Utility of Perspecta 3D Volumetric Display for the Completion of Tasks

by

Thomas Tyler

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UTILITY OF PERSPECTA 3D VOLUMETRIC DISPLAY

FOR THE COMPLETION OF TASKS

A Thesis Presented for the

Master of Computer Science Degree

The University of Tennessee at Chattanooga

Thomas R. Tyler

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DEDICATION

This thesis is dedicated to the one to whom I owe everything.

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I would like to express my thanks and appreciation to my advisor, Dr. Andrew Novobilski, for his invaluable guidance, encouragement and patience. I would also like to thank my committee members, Dr. Amye Warren and Dr. Joseph Dumas for their comments and stewardship. Without their support this work would not have been possible. My special thanks to Nancy, Joshua, and Rachel who renew my spirit daily.

ABSTRACT

This study analyzes experimental data generated by human subjects using the Perspecta 3D Volumetric Display and a 2D flat screen liquid crystal display (LCD). The analysis reveals differences in how experiment participants used the display technologies.

Study participants were asked to solve a series of simulated mazes rendered on the displays. Participants committed an appropriate series of joystick movements to alter the pitch and roll angles of the board upon which the mazes were constructed. These movements caused a simulated ball to roll toward the lowered sector of the maze. The maze was solved when the ball arrived at a designated finish position. The data collected from each instance of a game consisted of ball position, joystick control reversals and time to complete.

Trends discovered in the data show that participants benefited differently when using different displays. Because there is no non-simulated task to which the maze solution data can be compared, the meanings of trends discovered are discussed mainly as relative to display type.

Performance varied widely among participants. In aggregate, participants using the Perspecta display showed accelerated improvement in performance. Perspecta users also showed tendencies to solve the mazes through more complex and diverse routes. However, it was also found that Perspecta users subsequently failed to transfer this improved performance to comparative success on the LCD on some mazes, while LCD users were able to transfer improved performance to the Perspecta.

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SYMBOL	MEANING
ΔT_{bi}	Performance Gain i
$T_{previous\ best}$	Best time based performance before trial j where j is most recent trial
T_j	Time based performance on trial j
c	Constant in Time Utility equation
k	Time Utility
τ	Tortuosity (Tau) of maze path
$\text{min reversals}_{path}$	Minimum number of reversals required by random input maze solver to complete a given path
P_{path}	Probability that the random input maze solver will solve the maze by a given path

INTRODUCTION

BACKGROUND

Human beings have five senses that provide rich and unique input to the brain. Humans depend heavily on their visual input to quickly acquire large amounts of information. The ability of a human to understand and perform in the surrounding environment is tightly linked to sight. While other senses do much to enrich and deepen perception, it is estimated that up to 70% of one's sensory capacity is dedicated to processing visual information. [1] With this in view, it is clear that sight is the most important sense and therefore a major key in human performance. [2]

Techniques and technologies that correctly portray depth and detail of a rendered 3D object improve the ability of humans to correctly interpret the object. Since the early 1980's Computer Aided Design (CAD) has enabled engineers to rapidly evaluate and alter their designs. 3D modeling has now been recognized as a valuable design and analysis tool. Magnetic Resonance Imaging (MRI) and Computerized Tomography (CT) scans are further examples of technologies that produce 3D data. These data are currently presented and studied in "slices" on flat screen technologies. These data sets allow physicians to move through images revealing "answers to the mysteries of form and function" that are "couched in the domain of image processing and visualization." [3, pg 1]

Improvements in the clarity of presented data can benefit human understanding and improve the users' ability to interpret results. For a physician, this will translate directly to improving the confidence of surgical decisions and saving lives. [3]

Furthermore, in medicine, as well as other fields, there are classes of information which *cannot* be visualized adequately by humans using 2D display technologies. [4] The 3D structure of molecular docking simulations is an example member of this class of data. [4] These structures are not easily representable due to rich and complex spatial interactions that cannot be easily understood in anything less than 3D space.

