificial Intelligence (3IA 2004)*, France, 2004, pp. 101-112.

[21] Quest 3D. Available at: HTTP://QUEST3D.COM/, 2009 (Accessed on 26 December 2009).

[22] Essential Reality P5 Glove. Available at: HTTP://WWW.ESSENTIALREALITY.COM/, 2008 (Accessed on 15 December 2009).

[23] Nvidia 3D Vision Kit. Available at: HTTP://WWW.NVIDIA.COM/OBJECT/3D_VISION_MAIN.HTML, 2009 (Accessed on 15 December 2009).

Appendix B

Virtual Reality On The Web: The 21st Century World Project

Nicoletta Adamo-Villani, Eric Johnson, and **Tyler Penrod**

Purdue University, Department of Computer Graphics Technology, West Lafayette, IN, 47907, USA
This paper reports on the challenges of delivering web-based 3D learning environments which show complex geometry and sophisticated interactivity. The project provided lessons in the creation of web-efficient models and animations and demonstrated that it is possible to share geometrically complex, information-rich 3D interactive worlds over the web.

Keywords: Virtual Reality; Virtual Environments; Web.

1. Introduction

The 21st Century World is a collaborative project between Purdue University and Educate for Tomorrow (EforT, Hawaii). Its objective is the development of a 3D online virtual city designed to allow students, industry professionals, and the general public to interactively explore nanotechnology enhanced products of the 21st Century. The application is a single-user 3D environment that enables the participant to explore from the perspective of an avatar controlled through keyboard, mouse, or game controller. Users can travel through the city, enter buildings, interact with 3D avatars to learn about nanotechnology, and click on objects that allow for hyperlinking to web sites and multi-media databases. The virtual city includes buildings with nanoenhanced materials and self cleaning windows that absorb energy from sun light. It features cleaner and safer mass transportation, alternate fuel stations, cars with self-repairing body-paint scratches, buildings that grow crops indoors, and more. In the paper we discuss the technical challenges posed by projects whose goal is to develop and deliver complex web 3D environments with rich hyperlink structures. The paper is organized as follows. In section 2 we give an overview of Virtual Reality (VR) technology and we report current limitations of web-based VR. In section 3 we discuss the development of the 21st Century World including design, modelling, texturing, animation, interactive application development, and preparation for web delivery. Conclusive remarks are included in section 4.

2. Background

2.1 VR Technology

VR is a technology that allows users to explore and manipulate computer-generated, three dimensional, interactive environments in real time [1]. VR is based on the theory that people do not experience reality directly, they receive a series of external stimuli which are interpreted by the brain as reality. "If a computer application can send the same external stimuli that the brain can interpret, then the simulated reality is potentially undistinguishable from reality" [2].

The research team selected VR as the technology of choice for the project primarily because it offers three main advantages: (a) representational fidelity; (b) immediacy of control and high level of active user participation; and (c) presence [3]. (a) Representational fidelity refers to the degree of realism of the rendered 3D objects and the degree of realism provided by temporal changes to these objects. (b) User control and high level of participation refer to the ability to look at objects from different points of view, giving the impression of smooth movement through the environment, and the ability to pick up, examine and modify objects within the virtual world [4]. (c) The feeling of presence, or immersion, occurs as a consequence of realism of representation and high degree of user control. It makes the VR environment intrinsically motivating and engaging by giving the users the illusion of really being part of the reconstructed world, and by allowing them to focus entirely on the task at hand. In addition, several studies have shown that VR applications can provide effective tools for learning in both formal and informal settings [5; 6].

Two types of VR environments exist: desktop (non-immersive) and total immersion. Non-immersive virtual environments can be viewed on a regular PC with a standard monitor. Interaction with the virtual world can occur by conventional means such as keyboards, mice, trackballs, and joysticks or may be enhanced by using 3D interaction devices such as a SpaceBall or DataGlove. Non-immersive VR has advantages in that it does not require special hardware; it can be delivered via web, and therefore can reach broad audiences. Immersive VR applications are usually presented on single or multiple screens, or through a stereoscopic head-mounted display unit. The user interacts with the 3D environment with specialized equipment such as a data glove, a wand or a 3D mouse. Sensors on the head unit and/or data glove track the user's movements/gestures and provide feedback that is used to revise the display, thus enabling smooth, real time interactivity.

