Stereoscopic Displays: Factors Affecting Realism

by

Ayuni bt Ayatillah

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Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Technology (Hons)
(Information and Communication Technology)

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CERTIFICATION OF APPROVAL

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Approved by,

(Assoc. Prof. Dr. Abas Bin Md Said)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
May 2006

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 reference and acknowledgements, and that the original work contained herein has not been undertaken or done by unspecified sources or persons.

AYUNI BT AYATILLAH

ABSTRACT

This paper presents the final outcome of the Final Year Project entitled Stereoscopic Displays: Factors Affecting Realism. The term "Stereoscopic Displays" refers to the stereoscopic technology that is being used in Virtual Reality in order to project a realistic image. The aim of the study is to find out the factors that affect the realism of the projected image in stereoscopic displays as well as to identify image parameter that gives the most impact to user's depth perception of a 3D scene. The study is done by undertaking intensive research from previous literatures, and then carrying out an experiment to determine the parameters that gives the most impact to the depth perception of user. By knowing which parameters that affects the depth perception the most, it can be useful in designing an application that will project a quality 3D image, which will therefore increase the realism effect and then also increases the sense of presence in the users. The research has found out that the factor that affects the realism revolves around on the technical and the human issues. The experiment have been focusing on the testing of 4 parameters, which are motion cues, number of edges on objects, background brightness and distances of objects from the user. From there it has been proven that motion cues, background brightness and distances of objects from user have a positive impact on the depth perception, while the number of edges on the objects is proven to have an impact, but the extent of its effect is inconclusive. As a conclusion to the study, the author believes that this study is only complete at a preliminary level, and still needs continuation to further support the findings that have been made.

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In the name of ALLAH, the most merciful.

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ABBREVIATIONS AND NOMENCLATURES

FYP	Final Year Project
UTP	Universiti Teknologi PETRONAS
3D	3Dimension
2D	2Dimension
VR	Virtual Reality
CRT	Cathode Ray Tube
PC	Personal Computer
HMD	Head Mounted Device
HTD	Head Tracking Device
IVR	Immersive Virtual Reality
CGI	Computer Generated Imagery
VE	Virtual Environment
GFOV	Geometric Field of View
HVS	Human Visual System
FOV	Field of View
VDS	Visual Display System
LCD	Liquid Crystal Display
OPENGL	Open Graphics Language
Exp	Experiment

CHAPTER 1
INTRODUCTION

1.1 BACKGROUND OF STUDY

Stereoscopic display is one of the essential capabilities being used in Virtual Reality (VR). This term is associated with the projection of virtual environment to the users, and it is generated based on the natural system of human eyes, which is the stereopsis. In the context of virtual reality, a stereoscopic display is one of the essential technologies that are being used to achieve the sense of presence from the virtual environment.

To understand the stereoscopic imaging technology, it is vital to first understand the concept of stereopsis in the human eyes. Stereopsis is also known as 3D vision or binocular vision. Wikipedia[1] defines stereopsis as the process in visual perception leading to perception of the depth or distance of objects. It comes from two Greek roots, stereo meaning solidity, and opsis meaning vision or sight. That means it could refer to any sort of visual depth perception, but since about the 1960s it has come to refer to depth perception from binocular vision, requiring two eyes. Prior to then, it was often referred to as "binocular stereopsis". It is the remarkable power of the visual sense to give an immediate perception of the third dimension, which is depth. It exists in those creatures with overlapping optical fields, acting as a range finder for objects within reach [2]. Stereopsis works as each eye captures its own view and the two separate images are sent on to the brain for processing .When the two images arrive simultaneously in the back of the brain, they are united into one picture. The mind combines the two images by matching up the similarities and adding in the small differences. The small differences between the two images add up to a big difference in the final picture. With stereo vision objects can be seen as solid in three spatial dimensions--width, height and depth--or x, y and z [3].

This concept is then being applied in stereoscopic imaging. Stereoscopic imaging basically is any technique capable of recording three-dimensional visual information or creating the illusion of depth in an image. In virtual reality, stereoscopic is being applied in hardwares to generate 3D images. The hardwares that produce such images range from the simplest to the most extensive systems. Below is a chart that represents the ranges of stereoscopic hardwares systems that are being used in stereoscopic projection.