Clearly, analysis of data in more than two dimensions holds great promise, regardless of the tools used to present the data. For some visual data types, computer-aided rule-based systems are employed for analysis of multidimensional data. [5] Lindahl et al. confirm that artificial neural networks can be applied to myocardial perfusion images to diagnose acute myocardial infarction (heart attack) as accurately as an experienced physician. [6] While artificial neural networks or rule-based analysis may temper the future need for advanced displays, today most data analysis is done by humans. [7]

The displays used today are most commonly 2D displays. As such, human understanding and performance using 2D display technologies is still the key factor in the success of the widest range of endeavors that utilize computer technologies. Pushing beyond the 2D displays may thrust human imagination above the technological plateau in understanding maintained by 2D displays.

PRIOR ART

Human Computer Interaction (HCI) in relation to 3D graphics is the subject of significant interest. Ritter et al. studied human subject interaction with computer generated 3D bones of a dissected human ankle. The study presented an ankle modeled as a jigsaw puzzle to be assembled by the subject. This study found that "the virtual 3D jigsaw puzzle does indeed improve the understanding of spatial relations from 3D illustrations." [8, pg 372] In addition, these researchers found that the ankle/puzzle model produced an improved excitement and desire for learning. [8]

The Ritter study focused on providing a robust and convincing presentation of data on a typical 2D screen. Other work in virtual reality has focused on immersing a subject inside of the display. Much of this work seeks to improve HCI with the virtual environment, or qualify human experiences within the virtual world.

Literature on the benefits of improved display technology is plentiful. Most of this work focuses on the benefits of these technologies from a qualitative perspective. These qualitative analyses point the way to benefits for users, but what are the benefits and how meaningful are they?

RESEARCH OBJECTIVES

Volume display, virtual/augmented reality, and technological advances bring the prospect of "seamless" HCI closer. The aesthetics and depth cues of volumetric displays are a step in this direction, but are there real benefits to seamless HCI? Furthermore, if benefits and advantages are present, to what degree are they present? This research seeks to define the benefits and advantages provided by the Perspecta 3D Volume-Filling Display when compared to a standard LCD with regard to completing computer oriented tasks. This will be done in a quantitatively by:

1. Interpreting performance data produced by experiment participants while using both the Perspecta and the flat-screen LCD.

2. Comparing strengths and weaknesses of participants using the display technologies.
3. Examining the data for relationships related to the order in which participants used the displays, the level of difficulty sought by participants, and the nature of the task for which performance was measured.

CHAPTER 1

EXPERIMENT MODEL

PARTICIPANTS

Study participants were selected from university students. A total of 106 male and female college students between ages 18 and 26 were invited to participate. [Table A1] Participants were screened for problems such as uncorrected vision or depth perception problems. Participants were randomly assigned to one of two groups. These two groups differed in the order in which they used the display devices.

APPARATUS

The Perspecta Spatial 3D system by Actuality Systems, Inc was used to run all experiments. This system consists of a computer, joystick, LCD and the Perspecta spatial 3D display. [Fig. A1a] The 3D display is an autostereoscopic volumetric 3D display. This 360-degree-viewable display gives projected graphics true depth, producing imagery that appears three-dimensional without the use of additional eyewear. [5]

The 3D display appears as a domed assembly of plexiglass, mirrors, screen, and weights. [Fig. A1a] The protective outer dome is constructed of plexiglass and is

