VIRTUAL TOWER OF HANOI

WAN EMMY ROSHAIMA BT WAN ABDUL RAHIM

INFORMATION TECHNOLOGY
UNIVERSITI TEKNOLOGI PETRONAS
JUNE 2004

VIRTUAL TOWER OF HANOI

by

WAN EMMY ROSHAIMA BT WAN ABDUL RAHIM

Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Technology (Hons)
(Information Technology)

JUNE 2004

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

Virtual Tower of Hanoi

by

Wan Emmy Roshaima bt Wan Abdul Rahim

A project dissertation submitted to the
Information Technology Programme
Universiti Teknologi PETRONAS
in partial fulfillment of the requirement for the
BACHELOR OF TECHNOLOGY (Hons)
(INFORMATION TECHNOLOGY)

Approved by,

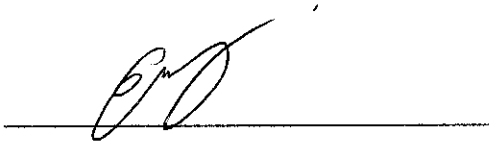
_____

(Mr. Jafreezal Jaafar)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
June 2004

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources of persons.



WAN EMMY ROSHAIMA BT WAN ABDUL RAHIM

ABSTRACT

This project focuses on the effectiveness of task assembly in virtual environment by implementing it with the Tower of Hanoi game. The main objective of this project is to construct an effective task assembly in virtual environment by implementing the Tower of Hanoi game while augmenting the applications of virtual reality games. Other than that, the objective is to conduct evaluations to perceive the effectiveness of assembly task in virtual environment by experimenting it with Tower of Hanoi game. Towards achieving the objectives, three focal phases are conducted; Planning and Analysis phase, Design and Construction phase and Testing and Evaluation phase. The first phase includes data gathering and data analysis; the second phase comprises of modeling the Tower of Hanoi and implements the user interaction with it, and the final phase is doing an evaluation on the effectiveness of task assembly in virtual environment. The results from the testing and evaluation have shown that H_A hypothesis is accepted as true, which is performing assembly task in virtual environment by implementing it using Tower of Hanoi is effective. From the summary table for evaluation of assembly task in virtual environment using Tower of Hanoi, it stated that the minimum mean for the evaluation is 8.20 and the maximum mean is 9.00. The range for this evaluation is $R = 0.8$ and the mean overall for this evaluation is 8.52. This indicates that the range is lesser than the overall mean, $R < M$ (Overall) hence the hypothesis is accepted. For future project development, it is recommended to further develop a more complex and challenging task assembly in various applications.

ACKNOWLEDGEMENT

Completing a project on this title is a very intensive process and it takes the support and dedication of many people to make it possible. Above all, I would like to express my gratitude to the Lord Almighty for giving me the strength, wisdom and patient to complete this project on time.

My deepest gratitude goes to Mr. Jafreezal Jaafar, Final Year Project (Information Technology) Supervisor for all the guidance, advises, incentives, and of course his patience which have given me the motivation and strength towards finishing this project.

Special credits go to Teh Azreen Mohamed Yusof and Siti Yusnorshuhaza Yusof, whom had went through the research process together with me. Your collaboration and support is very much appreciated. And, thanks to the respondents who participate during the Testing and Evaluation phase with the intent of building a better tomorrow.

I must give thanks to my beloved parents, En. Wan Abdul Rahim bin Wan Ishak and Pn. Rosita bt Jasman, whom had given me the inspiration to carry the project through to the end. Thank you both for your love and encouragement.

Lastly, this project would not be complete without acknowledging the contributions of my friends, for being helpful and committed throughout the project development. I could not mention anyone's name without slighting a dozen others, so I would just like to thank each and every one of my friend.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1
INTRODUCTION

Technology has advanced at an ever-increasing, almost exponential rate. One of these spin-off technologies is virtual reality, defined as an artificial computer generated environment in which the user has the impression of being part of that environment with the ability to navigate and manipulate objects which have properties and behaviors that reflect real world objects.

During the last years, Virtual Reality (VR) has proven its potential for the visualization and manipulation of complex data like 3D geometries generated by means of CAD applications. An interesting and promising area of application for virtual environments is assembly simulation. This project describes a process for integrating an interactive Virtual-Reality–based assembly simulation. It uses the Tower of Hanoi puzzle to illustrate a well defined task structured assembly planning using input devices.

In this project, the author also focuses on several features that exist to help the user find out collisions, clashes, or near-clashes. Besides that, to probe, understand and apply the assembly task operations using relatively simple functions in VRML for user interaction.

1.1 Background of Study

The Tower of Hanoi puzzle was invented by the French mathematician, Edouard Lucas, in 1883, in ancient times when 64 gold disks where stacked on diamond needles. Priests began to transfer the disks in search of the solution. It was conjectured that when the puzzle was eventually solved, that the universe would cease to exist. Well, the puzzle was solved long ago and the universe continues to exist.

The puzzle consists of any number of disks (not limited to just 64) and three poles, which are attached to a baseboard. Each disk has a different outside diameter and a hole in the middle large enough for the poles to pass through. To begin, all of the disks are on the left pole with the smaller diameter disks on top of the larger ones.

The object of the puzzle is to move all the disks from the left pole to the right pole and ordered the same as the start (i.e., the smaller diameter disks on top of the larger ones). Only one disk can be moved at a time and no disk is allowed on top of a smaller disk. The middle pole may be used as a temporary resting-place for disks, but at no time is a larger disk to be on top of a smaller one. This problem can be easily solved with one or two disks, but becomes more difficult with three or more disks.

The research is focused on human presence in virtual environments from different angles. The purpose is to find and investigate new concepts that can contribute to the field of Virtual Reality. The approach will be humanistic rather than technological, although technical studies will be necessary to develop new concepts and applications. VR-based assembly simulation systems provide new ways to help users solve puzzles interactively by being immersed in the environment.

The project is mainly to study the on the assembly task operations involved in designing and controlling the puzzle in the virtual environment whereby user interaction is vital here in order to complete the assembly of task.

1.2 Problem Statement

Assembly of tasks should be implemented in virtual environment by various applications including games, prototypes and manufacturing. Here the author focuses on the effectiveness of task assembly in virtual environment by implementing it with a strategy game called Tower of Hanoi. Moreover, 3D puzzles and games needs to be complemented with more improved method for the people to discover the underlying regularities of a complex computer environment they have never seen before in order to

propose new efficient help tools. The fundamental idea is to allow people to solve the Tower of Hanoi puzzle in a virtual environment using input devices, at almost realistic way.

Immersion in an experience is also often as enhancement factor for learning: As states [Ackermann, 1994a, p. 13,], ``interactivity is a key to learning" and ``An increasing number of software designers, cognitive scientists and educators have come to the view that experience is actively constructed and reconstructed through direct interaction with the world, and that, indeed, knowledge is experience". Both social realities and full VR sensory immersion amplify experience. However, it has yet to be shown when strong immersion is really effective for a given task. E.g. a recent study on VR as education tool [Byrne, 1996], showed significance of ``interactivity" but not ``physical immersion". On the other hand it's not clear in what cases social immersion into a VE is really desirable and effective. Therefore, the virtual puzzle is expected to increase the virtual learning experience to ensure people gets involved in the virtual environment.

To be effective, the Virtual Tower of Hanoi must consider about collision detection. Collision detection has been a fundamental problem in computer in order animation, physically-based modeling, geometric modeling, and robotics. In these applications, interactions between moving objects are modeled by dynamic constraints and contact analysis. The objects' motions are constrained by various interactions, including collisions.

A virtual environment, like a puzzle using input devices, creates a computer-generated world, filled with virtual objects. Such an environment should give the user a feeling of presence, which includes making the images of both the user and the surrounding objects feel solid. For example, the objects should not pass through each other, and things should move as expected when pushed, pulled or grasped. Such actions require accurate collision detection, if they are to achieve any degree of realism.

1.2.1 Significant of the Project

Virtual environments (VEs) for education, research and life have have been discussed in various disciplines. While advanced multi-user educational VEs are still mostly speculation (e.g. [Loeffler, 1993]), simpler VEs based on standard technologies have ben in existence for some time. (e.g. [Hiltz, 1988], [Hiltz, 1993]) [Scardamalia et al., 1992],[Eisenstadt et al., 1995]). However, very little research on Virtual Reality as a tool for solving puzzles and games has been carried out. Therefore, in this project, the author concentrates on a virtual puzzle; Tower of Hanoi. The research focuses on the effectiveness of using 3D input devices in assembling a task in a virtual environment. Besides that, this project gives possibilities for local designers and programmers to create virtual puzzles and games by using suitable algorithms and collision detections as guiding principles.

The Tower of Hanoi game is implemented to show the effectiveness of assembly task in virtual environment because Tower of Hanoi is a game that requires the users to perform the tasks of an assembly such as select, move and position. Since the project is also to highlight virtual games, Tower of Hanoi game is the most suitable application to be implemented.

1.3 Aim and Objectives

The aim of this project is to develop Tower of Hanoi puzzle based on task assembly in a virtual environment whereby users use 3D input devices to interact with components.

The objectives of the project are:

1. To construct an effective task assembly in virtual environment by implementing the Tower of Hanoi game.
2. To augment the applications of virtual reality games.

3. To construct and conduct an evaluation in order to perceive the effectives of assembly task in virtual environment.

1.4 Scope of Study

On the whole, the project analyzes the task assembly that can be applied in the Tower of Hanoi game in a virtual environment. The task assembly is the main aspect being looked into and is applied throughout this project. Besides, the author also highlights the performance of the 3D game.

The puzzle supports a VR interface for performing task-oriented virtual assembly, constraint analysis, and collision-free assembly planning. It provides a virtual reality interface which allows users to freely navigate in the assembly environment, select one of the parts, and move it to the other pole. To accomplish the goal, the free motion of an input device is restricted by both a collision-free path and allowable motion derived from mating constraints between the parts. The allowable motion with reduced degrees of freedom guides the user assembling the parts in a constrained direction or around a specified rotating axis. Any illegal motion that will possibly cause a collision or disabled movement is not allowed, which prompts a warning sound or error messages to alert the user.

The end product for the project is the simulation of Tower of Hanoi puzzle in a virtual environment. Users are required to move all the disks from the left pole to the right pole using input devices with the smaller diameter disks on top of the larger ones. From the moves necessary to transfer one, two, and three disks, we can find a recursive pattern - a pattern that uses information from one step to find the next step - for moving n disks from post A to post C.

CHAPTER 2
LITERATURE REVIEW

An investigation is carried out to study other related work as part of the project research. There are five core research areas compiled as follows.