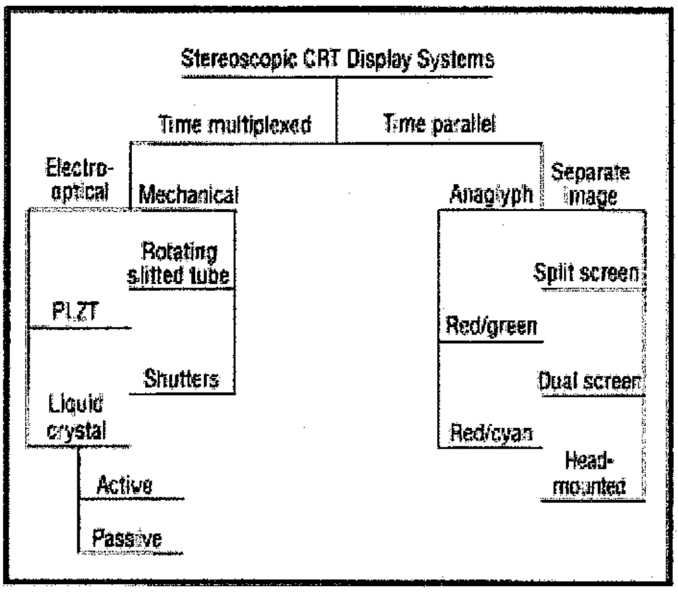


Figure 1.1 Types of stereoscopic CRT Display System [4]

Basically the system falls into two major categories, which is the Time-Multiplexed and Time Parallel. The popular system used in VR are Liquid Crystal (StereoGraphics Crystal Eyes) and also Head Mounted systems (HMDs, HTDs).Owing to rapid advancements in computer graphics and the continuing miniaturization of video and other equipment these devices are beginning to become available at more reasonable cost.

However, there is a simple and cost-effective system that can be used to view stereoscopic images. The system is called Anaglyphs, which is the use of special glasses that filters the images and sends them to the brain to be processed. This system will be the focus of the study for this project.

1.2 PROBLEM STATEMENT

It is agreed and proved that stereoscopic displays can be used in Virtual Reality for creating a realistic display to the user. It is aimed that from the projection, the sense of presence can be felt by the user and makes them feel the immersiveness of the application. However, this feeling depends on the degree of the realism that the display can achieve. In order to project a realistic and high quality virtual image, it is crucial to know the factors that affect the realism of the images. This is measured from the user's degree of depth perception that can be obtained from the projected image. By knowing this, it can help designers of virtual application to enhance the images and therefore leads them one step closer to reach the goal of a virtual application.

1.3 OBJECTIVES

The objectives of this project are:

- To find out the factors that affects the realism of the projected image in stereoscopic displays
- To identify image parameters that gives the most impact to user's depth perception of a 3D scene

1.4 SCOPE OF STUDY

The scope of the project is on Anaglyphs stereoscopic display system, using glasses with Red and Green filters. The images projected is developed on a standard PC and projected on a standard CRT. Researches and system development is done using facilities provided in UTP and also private equipments. Findings are presented in forms of visual aids and explanations.

CHAPTER 2
LITERATURE REVIEW

2.1 VIRTUAL REALITY, REALISM AND PRESENCE

Virtual Reality is a synthetic environment that is designed with the intention to provide experience to the users about an abstract location, real world location or even a non existent world. Myeung-Sook Yoh (2001)[5] has stated that virtuality is itself a bona fide mode of reality and that "virtual reality" must be understood as "things, agents and events that exist in cyberspace". Virtual reality has the following constructive features:

- it is both abstracted material and objectified mind through digital technology,
- it is the ultimate media, which coincides with its own message,
- it is a new emergent mode of reality in its own right, that comes together with actual reality to construct an extended world of human experience.

Virtual reality (VR) represents a new approach to the way people interact with computers. The goal is to replace current indirect interaction techniques, through the use of keyboard and pointing devices such as a mouse, with direct interaction, through movement, pointing, touching, speech and hearing. The roots of modern VR can be traced to the work of Ivan Sutherland, who in 1965 envisioned the "Ultimate Display," a system where computer-generated images would behave like their real-world counterparts. This "display" would involve all five senses, as the real world does. This vision has led to active research and development efforts, and to imaginative speculation in the popular media.