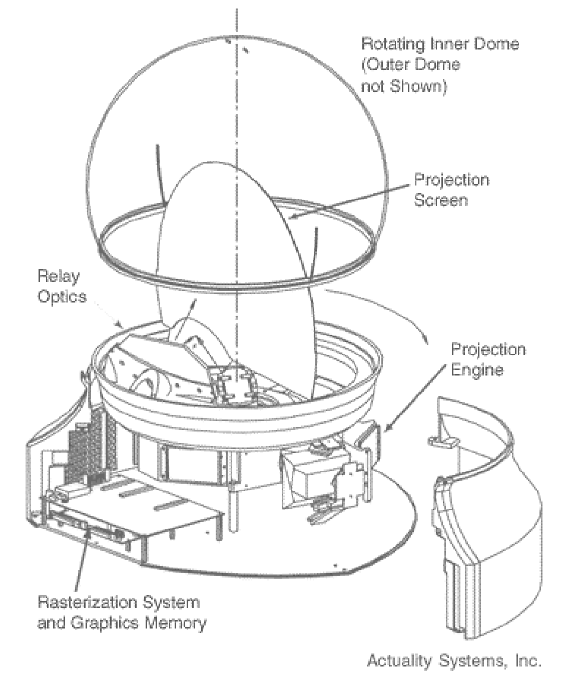

Image courtesy of Actuality Systems, Inc.

Figure 1: Cutaway of Perspecta Display Hardware

stationary. This protective dome shields the rotating inner dome from external contact. It is the mechanical nature of the rotating inner dome that imparts 3D features to the display. The inner dome holds a vertical translucent projection screen. During operation the inner dome and screen rotate at 900 rpm.

Images are transferred to the Perspecta through a high-speed SCSI port. The Perspecta hardware processes these images into slices about the z axis of the display with each slice assigned to a fixed rotational position of the screen. The Perspecta is lit by a standard high-pressure mercury arc lamp and uses mirrors to project the slices onto the screen through its 360-degree rotation. The assembled images possess depth cues that are congruous with human three-dimensional data-processing architecture. [4] Figure 2 shows the Perspecta display and the LCD screen of the system. This system was used in all of the experiments and is the property of The University of Tennessee at Chattanooga.

Figure 2: Perspecta 3D Volumetric Display system at The University of Tennessee at Chattanooga

As with any rotating equipment, the Perspecta is vulnerable to vibration. A relatively small shaft and high rotation speed give rise to some undesirable distortion of the images rendered. Additionally, calibrations to make programmatically generated images more stable can also reduce the resolution of the image. These factors make the volumetric images appear more artistically primitive than images rendered on the LCD.

TASK DEFINITION AND DESIGN

The task performed in this study consisted of a simple game. Participants used a joystick to manipulate the pitch and roll angles of a horizontal surface on which a simulated maze was constructed. Changing the board angles caused a simulated ball to roll toward the lowered sector of the maze. With an appropriate series of joystick movements, participants guided the ball from a start position through the maze to a finish position.

The mazes were presented in numerical order from 1 to 3. All mazes were designed with common start and finish positions. Mazes were designed individually to present specific types of information. Therefore maze-specific results must be considered within proper context before comparisons among mazes are made.

The maze design in use is saved as an ASCII file and is read by the game program at start-up. [Fig A1b] Maze 1, 2, and 3 designs are shown in Figure 3 a, b and c respectively. Maze 1 (Figure 3a) allowed subjects to learn the joystick response, reaction of the ball to tipping of the maze and wall/corner interaction. Maze 2 (Figure 3b) allowed subjects to understand maneuverability of the ball through a more complicated maze.