2.1 Virtual Reality and 3D Environment

Immersion, whether physiological or psychological in nature, is intended to instill a sense of belief that one has left the real world and is now "present" in the virtual environment. This notion of being present in the virtual world has been considered central to VE endeavors since its conception [Minsky, 1980]. Presence is traditionally thought of as the psychological perception of "being in" or "existing in" the VE in which one is immersed [Heeter, 1992; Sheridan, 1992; Steuer, 1992; Witmer and Singer, 1998]. Virtual Reality simulates an environment enabling a person to visualize and compare it to a real world, which may still be in its conceptual state. Users of a virtual reality application can move or manipulate the simulated objects according to their preferences. The users can therefore simulate an environment in this virtual world, which meets their demands in all respects before actually developing it in real life.

For this project, the author utilizes the virtual Tower of Hanoi simulation in 3D environment which means applying the 3D conceptual images and objects. Interactive 3D environment and 3D animation is a good technique to make the application more attractive and interactive. 3D animation is more realistic than 2D animation which has been used widely in most applications. Here, the objects such as the disks are created in 3D which manipulates the distances, depth and angles of objects and creates effects, which the human eyes perceived as real life 3D objects. The most essential elements that

differentiate the 2D environment and 3D environment are the manipulation of lights, colors and perspectives of the objects to create realism.

2.2 Virtual Learning and Fun Environment

Virtual Environments for education, research and life are interactive cyberspaces where many users can communicate and collaborate in various way. They also can build virtual like offices, books, blackboards, artificial persons and more. VEs should also provide optimal support for information storage, retrieval and manipulation. While advanced multi-user educational VEs are still mostly speculation [Loeffler, 1993], simpler VEs based on standard technologies have ben in existence for some time. ([Hiltz, 1988], [Hiltz, 1993]) [Scardamalia et al., 1992] ,[Eisenstadt et al., 1995]). VEs are collaboration tools. Many studies have shown that collaborative learning and collaborative work is efficient, some conditions for either success or failure are well known, others are still unknown [Dillenburg et Schneider, 1995]. Through this Virtual Reality application, it has been proven that an effective learning process can be achieved while having fun manipulating the 3D objects.

Compared to 2D environments, dealing with simulations in 3D environments are an inspiring and appealing factor. Immersion in an experience is also often as enhancement factor for learning: As states [Ackermann, 1994a, p. 13,], ``interactivity is a key to learning" and ``An increasing number of software designers, cognitive scientists and educators have come to the view that experience is actively constructed and reconstructed through direct interaction with the world, and that, indeed, knowledge *is* experience"

2.2.1 VEs need objects that can be manipulated

If VEs are to be fully operational people must be able to ``bring in" as many virtual objects as they need for work and communication. Ves can be seen as a social context for propagating constructionism (e.g. students manipulating ``symbolic physical" objects

[Moshell et al., 1995] or ``real virtual physical objects''). To ensure effective learning, users must perceive it from practice or performing specified tasks. Interactive objects favor reflection which in turn favors learning [Collins et Brown, 1988].

2.3 Virtual Assembly Environment

The Assembling consists of the act of putting two or more components together; but behind the scenes work includes many activities necessary to realise the complete product, repair it, and disassemble it for recycling or disposal An assembly task may be divided into six basic activities such as reach, select, grasp, move, position, and assemble. Activities such as "reach" and "move" are generated by biomechanics of body motions including human factors principles such as Fitts' law [Prabhu et al, 1992]. The integration of Virtual Reality with software systems for engineering, design, and manufacturing will provide efficient tools to the field of computer-aided-engineering. One aspect of design and manufacturing which may be significantly affected by virtual reality is product design and assembly.

Tower of Hanoi game is an assembly task as users have to do the basic activities of an assembly task such as selecting, moving and positioning the objects. The development of Tower of Hanoi in Virtual Reality is to illustrate the assembly task in a virtual environment.

2.3.1 Virtual Reality for Manual Assembly

The process of assembly is currently one of the most complexes in industry [Delchambre, 1992]. The term "assembly" actually applies to some 20 different procedures. For a human operator equipped with adequate tools, none of these tasks is impossible. The human combines logic and perception of the environment, and has two sophisticated tools, the hands, to do the work.

The objective of designing virtual assembly environment is to enables users to visualise and interact with a 3D computer representation of a product minimising the requirement to build physical prototypes. The main issues investigated by applying this technology in the area of product assembly are to evaluate parts' assemblability, part accessibility and part layout during the product design phase and the estimation of the assembly time. The Tower of Hanoi game consists of several parts that need to be assembled in order to accomplish the game.

Assembling virtual parts has highlighted several problems including differences between conducting the task in a real and virtual environment. If an assembly task is accomplished in a different manner in the real world than the VE, then the accuracy of the estimated assembly sequences and sequences and task completion times comes into doubt.

The Virtual assembly Environment incorporates virtual representations of components and objects, produces auditory responses when different objects collide, and enables the user to interact with virtual objects by different devices such as standard 3D mouse and a pair of pinch Glove. Tower of Hanoi in virtual assembly environment aims at the generation of assembly sequence from the user interaction with virtual parts. The time taken to accomplish the game also varies from one another depending on how trouble-free one can take to perform the task assembly.

Figure 2.1: Assembly manipulation using a 3D mouse as interaction device

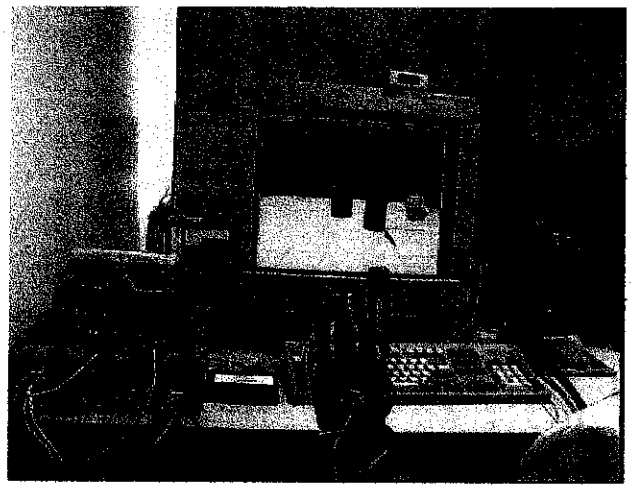


Figure 2.2: Assembly manipulati with pinch Glove

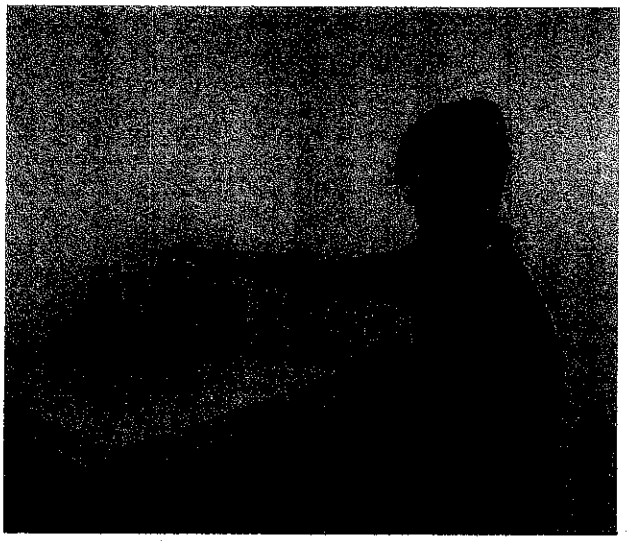


Figure 2.3: Part's assembly in re world

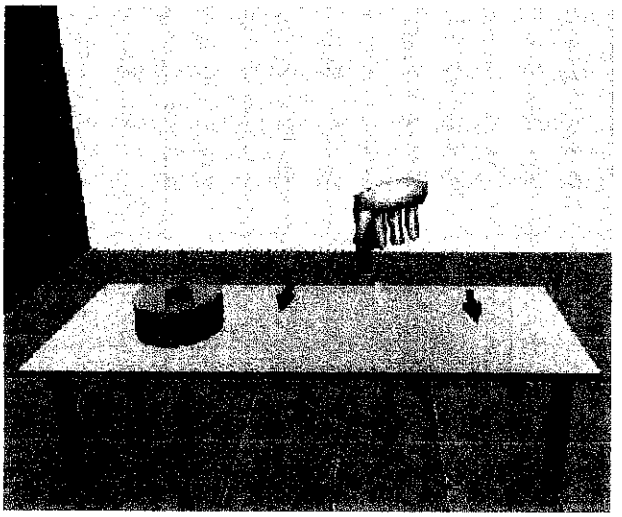


Figure 2.4: Part's assembly in vir environment

2.4 Investigation of Task-Performance for Interaction within a Virtual Environment for Assembly

The use of virtual environments to augment CAD environments has the potential to improve productivity and reduce costs in the product development life-cycle through the use of virtual prototyping [Maxfield 1996]. Virtual prototyping aims to construct a realistic digital simulation of the product [Haug et al 1993], for design and functionality analysis in the early stages of the product development process.

Virtual assembly, a component of virtual prototyping, is defined as the use of computer tools to "assist with" assembly-related engineering decisions through analysis, predictive models, visualization, and presentation of data without physical realization of the product or supporting processes [Connacher et al 1995]. In particular, interactivity is one of the most important assets to support closed-loop virtual prototyping [Jung et al 1997; 1998]. Easy and precise interaction, however, is difficult in a virtual world. It presents a real problem when dealing with complicated engineering assembly environments that demand high precision and accuracy [Fa et al 1993; Jung et al 1998]. In this context, there is a need to investigate how to design and evaluate interaction techniques in Tower of Hanoi game to achieve an intelligent task-level human-computer interface within the virtual assembly environment.

The design and development of technology to improve the quality of work and the quality of the products of work require us to pay close attention to the nature of the work, and to be explicit about how any technology that we design might affect people and their work [Johnson et al 1995]. This project describes an experiment to conduct a task-performance analysis regarding the usability of interaction techniques by using a constraint based assembly task model. In this project, a constraint is defined as a geometry constraint and assembly relationship between solids. The study advances understanding of how people undertake assembly tasks in a VE system and how the system will affect people in terms of how they could use it.