Virtual reality has been known to be related to realism and presence. A sense of presence is a sense of being there in the virtual environment, and in order to create a sense of presence, realism must be achieved. Myeong-Sook Yoh (2001) [5] also has presented that while the content of reflective experiences resides only in mind, in the case of sense experience, external objects that caused the sensation exist independently from mind. The external objects have qualities as a power to cause the ideas, and the primary qualities are ascribed to objective physical entities. In terms of the fact that this theory admits the reality of physical entities and also it refers to the intrinsic and extrinsic causes of experiences, Locke's representative realism could be considered as a background theory for clarifying the virtuality of the virtual reality.

Ijsselsteijn (2001) [6] states that the concept of presence has relevance and implications for the design and evaluation of a broad range of interactive and non-interactive media.

When planning a visualization strategy, ensuring that the information presented is perceived in the most accurate way possible should be the ultimate design goal. Thus, it is essential that designers and communicators strive to understand how each and every aspect of the visualization contributes to the achievement of that goal. The quality and degree of presence generated in an IVR are important components of such a visualization strategy for two reasons: First, the feeling of being there should enhance a subject's perception of visual stimuli, thus improving the effectiveness of visualization. Second, presence should ease the cognitive load with processing visual stimuli, by reducing the need to fill in the blanks or filter out external environmental data that may be necessary to sustain disbelief and engage with the virtual environment.(Withers, 2005)[7]

From these literatures it is understood that realism, presence and virtual reality has a vital connection between each other.

2.2 STEREOSCOPIC DISPLAYS AND DEPTH PERCEPTION

Generating 3D images is often related to depth perception (stereopsis) that creates the stereoscopic display technology.

Wartell, Hodges and Ribarsky (1999) [8] have included in their study that virtual environments aim is to perceptually place the user in an artificial computer-generated world. A key component of this illusion is interactive 3D imagery. To create a 3D imagery, the concept of stereopsis is the key thus creates stereoscopic displays. This stereoscopic imagery provides a true 3D image so virtual objects appear to float in front of and behind the physical display surface. Stereoscopic display for virtual reality has been shown to improve user depth perception and task performance in a variety of tasks. This is not surprising since real world experience shows that stereopsis is an important especially for objects within the user's personal space (1.5 meters).

Stereoscopic displays are increasingly being used for both professional and entertainment purposes. A number of studies have shown that 3D stereoscopic images have a greater psychological impact, e.g., enhance the viewers' sense of presence, and provide better picture quality than conventional 2D images. (IJsselsteijn, Ridder, Vliegen, 2000)[6]

Depth Cue Theory is the main theory of depth perception. It states that different sources of information, or *depth cues,* combine to give a viewer the 3D layout of a scene. This theory asserts that there are some basic sources of information about 3D layout. These are generally divided into three types: *pictorial*, *oculomotor* and *stereo* depth cues. *Stereopsis*, or the use of the *binocular disparity depth cue*, is the process by which the angular disparity between the images in the left and right eye is used to compute the depth of points within an image. In modern day immersive systems, stereo display is believed to contribute to a sense of presence. Despite the continuing popularity of stereo presentation, its use in 3D CGI is often questioned. As a result, binocular disparity has been studied more than any other depth cue with respect to CGI.

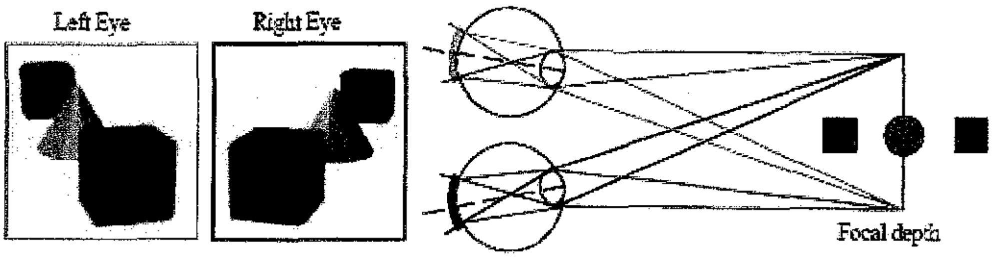


Figure 2.1 Binocular and oculomotor depth cues. The images on the left show the left and right eye views resulting from a binocular view of the scene shown in plan view on the right. Oculomotor information results in the depth of focus shown in the images, where the green cone is in focus and the red and blue cubes are not.
(J.D Pfautz, 2002)[9]