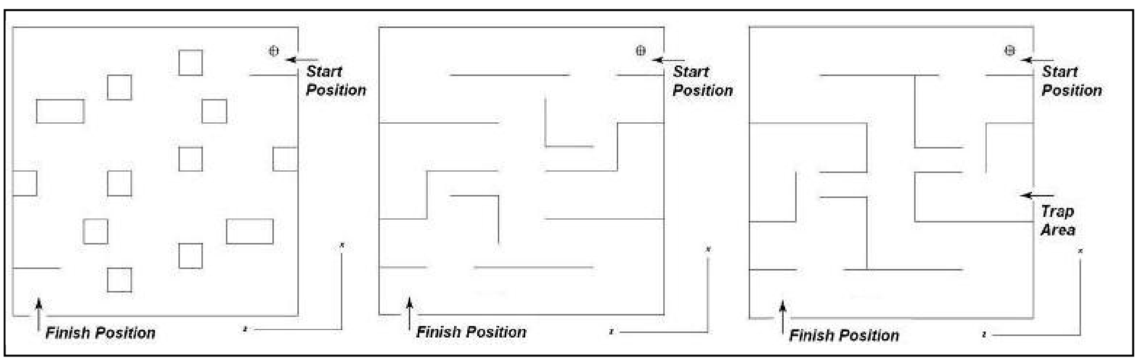

Figure 3a: Maze 1 Figure 3b: Maze 2 Figure 3c: Maze 3

Maze 3 (Figure 3c) was similar to Maze 2 but also reinforced the use of a superior solution path. The reinforcement is achieved using a trap area that complicates alternate paths making them inferior. During the experiment, participants were given a working perspective on the mazes which allowed them to perceive the angle at which the board was tipped. [Fig. A1c]

PROCEDURE

The experiment was divided into two sessions. Participants used one display during Session 1 and then the other display during Session 2. The display used in Session 1 was chosen at random for each participant. Participants who used the Perspecta first were identified as Group A and participants who used the LCD first were identified as Group B.

Before Session 1 began, the participants were instructed on details of the game. Instruction included:

1) A verbal description of the joystick and how to control the game.
2) Presentation of a mock maze board on a sheet of paper showing only where the entrance and exit of the maze were located.
3) A verbal description of the procedure including the number of mazes, number of repetitions and the displays to be used.
4) The participants were told that the objective of the game was to complete each maze as quickly as possible.

Mazes 1, 2 and 3 were presented in sequence and during each session. Participants solved each maze five times before proceeding to the next maze. Each participant solution is henceforth called a “trial”. The game program recorded maze board attitude and ball position at regular time intervals of approximately 200 milliseconds (ms). It was from these data that all results were calculated. The trials numbered from one to five for each of three mazes in each session for a total of 30 games per participant. Participants required between 15 and 20 minutes to complete the maze trials.

MECHANICS AND ENVIRONMENT

The Perspecta volumetric and LCD displays are different in many ways. The LCD was used from a sitting position with the maze tipped 30^0 and rotated 30^0. [Fig. A1c] This was a desirable perspective similar to viewing the Perspecta from a standing position. Participants needed to stand in order to see the Perspecta volumetric display which, unlike the LCD, is viewable from all directions. Both of the displays were used as one would normally expect. The room was arranged such that participants would sit at the LCD screen. For the Perspecta, participants had access to one side (about 180 degrees). [Fig. A1d] When using the Perspecta, participants chose where to stand. Participants were given no instruction as to what position would provide best results.

Due to the optical nature of the Perspecta, which uses a mercury arc bulb for projection, all trials on both displays were played in a darkened room. The only lighting was cast by the displays themselves. The impact of this condition was not explored beyond verifying that both displays were clearly viewable.

CHAPTER 2

RESULTS

TIME TO COMPLETE

Before considering the results of the experiment it must be understood that the participants in the experiment exhibited a wide distribution of ability and aptitude for completing the mazes presented. In addition, the display technologies surely provided different levels of utility to different participants. These factors frustrate and foil attempts to develop baseline performance values. However, the raw time data holds important clues and context for further analysis.

Tables 1 through 4 show completion time results sorted by average solution time in milliseconds. These results were compiled to include both male and female participants. Outliers were removed using the median of absolute deviation method and all of these outliers were larger than the mean. [9] Time averages and standard deviations were then calculated for session/group/maze combinations. The completion time

Table 1: Session 1 Average Solution Times for Trial 1

Group	Display	Maze	Ave (ms)	Std. Dev
B	LCD	1	20761	5951
A	Perspecta	1	22012	6630
B	LCD	2	30200	6275
A	Perspecta	2	33331	10238
A	Perspecta	3	39491	16742
B	LCD	3	47818	22489

Table 2: Session 1 Average Solution Times for Trial 5

Group	Display	Maze	Ave (ms)	Std. Dev
B	LCD	1	17139	5184
A	Perspecta	1	17791	4483
A	Perspecta	3	27677	9610
B	LCD	2	28692	6292
B	LCD	3	29361	8603
A	Perspecta	2	31276	8339