2.4.1 Related Task-Performance Analysis in Human-Computer Interaction

Task analysis is used to understand the user's activity in the context of the whole system, either in an existing or a future system [Kieras 1996]. A number of related studies have compared and evaluated interaction techniques related primarily to the assessment of user performance. For example, Poupyrev et al presented a study to compare two basic interaction metaphors for egocentric direct manipulation in object selection and positioning experiments [Poupyrev et al 1998]. Bowman & Hodges conducted a series of studies to evaluate interaction techniques for universal VE interaction tasks [Bowan & Hodges 1997, 1999]. Other related work includes Iowa State University's investigation of a spherical mechanism design task to compare two types of computer interface in order to determine if there are advantages of in using VR technology as opposed to computer workstation-based software. The results were discussed in terms of interaction device and visualization interface preferences (http://www.vrac.iastate.edu/~jmvance/EVAL). Gribinau compared a single- and two-handed 3D input interface for 3D object assembly tasks [Gribinau & Hennessey 1998]. To explore two-handed virtual manipulation for neurosurgical applications, Hinckley et al performed a series of experiments both in the physical world and virtual environment [Hinckley 1996, Hinckley et al 1998]. However, little research has been found to investigate task-performance for interaction with constraint based assembly models in a virtual environment, and compare this with the task-performance of the same assembly in the real world. This assists in the building of more intelligent task-level human-computer interfaces.

2.4.2 Interaction Techniques within the IVPS

The Interactive Virtual Prototyping System (IVPS) [Thompson et al 1998; Maxfield 1999] provides a 3D environment in which an engineer can visualise and interact with a particular product. A geometric model of the design can be exported from a CAD system and imported into the IVPS, where the components of the model can be visualised and manipulated as 3D geometric solids. The user can then assemble the product by directly

interacting with the components and manipulating the resulting assembly to test its kinematic behaviour.

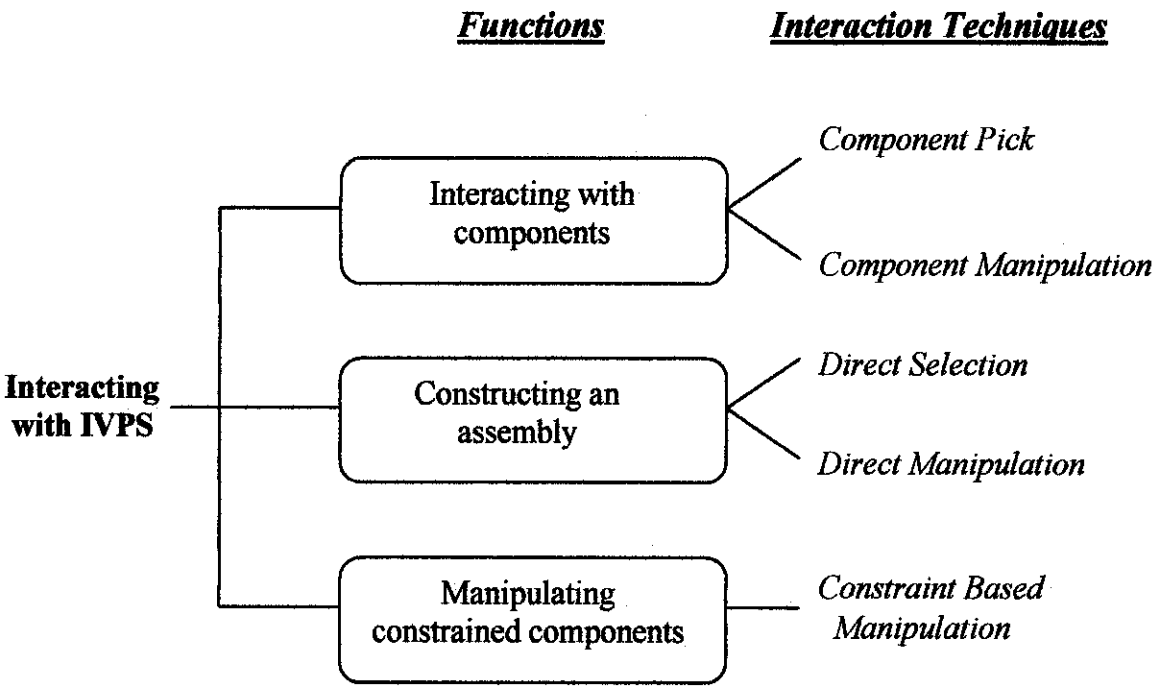


Figure 2.5: Interaction techniques to study

Currently, interaction with the IVPS system is achieved using a combination of mouse and keyboard input. Interaction with the IVPS system includes [Maxfield 1999]: interacting with the 3D viewer, interacting with components, constructing an assembly, manipulating constrained components, simulating non-nominal components and simulating lighting conditions. This study is particularly interested in interacting with components, constructing an assembly and manipulating constrained components. A simple classification of interaction techniques underlying the three interaction functions is presented in Figure 1.

For *Interacting with components*, the *Component Pick* technique is used to select a component. A target component will be highlighted by a bounding box to indicate it is currently under the select pointer or that it has been selected. *Component manipulation* is used to freely manipulate a selected component in 3D space.

To *Construct an assembly*, assembly constraints must first be defined between the components of model. *Direct Selection* is used to create a new constraint by directly picking two geometric entities to be constrained. The system will initially be in *Viewpoint Manipulation Mode*. In this mode the viewpoint can be altered. To specify the first geometric entity the user must first switch into *Geometry Picking Mode*. In this mode the entire model will become transparent so that the highlighted or selected geometric entities can easily be distinguished from the rest of the model. When an entity is under mouse pointer, it will be highlighted in red. Figure 3 illustrates the process of switching between the various modes within the system when using *Direct Selection*.

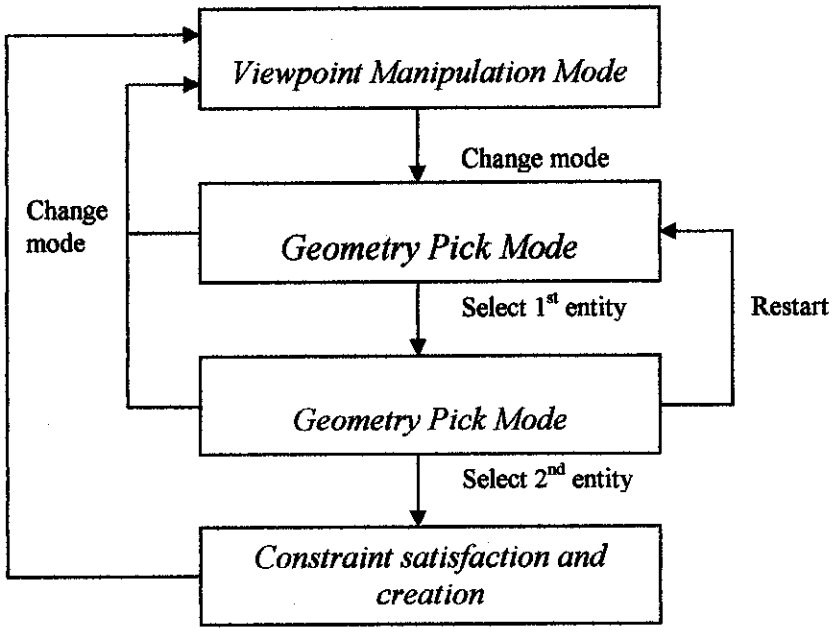


Figure 2.6: Switch between modes for Direct Selection

Direct Manipulation is used to create a new constraint by selecting a particular component and manipulating it while the system attempts to predict all possible mating conditions that exist given the current position and orientation of the selected component and all other components in the model. First the user enters *Component Pick* Mode to select a component. Once selected the system enters *Direct Manipulation Mode*. In this mode all components (including the selected one) become transparent so that the highlighted geometric entities can be distinguished from the rest of the model. The selected component can be manipulated using the mouse. Each time the component is manipulated, the system will predict all valid mating conditions between the selected component and any others in the model. At each step of the manipulation, the most likely constraint is offered to the user. This can be accepted by releasing (deselecting) the component. The system will then satisfy and create the necessary assembly constraint, and switch back into the *Viewpoint Manipulation Mode*. Figure 3 illustrates the process of switching between the various modes within the system when using *Direct Manipulation*.

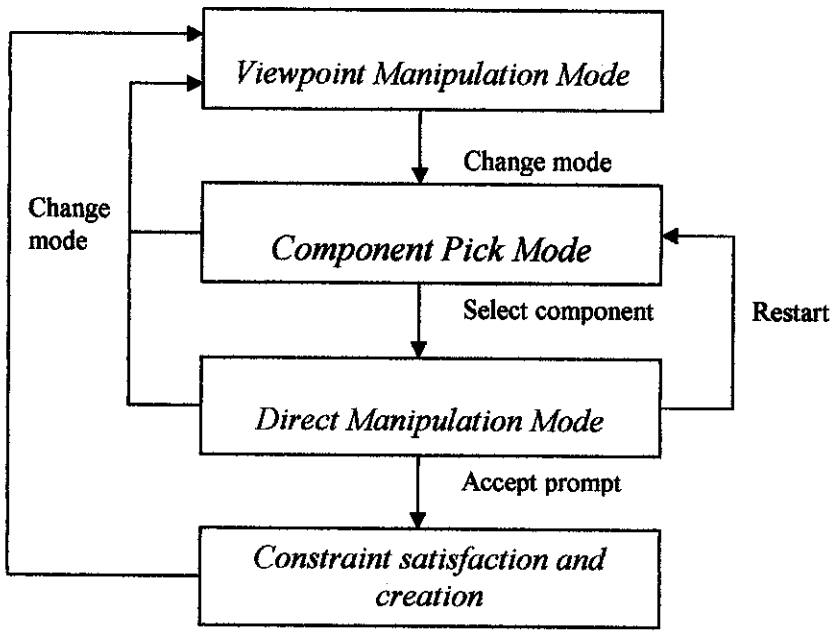


Figure 2.7: Switching between modes for Direct Manipulation

2.5 Tower of Hanoi

The Legend. In an ancient city in India, so the legend goes, monks in a temple have to move a pile of 64 sacred disks from one location to another. The disks are fragile; only one can be carried at a time. A disk may not be placed on top of a smaller, less valuable disk. And, there is only one other location in the temple (besides the original and destination locations) sacred enough that a pile of disks can be placed there. So, the monks start moving disks back and forth, between the original pile, the pile at the new location, and the intermediate location, always keeping the piles in order (largest on the bottom, smallest on the top). The legend is that, before the monks make the final move to complete the new pile in the new location, the temple will turn to dust and the world will end.

The Game The Tower of Hanoi puzzle was invented by the French mathematician Edouard Lucas in 1883. There are three poles one of which contains threaded disks sorted from the biggest one at the bottom to the smallest on at the top. We can take disks from one pole and put them on another one, but we can lift only one disk at a time, and only smaller disk on the top of the bigger. So, the goal of the Tower of Hanoi game is to remove disks from the one pole and collect them at another empty pole.