2.3 ISSUES CONCERNING IMAGE PROJECTION

In designing visual displays, there are parameters that need to be taken into consideration to produce a quality display. Researches have been done to relate the parameters and their abilities to project visuals that adhere to the concept of virtual reality. Sherman and Craig [10] have outlined the Visual Presentation properties of Visual Displays in VR which are:

- Colour
- Spatial Resolution
- Contrast
- Brightness
- Number of display channels
- Focal Distance
- Opacity
- Masking
- Field of View
- Field of Regard

IJsselsteijn, Ridder, Freeman, and Avons [11] have reported in their studies that the determinants of presence is includes the extent and fidelity of sensory information. Systematic research into the causes and effects of presence has only recently started, but a large number of factors that may potentially influence the sense of presence have already been suggested in the literature. Although the terminology used tends to vary across authors, there appears to be a broad agreement on the major concepts. Based on various theoretical analyses, the factors thought to underlie presence include:

i) The *extent and fidelity of sensory information* - this is the amount of useful and salient sensory information presented in a consistent manner to the appropriate senses of the user. This includes Steuer's notion of' vividness', i.e. the ability of a technology to produce a sensorially rich mediated environment. Note that this category can apply to both interactive and non-interactive media. Examples from this category are monocular and binocular cues to spatial layout, resolution, field of view, or spatialized audio.

ii) The *match between sensors and the display* - this refers to the sensory-motor contingencies, i.e. the mapping between the user's actions and the perceptible spatio-temporal effects of those actions. For example, using head tracking, a turn of the user's head should result in a corresponding real-time update of the visual and auditory display.

iii) *Content factors* – this is a very broad category including the objects, actors, and events represented by the medium. Our ability to interact with the content and to modify it, as identified by Sheridan, is also likely to be important for presence. Other content factors include the user's representation or virtual body in the VE, and the autonomy of the environment, i.e. the extent to which objects and actors (e.g. agents) exhibit a range of autonomous behaviours. Social elements, such as the acknowledgement of the user through the reactions of other actors, virtual or real, will be important for establishing a sense of social presence. The nature of the potential task or activity, as well as the meaningfulness of the content has been suggested to play a role as well.

iv) *User characteristics* are likely to play a significant role as well, but have received little attention thus far. Such characteristics include the user's perceptual, cognitive and motor abilities (e.g. stereoscopic acuity, susceptibility to motion sickness, concentration), prior experience with and expectations towards mediated experiences, and a willingness to suspend disbelief. Allocating sufficient attentional resources to the mediated environment has also been proposed as an important component of presence. Relevant individual characteristics will probably vary with the age and possibly with the sex of the user. Huang and Alessi point out that various mental health conditions, like depression, anxiety, or psychotic disorders, are also likely to affect an individual's sense of presence, since they are known to have a clear effect on how people experience the world around them.

Factors i) and ii) may be regarded as *media form* variables that are aimed at making the medium as transparent as possible, thereby creating the illusion of non-mediation. To create and sustain this illusion, distractions and negative cues to presence should be avoided. An awkward interface will stress the mediated nature of the experience and may diminish the sense of presence. Examples of such negative cues include: bad stereoscopic alignment (causing eye strain), coding distortions in the image (e.g. visible blockiness or noise), weight of a head-mounted display, process interruptions (e.g. 'new mail has arrived', malfunctions, error notices), noticeable tracking lags, low update rates, stereo/occlusion conflicts, etc.

In Hendrix (1994) [12] literature, she has stated that Slater and Usoh (1993) has distinguished between external and internal factors which may contribute to a participant's sense of presence in virtual computer-generated environments. External factors of presence might include such determinants as technologies used to display virtual environments, parameters used to design the display, as well as perceptual cues used to emulate human interaction in the real world. Internal factors, on the other hand, deal with how an individual's experiences in the virtual world are processed internally. In the thesis, three experiments have been done to study the sense of presence as a Function of Visual and Auditory Display Parameters in Virtual Environments. The variables for the first experiment included the presence or absence of head tracking, the presence or absence of stereoscopic cues, and the geometric field of view (GFOV) used to design the visual display. The results showed that the GFOV used to design the visual display highly influenced the reported level of presence, with more presence associated with a 50 and 90 degree GFOV when compared to a narrower 10 degree GFOV.