The interactive application described in this paper is a non-immersive VR environment specifically designed for web delivery.

2.2 Virtual Reality on the web: current limitations

Although some interesting examples of web virtual environments exist , VR on the web is not mainstream yet. Several barriers still preclude its widespread use. Due to diversity of network connections and computer performance, efficient representation of virtual objects is a fundamental factor for web presentations [7]. Virtual scenes are always a simplification of reality and this is particularly true for web-based VR presentations, which have to balance between visual quality and rendering/data download speed. In order to overcome the quality/performance trade-off problem, the 3D models need to be carefully prepared for efficient web delivery using a variety of techniques including optimization methods for converting 3D models to web based format, and Level of Detail (LOD).

In addition to problems of download and rendering speed, a barrier is posed by the fact that VR content cannot be viewed with just a standard browser; a special viewer - either a special-purpose browser or a plug-in is often needed. Since a universal viewer that can display all VR web content does not exist yet, it is often necessary to download a different plugin for each different VR application. Plugins can be large and their installation may require a certain degree of technical expertise, thus making web VR content inaccessible to people who have very little computer knowledge.

Another current limitation of web VR is the lack of a standard user interface for navigating 3D worlds and for interacting with 3D objects. Users are often accustomed to GUIs which use point-and-click as the major interaction technique. Moreover, web pages with hyperlinks are also based on the same click-and-go interaction method. On the contrary, a large number of different navigation/interaction paradigms have been suggested and/or implemented by researchers in VR environments. According to Bowman et al. [8] most of these techniques fall into four categories: natural travel metaphors, that is techniques that use physical locomotion or some real/pseudo world metaphor for travel; steering metaphors that involve continuous specification of direction of motion (i.e., gaze-directed, pointing, and physical device techniques); target-based metaphors which require a discrete specification of goal; and manipulation metaphors which involve manual manipulation of viewpoint (i.e., for instance, 'camera in hand'). A user interface for travel and object selection/manipulation in web-based virtual environments is not yet standardized. Even VRML (Virtual Reality Markup Language) browsers complying with ISO standards differ in a number of control elements and in their arrangement on the screen. This fact can increase difficulties, and therefore skepticism, in web users with limited computer knowledge.

In the next section we discuss the approach that we have taken in the 21st Century World project in order to overcome some of these limitations.

3. Methods

3.1 The 3D world: design, modelling, texturing and animation

The 21st Century World is an example of virtual place that draws on knowledge of architectural design. Maher argues that most virtual environments are created by programmers rather than designed by architects and, as a result, we are in the "era of vernacular virtual architecture" [9]. In the development of the 21st Century World, provision of functionality and geometric description of the space were considered equally important factors. The objective was not only to create a highly interactive and functional environment, but also to design a city based on the principles of good urban design. In particular we considered the principle

of 'Legibility and Wayfinding' to help the users in orientation and navigation tasks; the principle of 'Character and Meaning' to help the participants recognize and value the differences between one area and another; and the principle of 'Order and Incident' (e.g., balancing consistency and variety) to provide the users with an appealing environment that promotes curiosity and motivates them to continue to explore [10; 11]. 27 users have evaluated the 21st Century World so far. Their feedback on usability and appeal has been extremely positive, thus confirming the importance of implementing architectural and urban design principles in the design of virtual places.

Fig. 1 Renderings showing part of the 21st Century World (left); rendering of interior of train station with detail of water and dirt repellent floor (right).