TOWER OF HANOI

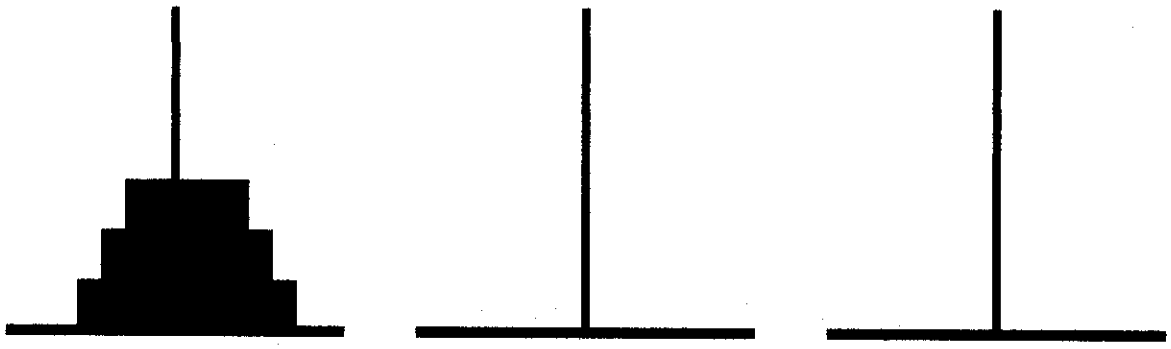


Figure 2.8: Tower of Hanoi game

CHAPTER 3
METHODOLOGY

3.1 Procedure Identification

The author had gone through a series of conventional steps or also known as a road map for this project that facilitate the author to produce a well-timed, high quality results. In other words, the author had created a research framework to ensure the research project is successfully done. The research framework can be view in Figure 3.1.

The research framework can be categorized under the Rapid Application Development (RAD) model because the research project development process is a linear sequential software development process that emphasizes an extremely short development cycle. RAD can be a good development model for information technology applications that are limited in scope and time. The author uses RAD model as it is able to meet business needs as fast as possible which are necessary for today highly-competitive business environment. By using RAD, it enables the author to complete the 3D Virtual Tower of Hanoi within a very short time period; 60 to 90 days.

On the whole, this research project consists of 3 main phases; planning and analysis phase, design and construction phase, and testing and evaluation phase. The author could not proceed to the next phase until the phase is carried out since the phases are directly dependent on each other.

Firstly, the planning and analysis phase consist of two key elements which are data gathering and data analysis. The author had done a distinctive research and deals with a range of information that is related with the research project. The information gathered must then be analyzed thoroughly to ensure that it is still within the scope of the project.

The planning and analysis phase is an ongoing phase throughout this project as it enables the author to collect related information from time to time.

The research and analyzed information from the first phase had then been used to the next phase; the design and construction phase. This phase consists of two key elements which are the modeling of the virtual Tower of Hanoi that is the disks and poles and also applying the appropriate collision detection for the game.

Lastly, the product from the research project had also undertaken the testing and evaluation phase. Here, the author had carried out one main testing and evaluation whereby the game is being played according to the rules and the collision detection that had been applied is observed to ensure correct movements between the disks and the poles. As a final point, the data gathered during the testing and evaluation phase is analyzed.

3.2 Planning and Analysis Phase

The planning and analysis phase is divided into two key elements which is data gathering and data analysis.

3.2.1 Data gathering

During this phase, the author did the project planning thoroughly as she needs to complete the final product within a certain time frame. The author had established the project scope and the work schedule in this phase which is necessary to ensure the proper product completion. Identifying the project scope is very crucial here because of the limited time the author had to complete the project. She had to make sure of the scope of the project so that the phases done throughout the project for instance the analysis and constructing phase are restrained from going wider than what the project should covers.

Related data for the project such as the 3D environment, virtual disks and poles of the Tower of Hanoi, collision detection, assembly of task, the original Tower of Hanoi game as well as virtual reality applications are gathered for analysis purposes. Fundamentally, data gathering is focused on the secondary data sources to support the hypothesis and theory of the research, which includes data gathering of existing reading materials like online materials including journals and articles and also printed materials comprising of magazines, books and newspapers. Furthermore, the community views of the advantages of the project must be considered in order to have better understanding on the project. Consequently, the author had distributed a preliminary survey to get any related information ***(Refer to Appendix A for the Initial Survey Form)***.

Moreover, observation was conducted for gathering data purposes to increase the author's understanding of the research. The author played the Tower of Hanoi game in a 2D environment numerously to observe the movements of the disks. The author too

studied several 3D environments which involves movements of objects that implements collision detection.

Above all, the planning and analysis phase had taken the most effort and time during the project development as it mainly contributes to the success of the project upon completion. It is also an ongoing process throughout the project.

3.2.1 Data analysis

There are several other measures that should be taken once the data gathering process had been completed to understand the meaning of the collected data. For that reason, the data analysis process is where the collected data is filtered, analyzed, separated and transformed to constructive information whereby it is then used to develop the product during the design and construction phase. This is another important process because having the right and useful information is vital in order to proceed accurately in the later phases.

In this phase, the author had also analyzed the suitable tools to be used to simulate the Tower of Hanoi game appropriately. The hardware needed for this project is a personal computer equipped with graphic card, sound card, and a high performance processor in order to develop high-quality graphics, animations and motions. Low performance processor would result in slow development and modeling processes.

Finally, the author can design the target product; 3D Virtual Tower of Hanoi, after reviewing and analyzing the findings of data. These useful data are implemented in the next phase which is the design and construction phase.

3.3 Design and Construction Phase

The design and construction phase is also divided into two key elements which is modeling virtual Tower of Hanoi and the user interaction for Tower of Hanoi.

3.3.1 Modeling Tower of Hanoi

To model the 3D Tower of Hanoi, basically only two geometric modeling are used; cylinder and doughnut. Cylinder acts as the pole or the tower while doughnuts act as the disks. There are three cylinders designed which have the same size and are positioned at the same plane of the X-axis. There are also three different sizes of doughnuts modeled and are placed at the leftmost cylinder.

Users must be able to differentiate the three sizes of the disks in order to play the game. Hence the author created three different scales for each disk. The disks are also modeled in different colors to make easier for the users to perceive the disks. The right transformation and translation for each object is also very essential in order to place the objects properly.

3.3.2 User interaction for Tower of Hanoi

Task assembly is concerned with movements of objects from one position to another. Therefore user interaction is the essential part of developing this project. The author used the javascript to sense objects and trigger events. There are several events that can be generated from these depending on how user interacts with the objects. Users are able to pick, move, and position the objects accordingly. Therefore suitable functions are included in the coding to generate the actions by users.

3.4 Testing and Evaluation Phase

The testing and evaluation phase is divided into four key elements which are the test design, hypothesis development, evaluation and data collection and also data analysis.

3.4.1 Test design

Mainly, test design is a method of testing which conducted by the designer in order to obtain the intended results. The author had tested the 3D Virtual Tower of Hanoi repeatedly during the construction phase. When the functions and sensors are applied, the simulation result is tested to check the proper movements between the disks. Moreover, the movements of the disks between the poles must be checked correctly according to the rules of the game. The test design is repeated until the desired results are accomplished.

3.4.2 Hypothesis development

Hypothesis is required for this project to perform the evaluation that had been planned earlier. With the hypothesis, the data collections after the evaluations are very much simpler to be interpreted. Predominantly, the data gathered from the evaluation are converted into constructive tables of descriptive statistics and histogram charts for better visualization of the results. A basic formula is applied to determine whether a hypothesis can be accepted or rejected. For this project, there is only one main evaluation that had been carried out. It is to perceive whether assembly task in virtual environment is effective by implementing it with Tower of Hanoi game.

The evaluation: Perceive assembly task in virtual environment using Tower of Hanoi

H_O: *Performing assembly task in virtual environment by implementing it using Tower of Hanoi is not effective.*

H_A: *Performing assembly task in virtual environment by implementing it using Tower of Hanoi is effective.*

From the descriptive statistic, the attribute of the effectiveness of assembly task in virtual environment using Tower of Hanoi are shown.

Find range (R) and mean overall; M (Overall) as below:

Attribute of the effectives of assembly task in virtual environment using Tower of Hanoi	**Mean**
A_1	M_1
•	•
•	•
A_2	M_2
•	•
•	•
A_n	M_n

$A_1, A_2 \ldots\ldots\ldots\ldots\ldots A_n$ = attribute

$M_1, M_2 \ldots\ldots\ldots\ldots\ldots M_n$ = mean for each attribute

Range (R) = M(max) – M(min)

Overall Mean, $M(\text{overall}) = \frac{M_1 + M_2 \ldots\ldots\ldots\ldots + M_n}{n}$

Therefore, by using this simple calculation, the HO hypothesis is rejected if $R < M$ (overall)

3.4.3 Evaluation and data collection

The author conducts the evaluation process by utilizing the heuristic evaluation whereby it is the process of determining the acceptability of the end product of how appealing it is and how well it matches the required objective. These evaluations are gathered from the evaluators' feedback on the simulation results.

There is only one evaluation conducted in this stage for the project. The evaluation is to perceive that assembly task in virtual environment using Tower of Hanoi is effective. The main objective of this evaluation is to find out the accomplishment of doing an assembly task in a virtual environment by playing Tower of Hanoi game.

- **The evaluators' profile**

5 people were chosen in order to make the products comparison, which was held on the April 6, 2004. The venue is at the café in Village 4, Universiti Teknologi PETRONAS (UTP). Considering the time constraints, only 5 respondents from UTP were chosen to give their response and feedback. There are 2 evaluators whom well-verse with computer graphics and virtual reality applications. In fact, they are the Information Technology (IT) and Information System (IS) students. There are also 2 evaluators whom well-verse with computer graphics and virtual reality applications but they are not familiar with Tower of Hanoi strategy game. Another evaluator whom is not familiar with computer graphics and virtual reality applications and she is also not familiar with Tower of Hanoi strategy game.

- Method of conducting evaluation

Before the author conducted the evaluation session, a small briefing on Virtual Tower of Hanoi is carried out in order to foster understanding on the evaluated subjects. Rules of the game were given so that the evaluators are able to execute the game correspondingly.

The evaluation is basically to let the evaluators try out the 3D Virtual Tower of Hanoi according to the exact rules of the strategy game. When an evaluator is playing the game, the other evaluators are not able to observe he or she accomplishing the game since it requires own strategy. Hence individual time is taken for each game that has been completed.