According to Pfautz (2002): [9]

The depth perception in 3D images is generated from 3 types of depth perception which is the pictorial, occulomotor and stereo depth cues. All the depth cues discussed above are combined by the HVS to give a sense of 3D layout. In general, the more cues presented, the better the sense of depth (Figure 2.5). In CGI, carefully chosen geometric enhancements can reduce the ambiguity of pictorial depth cues [Ellis 1993]. However, the best way to disambiguate pictorial depth cues is to present stereo depth information. Some cues dominate others in certain situations [Cutting & Vishton 1995]. For example,a person threading a needle primarily uses stereo cues to determine the location of the end of the thread and the eye of the needle, and usually brings the objects close to the eyes to increase the accuracy of stereo and occulomotor cues. However, a submarine pilot is unlikely to use stereo or occulomotor cues to determine the distance to a far-off buoy, instead relying on multiple pictorial depth cues [Pfautz 1996]. An important criterion for the dominance of one cue over another is the distance from the viewer to the objects of interest.

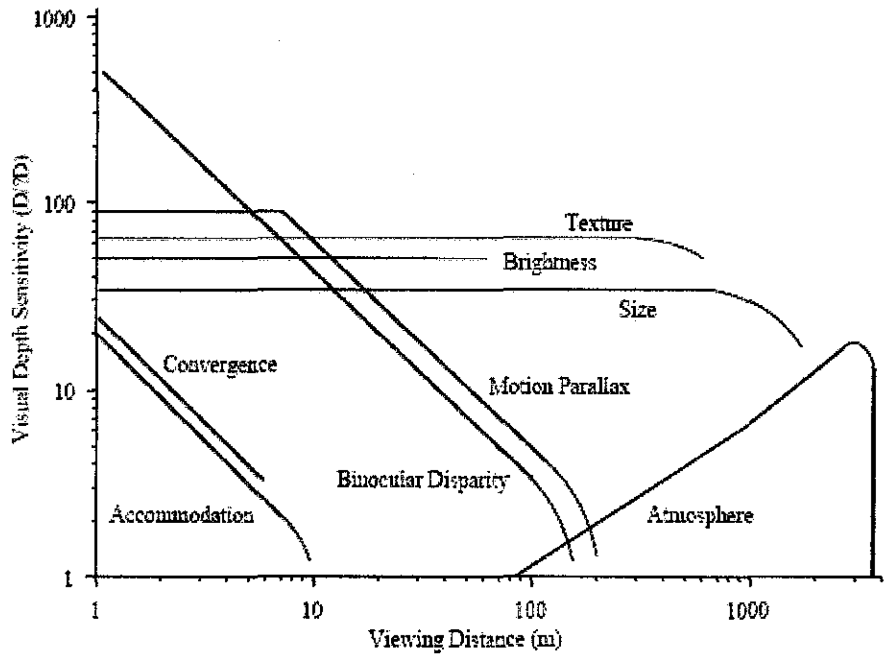


Figure 2.2 The effectiveness of depth cues as a function of distance [9]

Some depth cues are more accurate at closer distances. Cutting and Vishton [1995] classify types of depth perception in *personal*, *action* and *vista* zones and evaluates various depth cues in these spaces.After occlusion, they rank linear perspective as the most effective across all viewing zones. They also note that binocular and oculomotor cues decrease in value with increased viewing distance.

In 3D CGI, increasing the displayed depth (i.e., the depth of the object according to the various depth cues shown in the scene) decreases the effectiveness of some depth cues [Surdick et al. 1994]. Linear perspective and stereo cues are among the most effective over a range of displayed depths [Surdick etal. 1994; Wanger, Ferwerda & Greenberg 1992]. Other cues, like luminance or contrast, have comparatively little effect [Hone & Davies 1993].