The futuristic city was designed and modeled entirely in 3D STUDIO MAX 9.0 software [12] by a team of architects, computer graphics technologists, and nano-science experts (figure 1 shows two renderings of the city). All models were developed using polygonal modeling techniques and surfaces and textures were kept relatively simple (i.e. with a fairly low poly count and low texture resolution) in order to ensure high speed of response in a real time web environment. The majority of the buildings were textured using highly reflective and transparent surface maps representing metallic and glass construction materials. A cube map was used to render a believable sky. The animation of objects and characters was created with two different techniques.

Simple animations involving basic rigid transformations (i.e translation, rotation and scaling) were produced directly in the game engine using envelopes and timers. Character animations created with skeletal deformation systems were exported from the 3D anmation software to .X and Channel Group (.CGR) formats and imported in the development environment.

Images and fly-trough animation of the 3D world can be accessed at:
http://www2.tech.purdue.edu/cgt/i3/nanofactor/web%20site/index.htm

3.2 Development of the interactive application

Quest 3D [13] is the integrated development environment (IDE) that was chosen to develop the web-based realtime interactive application. The selection of this third party game engine was motivated by several considerations. Quest 3D allows for a relatively short development time and low development cost because the framework for displaying realtime graphics is already layed out. Because it is a DirectX 9 game engine, it is supported by all DirectX 9 compliant graphics cards and operating systems by default (i.e. Windows). In addition, it provides realtime feedback with no need to compile code. This shortens debugging time significantly when compared to other game engines, and allows for the use of a WYSIWYG ("What you see is what you get.") editor. All of the coding in Quest 3D is done using Visual Programming, i.e. the code is displayed using 'blocks' that are linked together to create hierarchical structures (trees) (see fig 2, left). This provides an intuitive working environment for developers who are not very experienced in C/C++ programming languages, which most game engines require. Finally Quest 3D was selected because it supports a large number of delivery formats including web, executable, installer and windows screensaver.

Fig. 2 Example of Visual Programming (left); screen shot of the application showing the User Interface (right).

Although Quest 3D requires the user to download and install a plugin in order to view the content, the size of the plugin is relatively small and its installation is very straight forward, thus it does not require technical
expertise.

3.2.1 Preparation of the 3D world for web delivery

In order to reduce download/rendering times, several modeling and texturing optimization techniques were applied to the original 3D model of the 21st Century World. Each individual 3D object was calculated for overall performance demands, and the polycount was reduced based on the amount of occurrences and prominance within the city. Streetlights, for example, were reduced to a very low level of detail because of their numerous instances yet relative unimportance, whereas the most prominent buildings within the city were given a higher level of detail. In addition, repeatedly placed objects/details were defined via references, rather than by copy-paste method. This process was applied to textures as well.

Model detail was balanced with texture detail. In other words, the higher the detail in the mesh, the lower the detail in the texture and vice versa. This allowed us to achieve an acceptable real-time rendering performance while maintaining good visual quality. All textures were downscaled to low resolution (usually not higher than 256 pixels in any direction) and texture maps were also compressed using the DDS format, which is the native format used in Quest 3D. DDS images contain mipmaps used in the rendering process. Although mipmaps can increase the image file size slightly, they allow for higher rendering speed because they do not need to be calculated at runtime. Large surfaces were textured with tiled texture maps layered with a low resolution luminance map. This provided higher detail up close, and variance accross the surface from a distance.

Another technique widely used in VR is Level of detail (LOD). LOD refers to the process of describing a complex 3D model using different representations, from very detailed to extremely simple ones. A presentation system switches among these representations based on the distance between the virtual camera and the rendered object. Quest 3D supports automatic and manual LOD meshes. Automatic LOD was used on secondary 3D objects that are never close to the camera, whereas manual LOD was used on all primary models.

3.2.2 User Interface

In order to overcome the problem of absence of a standard web 3D interface, we created the User Interface (UI) as an integral part of the 3D scene. The 21st Century World interface (shown in Fig. 2 right) consists of a HUD (*Heads-Up Display)* that remains in the same position on the screen while the user navigates through the virtual world. The UI includes navigation icons (i.e. arrows indicating direction of travel), text buttons that allow the users to enter the 3D world at specific locations, a small 2D map indicating the current position of the user in the 3D environment, and hyperlinks that link specific 3D objects to web sites and multimedia databases.