Each and every evaluator is interviewed after the evaluations were carried out. At the end of the evaluation phase, the checklists and questionnaires are collected for data analysis. The data collected form the interviews are also collected to be analyzed. ***(Refer to Appendix B for example of Evaluation Checklist).***

3.4.4 Data Analysis

In this phase, the data collected from evaluation phase is analyzed. These important data are calculated and tabulated in the statistic tables. The calculated data is then plotted into histogram for better visualization of the evaluation results. All the details of the calculations and results are discussed in Chapter 4.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Results and Discussion for Planning and Analysis Phase

4.1.1 Preliminary Survey

Preliminary questionnaire has been distributed to 5 students from Universiti Teknologi PETRONAS (UTP) in order to get their feedback about the research project and the development of 3D Virtual Tower of Hanoi. This is the initial respond for analyzing the user's requirements and their expectations of the product.

The age level of respondents is between 20 years old to 23 years old. The questionnaire consists of ten simple questions, so that they would be able to understand the questions easily as well as providing appropriate responds (refer to Appendix). The reason of choosing that age level is because they are the target user and they are also exposed on the current advances of technology. In addition, most of them know how to use a computer. Basically, the process of selecting suitable respondents is important because the author would like to meet the objective of gathering data through questionnaire.

The results from the Initial Survey Form are divided into few categories according to the rationale of the data. The results for each category are explained as follows:

1. Strategy Games Genre

Data analysis:

Games Genre	*Number of respondent*
Action-adventure	2
Puzzles	2
Sims	1
Race	0
	5

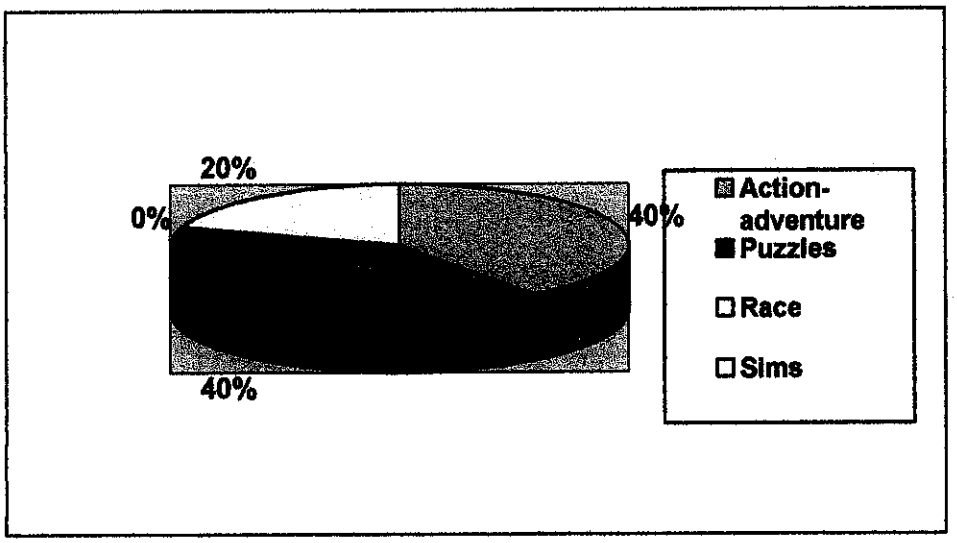


Figure 4.1: Strategy games genre

Discussion and result interpretation:

From the pie chart above, it is clearly stated that respondents are fonder of action-adventure and puzzle games as they gain 40 percents of the total respondents compared to Sims which gain 20 percents and none for race.

2. The Most Preferred Way of Playing Strategy Games

Data analysis:

Ways of Playing Strategy Games	*Number of respondent*
3D virtual environment	3
Board game	1
2D computer game	1
	5

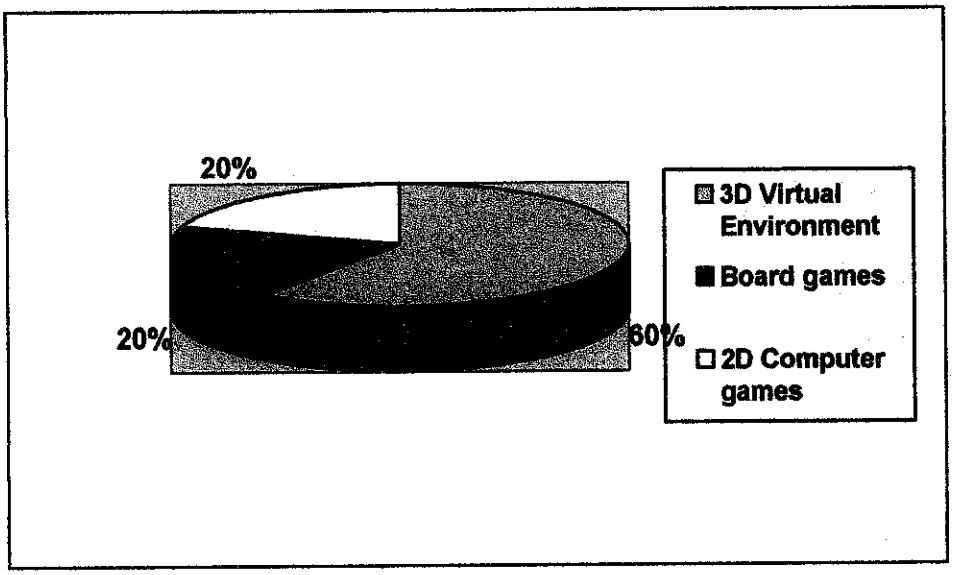


Figure 4.2: The preferred ways of playing strategy games

Discussion and result interpretation:

From Figure 4.2, it shows that 60 percents of the respondents prefer to play strategy games using 3D virtual environment. While 20 percents prefer to play using board games and 2D computer games each. The reason based on this result is because the respondents are interested to try new advances of technology which is associated with virtual environment. Furthermore games related to virtual reality applications are more exciting and attention-grabbing compared to board games and 2D computer games.

3. Users' Acceptance of 3D Virtual Tower of Hanoi

Data analysis:

Users' Acceptance of 3D Virtual Tower of Hanoi	*Number of respondent*
Interested	4
Not interested	1
	5

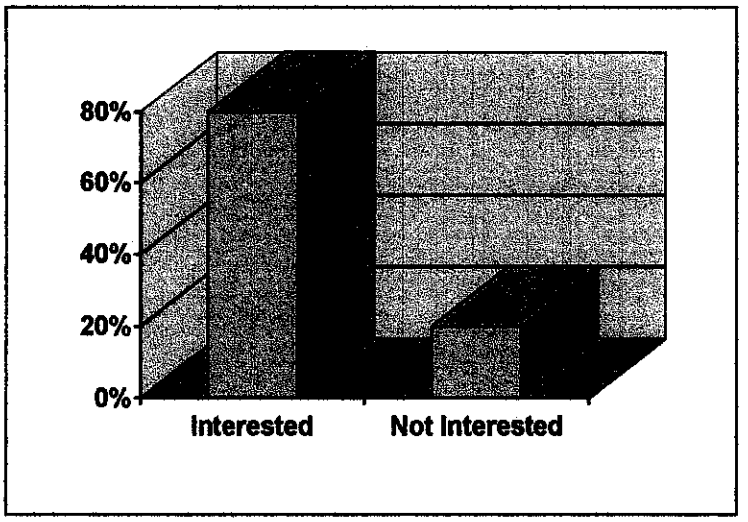


Figure 4.3: Interest of respondents about 3D Virtual Tower of Hanoi

Discussion and result interpretation:

The histogram above indicates that 80 percents of the respondents are interested in the Virtual Tower of Hanoi. They might find that games using virtual reality applications are more exciting than the typical 2D games. However there are 20 percents who are not interested in the virtual game maybe because they are not much exposed to virtual reality games.

4.2 Results and Discussion for Design and Construction Phase

During the design and development phase, the author had modeled the Tower of Hanoi and applied the appropriate sensors for user interaction.

The first step in design and construction phase is to model the Tower of Hanoi by creating objects that are most suitable. Basically two 3D objects were shaped; cylinder and doughnut. Displaying 3D graphics is very different from displaying 2D images. Objects are positioned in three dimensions but must be viewed on a two-dimensional computer display. Because the objects exist in three dimensions, it must be decided from which direction they should be viewed.

Although this makes it harder to work with 3D, it also gives 3D huge advantages over 2D. The compactness of 3D comes from the ability of the author to define objects as skeletons, to be filled in by the computer rendering the image. The author did not just make a VRML file with just a Cylinder and Doughnut node as it will not do anything. The Cylinder and Doughnut specify only the geometry (shape) of an object, not its appearance (color). VRML also has an Appearance node, to define its color. Once the author has geometry and appearance, she had enough to define a VRML object. All she needed was a way to associate the color with the geometry. In VRML, the author did this with the Shape node.

A VRML scene graph uses a Cartesian coordinate system. Every point in the world can be described by a set of three numbers, called a coordinate. The first number is the X component, which places the object right and left in the world. The second is the Y component, which places the object up and down in the world. The third is the Z component, which places the object nearer and farther from the front of the screen. The author need to use the coordinate system for all objects created in the VRML scene for proper placement, scale, and orientation in the scene. The Transform node has a children field that can hold a Shape node. Most of the other fields of Transform allow the author to change the position, size, and orientation of the nodes in the children field. The fields

controlling these transformations are center, rotation, scale, scaleOrientation, and translation.