The UI is a keyboard/mouse interface that can function even if one of the two input devices is not available.The user can walk or run using keyboard keys or by clicking on the appropriate icons in the Heads up Display (HUD). The movement system is physics-based, i.e. users will collide with the terrain and other objects in the virtual environment as they would in the physical world. However, because this is a virtual world, liberties are taken with movement over large distances and 'riding' vehicles in the world. Users can 'warp' to predefined locations using the menu in the HUD, as well as attach their view to predefined moving objects, such as a plane, to fly over the world and view it from a different angle.

Some usability studies on web-based virtual environments have shown that users have a tendency to not recognize (and therefore click on) active 3D objects even if they are represented as signs [7]. For this reason, we have added highlighting to all the active objects in order to make them easy to identify. Moreover, the interface makes use of on screen prompts, or contextual commands, which allow for multiple actions to be assigned to one button or gesture, thus simplifying the number of controls the user must learn.

The UI was developed using an iterative design process. Numerous formative evaluations were carried out throughout the development of the UI and the results of each evaluation provided suggestions for design improvements. Full scale evaluation with a large group of target users is currently ongoing. Results will be reported in a future publication.

4. Conclusion

In this paper we have described a project whose goal was to develop and deliver a highly interactive web-based virtual environment. The objective of the VR application is to inform the general public about nanotechnology enhancements that have the potential to benefit society significantly in the near future.

The work discussed in the paper demonstrated that graphically rich, 3D worlds can be effectively shared across the World Wide Web, with links to multi-media databases. It also provided an outstanding opportunity to discuss the technical challenges posed by projects whose goal is to develop and deliver complex, information rich web 3D environments. Although web VR is not widespread yet due to several current technological barriers, we anticipate that it will become widely accepted in the near future as

desktop computers will gain speed and will be optimized for 3D graphics and higher-bandwidth and more reliable connections to the Internet will become more common.

References
[1] W. R Sherman and A. B. Craig. Understanding Virtual Reality. (Morgan Kaufmann, 2002)
[2] A. S. Akins. Virtual Reality and the Physically Disabled: Speculations of the Future. Proceedings of Virtual Reality and
Persons with Disabilities Conference, Northridge, CA, 1992.
[3] J. Hedberg and S. Alexander. Virtual Reality in Education: Defining Researchable Issues. Educational Media
International, 31 (1994), pp. 214-220
[4] B. Dalgarno, J. Hedberg and B. Harper. The contribution of 3D environments to conceptual understanding. Proceedings
of ASCILITE, New Zealand, 2002
[5] C. Youngblut. Educational Uses of Virtual Reality Technology. VR in the Schools, - coe.ecu.edu, 3, 1 (1997)
[6] M. Roussou. Learning by doing and learning through play: an exploration of interactivity in virtual environments for
children. ACM Computers in Entertainment, 2,1 (2004), pp. 1-23
[7] J. Zara. Virtual Reality and Cultural Heritage on the Web. Proceedings of the 7th International Conference on Computer
Graphics and Artificial Inteligence (3IA 2004), Limoges, France, 2004, pp. 101-112
[8] D. A. Bowman, D. Koller and L. F. Hodges. Travel in Immersive Virtual Environments: An Evaluation of Viewpoint
Motion Control Techniques. Proceedings of VRAIS '97 - Virtual Reality Annual International Symposium, Albuquerque, NM, 1997
[9] M.L. Maher, S. Simoff, N. Gu and K.H. Lau. Designing Virtual Architecture. Proceedings of CAADRIA 2000,
Singapore, 2000
[10] J. Barnett. An Introduction to Urban Design. (Harper & Row, New York, 1982)
[11] M. Larice and E. MacDonald (editors). The Urban Design Reader. (Routledge, New York London, 2007)
[12] Autodesk 3D Studio MAX. (http://www.autodesk.com)
[13] Quest 3D. (http://quest3d.com)