Its definition looked like this:

```
Transform {
            children Shape {
                  appearance Appearance {
                        material Material {
                              diffuseColor .7 .4 0.2
                           }
                        }
                        geometry Box {
                           size 12.5 0.2 2
                        }
                  }
               }
```

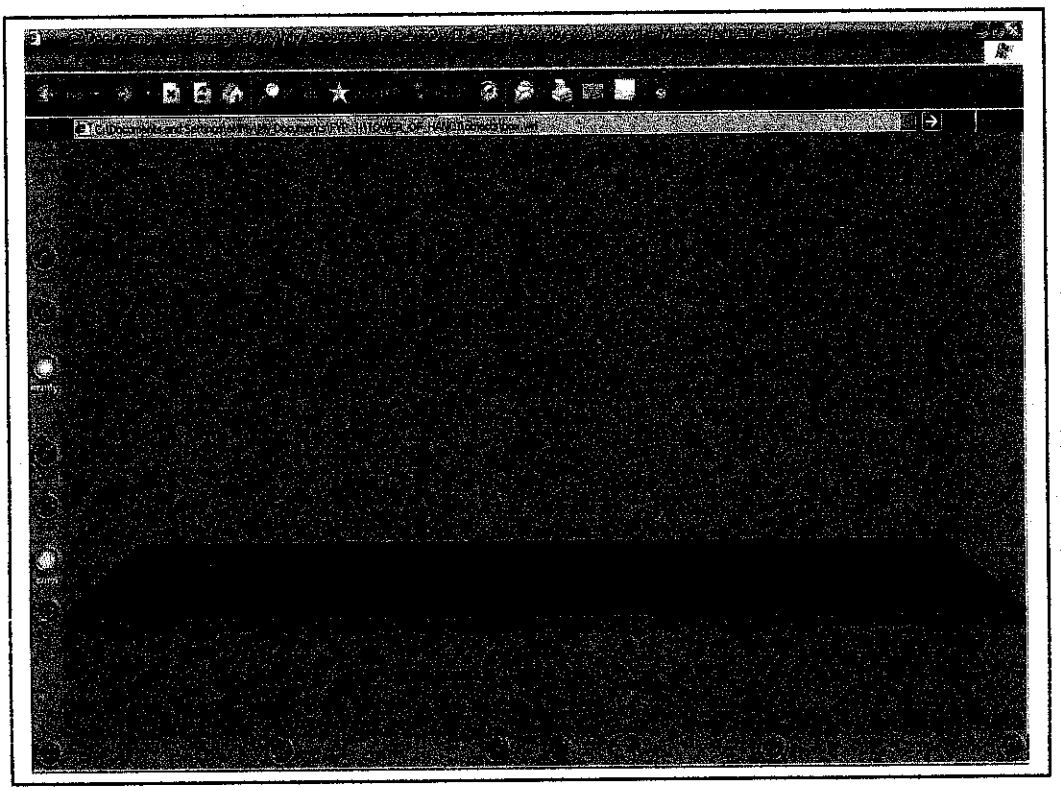


Figure 4.4: A 3D box for the base of the game

Fundamentally, the author created three cylinders and three doughnuts. The cylinders act as the poles and the doughnuts act as the disks. The doughnuts were modeled in three different sizes and colors. The sizes and colors can be determined by the scale and appearance in the code. The sizes of the disks are essential as they are the main objects that are manipulated by users. The author determined the accurate scale and positioned them accordingly in the first cylinder. Meanwhile the three cylinders are typical in sizes and colors.

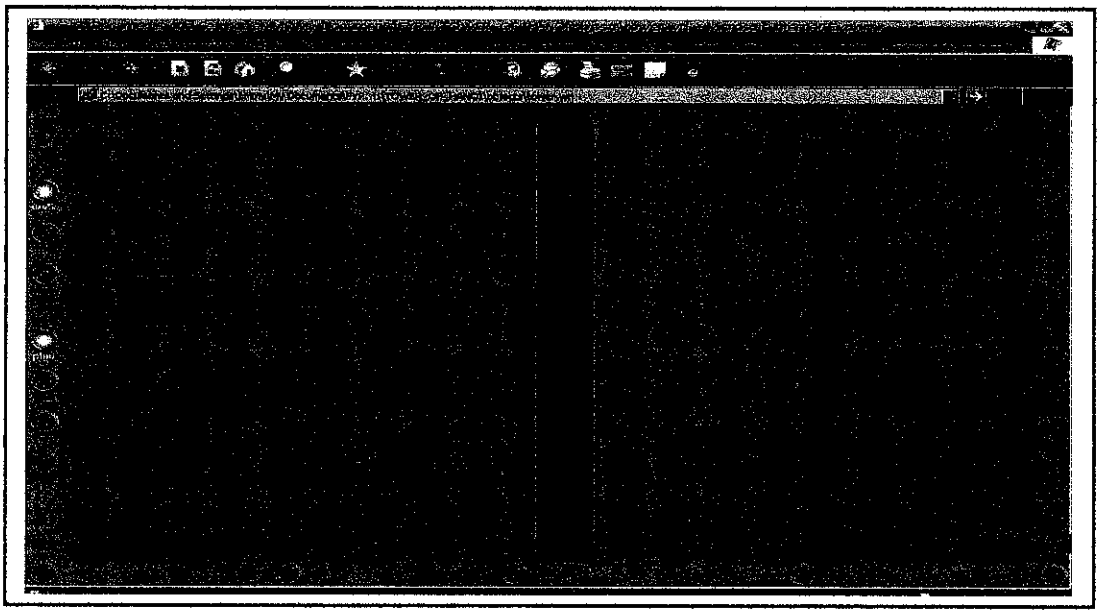


Figure 4.5: A 3D cylinder as the tower

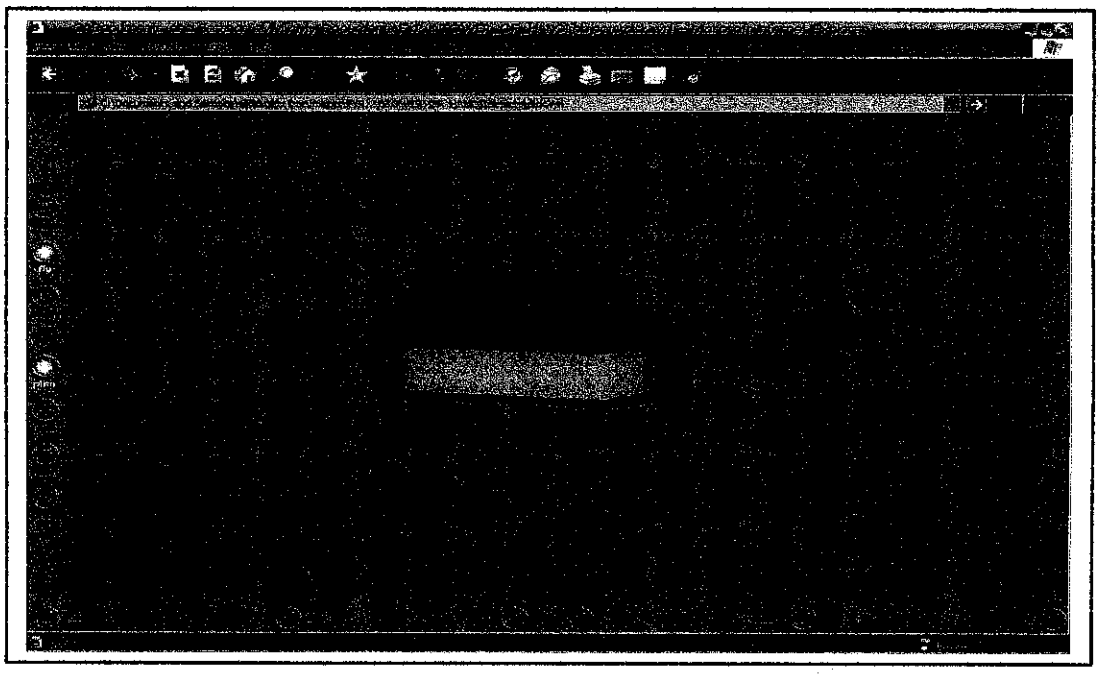


Figure 4.6: 3D doughnuts as the disks

The portion of the javascript used for user interaction:

```
function isLit_P1(eventValue) {
            if (eventValue==true) {
               color_P1 = activeColor;
               color_P2 = inactiveColor;
               color_P3 = inactiveColor;  }
               else {
               color_P1 = activeColor;
               color_P2 = inactiveColor;
               color_P3 = inactiveColor;  }
            end_peg = 1;    }
         function isLit_P2(eventValue) {
            if (eventValue==true) {
               color_P2 = activeColor;
               color_P3 = inactiveColor;
               color_P1 = inactiveColor;   }
            else {
               color_P2 = activeColor;
               color_P3 = inactiveColor;
               color_P1 = inactiveColor;    }
            end_peg = 2;    }
         function isLit_P3(eventValue) {
            if (eventValue==true) {
               color_P3 = activeColor;
               color_P2 = inactiveColor;
               color_P1 = inactiveColor;    }
            else {
               color_P3 = activeColor;
               color_P2 = inactiveColor;
               color_P1 = inactiveColor;   }
            end_peg = 3;
         }
```

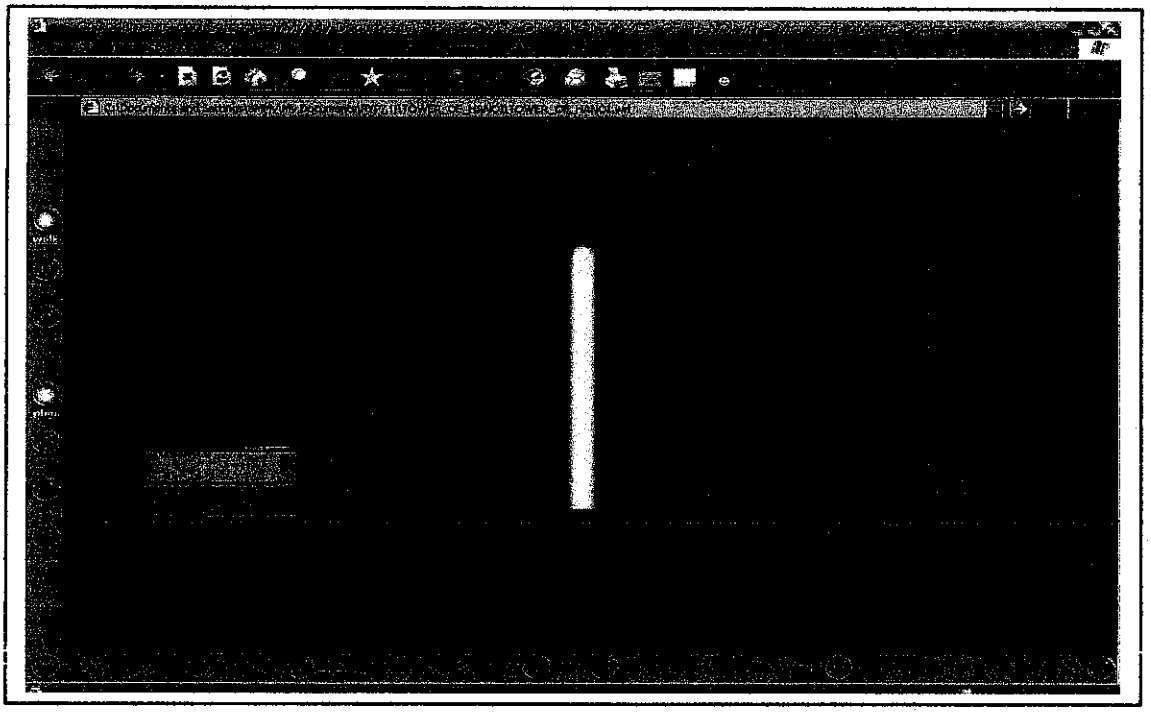


Figure 4.7: The center pole is selected to position a disk

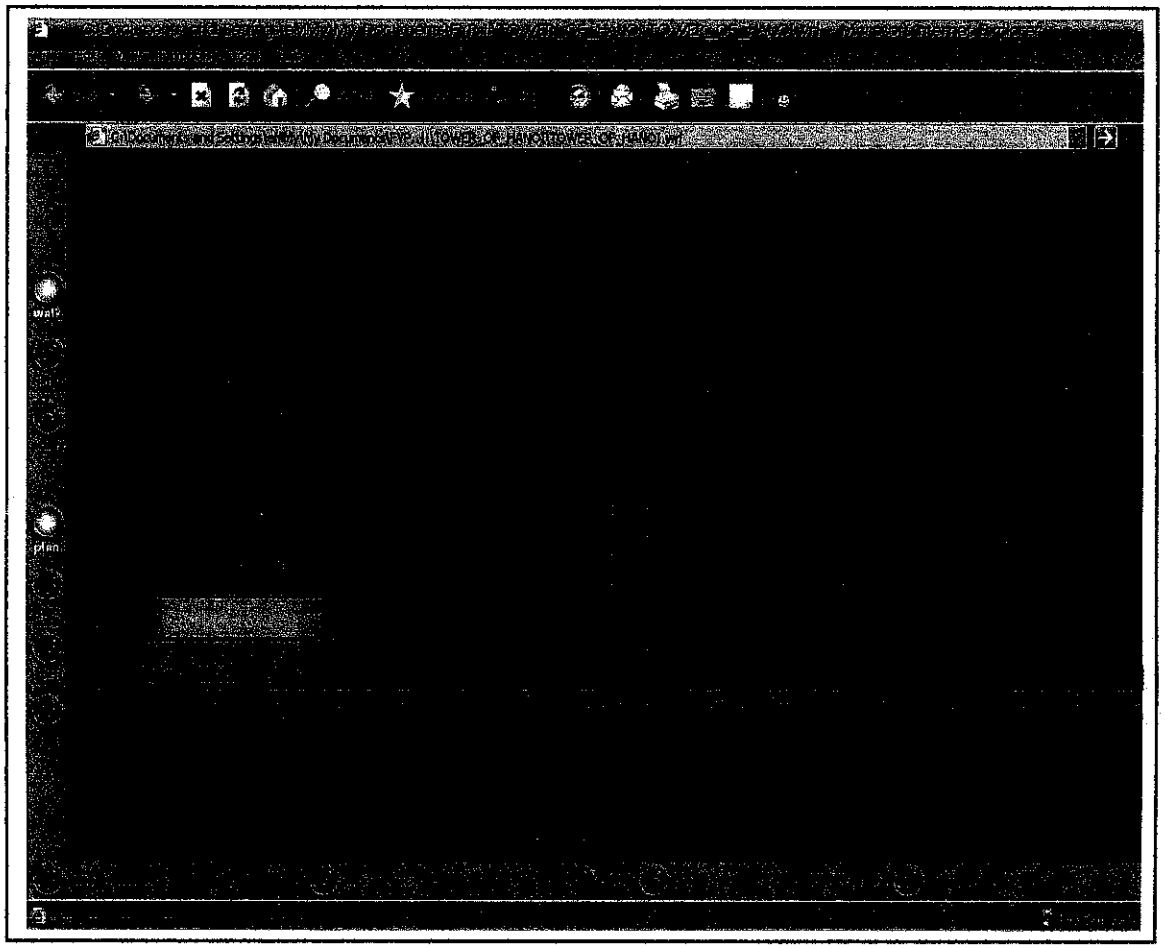


Figure 4.8: Virtual Tower of Hanoi

4.3 Results and Discussion for Testing and Evaluation Phase

In the final section, during the evaluation phase valuable data are collected. In this section the data are converted to statistical data and histogram charts for simplicity to interpret and evaluate.

4.3.1 Evaluation - Perceive assembly task in virtual environment using Tower of Hanoi

In this evaluation, the author intends to perceive the effectiveness of assembly task in virtual environment by implementing it with Tower of Hanoi game. The evaluators are asked to play the Tower of Hanoi game and complete the task of the game and see the efficiency of assembly task in virtual environment using Tower of Hanoi. Table 4.1 below shows the data collected and analyzed from the evaluation phase. The histogram is plotted according to the mean calculated.

	N	Min	Max	Sum	Mean
The difficulty of performing assembly task in virtual environment using Tower of Hanoi	5	8.00	9.00	43.00	8.60
The difficulty of completing the Virtual Tower of Hanoi in time	5	7.00	9.00	41.00	8.20
The effectiveness of performing assembly task in virtual environment using Tower of Hanoi	5	8.00	10.00	45.00	9.00
Level of interest on the Virtual Tower of Hanoi	5	7.00	9.00	41.00	8.20
The probability of virtual environment to become an effective way of doing assembly task	5	8.00	9.00	43.00	8.60
Valid N	5				

Table 4.1: Descriptive statistics for evaluation of the effectiveness of assembly task in virtual environment using Tower of Hanoi

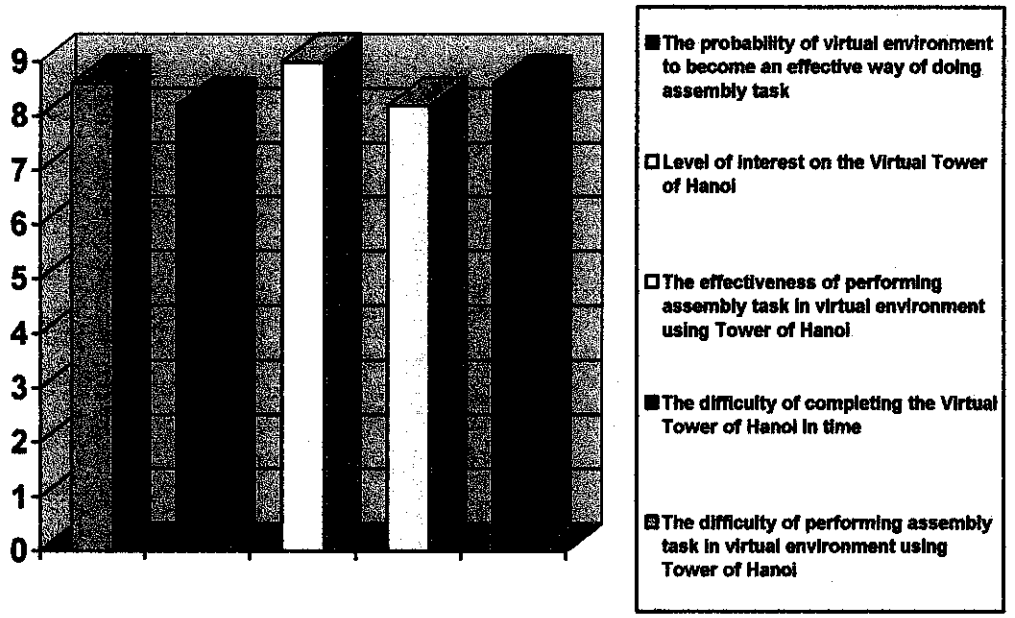


Figure 4.9: Histogram for evaluation of the effectiveness of assembly task in virtual environment using Tower of Hanoi

Features	Mean
▪ The difficulty of performing assembly task in virtual environment using Tower of Hanoi	**8.60**
▪ The difficulty of completing the Virtual Tower of Hanoi in time	**8.20**
▪ The effectiveness of performing assembly task in virtual environment using Tower of Hanoi	**9.00**
▪ Level of interest on the Virtual Tower of Hanoi	**8.20**
▪ The probability of virtual environment to become an effective way of doing assembly task	**8.60**
Mean Overall	**8.52**

Table 4.2: Summary for evaluation of the effectiveness of assembly task in virtual environment using Tower of Hanoi

Hypothesis

The evaluation: Perceive assembly task in virtual environment using Tower of Hanoi

H_O: *Performing assembly task in virtual environment by implementing it using Tower of Hanoi is not effective.*

H_A: *Performing assembly task in virtual environment by implementing it using Tower of Hanoi is effective.*

From the summary table for evaluation of assembly task in virtual environment using Tower of Hanoi, it stated that the **minimum mean** for the evaluation is **8.20** and the **maximum mean** is **9.00**. The **range** for this evaluation is **R = 0.8** and the **mean overall** for this evaluation is **8.52**. This indicates that the range is lesser than the overall mean, **R < M (Overall)** hence the hypothesis is accepted. As a conclusion for the evaluation, the H_A hypothesis is accepted as true, which is

H_A: *Performing assembly task in virtual environment by implementing it using Tower of Hanoi is effective.*

CHAPTER 5
RECOMMENDATION AND CONCLUSION

5.1 Summary of the project

In this project, the author had managed to achieve the initial objectives and successfully developed a strategy game that have applied the task of assembly in a virtual environment entitled 3D Virtual Tower of Hanoi. The author had successfully implemented the appropriate functions and sensors for the user interaction in the virtual environment. Furthermore, from the evaluation that had been conducted, the author found out that the project is capable to intensify the performance of task assembly by experimenting it using the Tower of Hanoi game which utilizes the Virtual Reality and 3D environment.

Moreover, the result from the evaluation also proves that performing assembly task in virtual environment using Tower of Hanoi is effective, when evaluators solve the Tower of Hanoi game. It is shown that the implementation of task assembly in virtual environment is a successful performance altogether and it could be implemented in more applications.

Throughout the accomplishment of this project, the author had learnt most of the functions and sensors for creating 3D objects and making user interaction within the virtual environment. From this, the author had improved her VRML programming language by theoretical and putting it into practice. In addition, the author had also learnt on task assembly and collision detection in a virtual world. Even though the author had faced many obstacles during development, she managed to complete the game on time. Also, the author had learnt and improves the application of new and existing software throughout the completion of the project such as 3D Studio Max and 3D Exploration.

5.2 Recommendation

i) The end product of Virtual Tower of Hanoi could use a better texture for the 3D objects to create high realism and thus make the appearance of the game more appealing. Besides concerning the appearance of the product, the functions and sensors used for the user interaction could be enhanced to avoid complexity of users to perform the assembly task.

ii) The author also advocates particular people who are involved in virtual prototyping to enhance the application of assembly task in virtual environment for beneficial purposes. Besides that, the author aspire gamers to try out more 3D virtual games as it is more attention-grabbing and to utilize the computer advanced technologies.

iii) In the future, students whom are interested to further continue this research paper should create more complex and challenging task assembly in various applications besides games. This is because task assembly can contain many more objects to be manipulated as it can be applied in diverse fields. They could focus their diligence with further user interaction like a better interaction with the components. Apart from that, students can also develop a more challenging and complex game in virtual world that make use of task assembly. The game should be more realistic and let the users feel the immersion of being in a virtual world.

iv) Users should be able to expand the usage of interaction devices in virtual environment projects. VR devices like pinch gloves and Head Mounted Display (HMD) ought to be used to enhance the interaction among users and the 3D environment. Furthermore with these VR devices, the realism for the users when interact with the virtual environment are increased.

5.3 Conclusion

This project had highlighted on the effectiveness of assembly task in virtual environment by implementing it with the Tower of Hanoi game. It also had introduced the new method of constructing an assembly task and a new way to play games which is by using the virtual environment. Essentially, it helps to foster understanding of the VRML codes used to develop the prototype which includes objects and user interaction. This project is to be a benchmark or guideline for designers to venture in depth in the area of task assembly and game applications in virtual environment. This project had also contributed to a small section of the computer graphics and advanced technology world especially in Virtual Reality and 3D environment.

REFERENCES

Books

1. Boothroyd, G. and Dewhurst, P., ***"Product Design for Manufacture and Assembly"***, Marcel Dekker, inc, 1994.

2. Stanney, K. M., and Zyda, M., ***"Virtual Environments in the 21st Century"***, in Stanney, K., ed., *Handbook of Virtual Environments*, Lawrence Erlbaum Associates, New Jersey, 2002.

3. Chris Marrin, Bruce Campbell ***"Teach Yourself VRML2 in 21 Days"***, Indiana, Sams.net Publishing, 1997.

4. Gamma, E,; Helm, R; Johnson, R,; Vlissides, J. ***"Design Patterns: Elements of Reusable Object-Oriented Software"***, Addison-Wesley, 1995.

5. Durlach, N.I. and A.S. Mavor, Eds.. ***"Virtual Reality: Scientific and Technological Challenges"***, Washington, D.C., National Academy Press, 1995.

6. Bloomsbury Publishing Ple, ***"Macmillan English Dictionary***", Radstock, United Kingdom, 2002

Journals and Websites

1. Peterson, B., Boswell, J., and Darken, R., ***"Collaborative Navigation in Real and Virtual Environment"***, Proceedings of I/ITSEC, Orlando, FL, 2001.

2. Wellbrink, J., ***"The Future of Modeling and Simulation"***, DWT-Forum fuer Modellbildung und Simulation [German Simulation Conference], 9/2002

3. Capps, M., ***"Gaming Techniques for Building Compelling Virtual Worlds"***, course offered at SIGGRAPH 2001, Los Angeles, July 2001

4. Zyda, M., ***"The Future of Modeling, Virtual Environments & Simulation"***, IITSEC 2001, Orlando, Florida, Nov. 29, 2001

5. Oliveira, M,; Crowcroft, J.; Slater, M. ***"Component Framework Infrastructure for Virtual Environments"***, Proceedings of the ACM Collaborative Virtual Environments Conference, 2000.

6. Tower of Hanoi DHTML Game
www.newbedford.k12.ma.us/elementary/gomes/stjohn/Kidsgames/towerhanoi.htm

7. VITAL – Investigation of Task-Performance for Interaction within a Virtual Environment for Assembly
www.informatics.leeds.ac.uk/pages/03_research/rp_vitali.htm

8. Development of an Immersive Assembly and Maintenance Environment
www.nicve.salford.ac.uk/~norman/VRAP2003.pdf

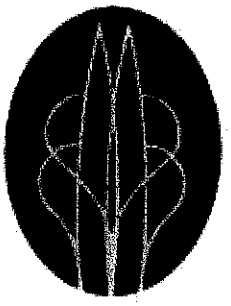
9. Virtual Assembly using Virtual Reality Techniques
www.mel.nist.gov/div826/library/doc/cadtech95.pdf

10. Integration of Virtual Reality based Assembly Simulation into CAD/CAM Environments
www.rz.rwth-aachen.de/vr/papers/IECON98.pdf

11. Research
http://web.bham.ac.uk/A.C.Boud/Research.html

APPENDICES

Appendix A



UNIVERSITI
TEKNOLOGI
PETRONAS

INITIAL SURVEY FORM
FOR
EVALUATORS

valuation is for Final Year Project: Virtual Tower of Hanoi
answer as appropriate. Your cooperation is highly appreciated.

INITIAL SURVEY FORM

Please answer as appropriate. Your cooperation is highly appreciated.

Name (optional): _____ Date: _____

Age: _____ Gender: _____

1. Are you aware of applications based on Virtual Reality?

   ☐ Yes

   ☐ No

2. How do you rate 3D Virtual Reality games?

   Not enjoyable | Less enjoyable | Neutral | Enjoyable | Very enjoyable

   |_____|_____|_____|_____|

3. What genre of strategy games are you most interested?

   ☐ Action-adventure ☐ Race

   ☐ Puzzles ☐ Sims

   Others (please specify): _____

4. What is your preferable way of playing the strategy game?

   ☐ Board games

   ☐ 2D computer games

   ☐ 3D virtual reality game

   Others (please specify): _____

5. Are you familiar with Assembly Task?

   ☐ Yes

   ☐ No

6. If yes, do you think it is effective to perform an assembly task in virtual environment?

   ☐ Yes

   ☐ No

7. Are you familiar with Tower of Hanoi game?

   ☐ Yes

   ☐ No

8. If yes, how do you rate Virtual Tower of Hanoi?

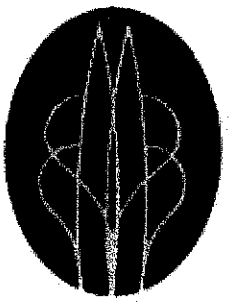
   Not interesting Less interesting Neutral Interesting Very interesting

9. Would you prefer to play Tower of Hanoi in 3D virtual environment?

   ☐ Yes

   ☐ No



UNIVERSITI
TEKNOLOGI
PETRONAS

EVALUATION CHECKLIST FOR EVALUATORS

valuation is for Final Year Project: Virtual Tower of Hanoi
answer as appropriate. Your cooperation is highly appreciated.

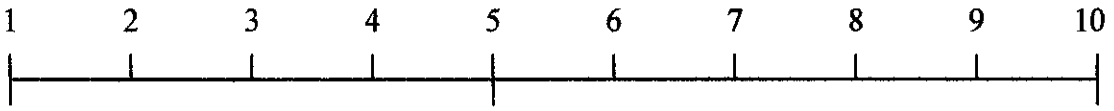
EVALUATION CHECKLIST

Please answer as appropriate. Your cooperation is highly appreciated.

Name (optional): _____ Date: _____

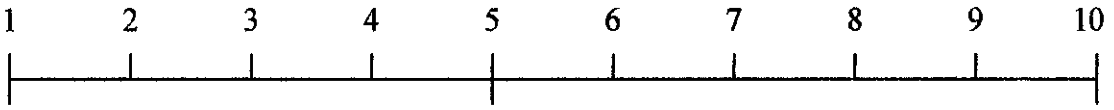
Age: _____ Gender: _____

The difficulty of performing assembly task in virtual environment using Tower of Hanoi



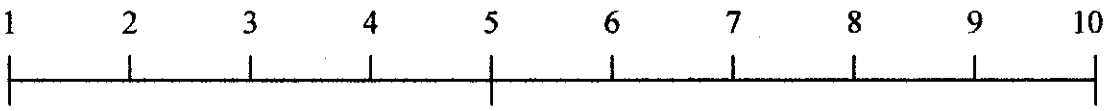
Very difficult Moderate Not difficult

The difficulty of completing the Virtual Tower of Hanoi in time



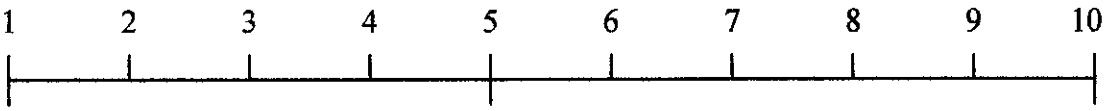
Very difficult Moderate Not difficult

The effectiveness of performing assembly task in virtual environment; by the means of Tower of Hanoi



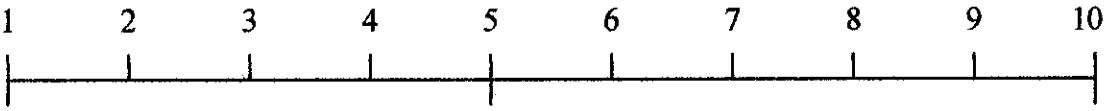
Not effective Moderate Very effective

Level of interest on the Virtual Tower of Hanoi



Not interested Moderate Very interested

The probability of virtual environment becoming an effective means to do task assembly



No probability Moderate High probability

Raw Statistics of Evaluation Checklist

		The difficulty of performing assembly task in virtual environment using Tower of Hanoi	The difficulty of completing the Virtual Tower of Hanoi in time	The effectiveness of performing assembly task in virtual environment using Tower of Hanoi	Level of interest on the Virtual Tower of Hanoi	The probability of virtual environment to become an effective way of doing assembly task
	Valid	**5**	**5**	**5**	**5**	**5**
	Missing	**0**	**0**	**0**	**0**	**0**
Min		**8.00**	**7.00**	**8.00**	**7.00**	**8.00**
Max		**9.00**	**9.00**	**10.00**	**9.00**	**9.00**
Range		**1**	**2**	**2**	**2**	**1**
Mean		**8.60**	**8.20**	**9.00**	**8.2**	**8.6**
Sum		**43**	**41**	**45**	**41**	**43**

1. The difficulty of performing assembly task in virtual environment using Tower of Hanoi

Valid		Frequency
	8	2
	9	3
Total	17	5

2. The difficulty of completing the Virtual Tower of Hanoi in time

Valid		Frequency
	7	1
	8	2
	9	2
Total	24	5

3. The effectiveness of performing assembly task in virtual environment using Tower of Hanoi

Valid		Frequency
	8	1
	9	3
	10	1
Total	27	5

4. Level of interest on the Virtual Tower of Hanoi

Valid		Frequency
	7	1
	8	2
	9	2
Total	24	5

5. The probability of virtual environment to become an effective way of doing assembly task

Valid		Frequency
	8	2
	9	3
Total	17	5