The display parameters that affect the computer generated images are:

- **Field-of-View:** The visual angle subtended by the display surface
  Increasing the FOV is linked to an increase in the subjective sense of presence. The decision to increase a VDS FOV is often based on the argument that closely matching the human FOV improves the sense of immersion. The decision to increase a VDS FOV is often based on the argument that closely matching the human improves the sense of immersion.
- **Spatial resolution:** The number, angular size and spacing of the pixels.
  Increased resolution causes images to appear clearer, sharper and more in-focus.
- **Refresh rate:** The frequency with which the display hardware can draw the image on the display surface.
- **Frame rate:** The frequency with which the image can be rendered into the frame buffer (i.e., the rate at which a new, updated scene is prepared for drawing to the screen)
- **Stereo image presentation:** Presenting binocular disparity information by displaying separate images for each eye.

Jean Hsu et al. [13] in their studies have outlined the specific issues that arise in the design of studies to determine the effectiveness of digital stereo imagery. The issues that need to be considered are:

- Viewing Conditions
- Ghosting and Flicker
- Subject Stereoacuity
- Image Intensity Differences
- Practice
- Feedback

- Fusible Stereo Pairs
- Image Generation
- Reading Order Effects
- Degree of Difficulty of the Discrimination Task
- Speed/ Accuracy Trade-off

A paper that is written by Paul Bourke[14] discusses the essential issues that need to be considered when creating stereoscopic images that will go easy on the eyes, therefore increases the chances for the user to experience more realism in the images. In his discussion, it is assumed that the correct stereo pairs have been created, that is, perspective projection with parallel cameras resulting is the so called off axis projection. However, it should be noted that not all the issues are hard and fast rules and they may be inherent in the type of image content being created. The issues are:

- Ghosting
- High Contrast
- Screen Border
- Occlusion by other viewers
- Motion Cues
- Vertical Structure
- Parallax / Structure Interference
- Noisy Texture
- Mirror Reflections
- Positive Parallax
- Focal Distance Changes

2.4 ANAGLYPHS

As the project will be using Anaglyphs as a means to create stereoscopic image, the author have done some research to understand how the hardware works.

Doneus and Hanke[15] have categorized anaglyphs into a mixed image system, whereby both pictures of the stereopair are put together into a single image. Viewing the images, the eye scan comfortably be converged and accommodated as they are used to. However, both parts of the mixed image have to be separated. This is usually done by filtering the light coming to the viewer's eyes using spectacles. If both images are looked at without filters, the viewer will get a blurred instead of a stereoscopic impression.

Anaglyphic system caters to this condition that is why it is categorized into the mixed image category. In anaglyphs, the left image is drawn in red and the right in cyan (or green) colour or projected using a red and cyan (or green) filter. If the viewer then looks at the mixed image through a cyan-filter in front of his right and a red-filter in front of his left eye, each complementary coloured image is filtered away. This results in a stereoscopic view, where each part of the stereo pair is viewed only by the corresponding eye.

Another study by A.J Woods [16] explained that anaglyphs uses colour to separate the two perspective views. Usually the left perspective image is displayed in the red channel of the display and the right perspective image is displayed in the blue and green channels of the display. The observer(s) wears glasses with the left lens red and the right lens cyan or green. Other combinations of colour primaries are also possible.

Using anaglyphs comes with a few advantages and disadvantages. This needs to be realized by the author because from here it can be seen what controls that the author has over the system, whether it can be adjusted accordingly or it is some limitations that needs to be accepted.

Canada Centre for Remote Sensing [17] website states that although anaglyphs are inexpensive; this method has some inherent limitations. The source data is limited to black and white imagery. Colour imagery results in ghost effects on an anaglyphic image. Applying red and green (or blue) filters to the original imagery causes light loss. This in turn causes some information to be lost. The red and green glasses may also cause eye fatigue, especially when viewed in a prolonged time.

Doneus and Hanke[15] states that the advantage of anaglyph is that it can be produced easily on all kind of media. The viewing devices are very cheap and can be produced by anybody. The disadvantage lies in the limited possibility of viewing coloured3D-models and in a considerable light loss.

A.J Woods [16] states that anaglyph method is widely used because it is compatible with all full colour displays, however the quality of the perceived stereoscopic image is relatively poor as compared to other stereoscopic methods and truly full-colour stereoscopic images cannot be achieved using anaglyph. A recent study revealed that anaglyph image quality was dependent upon the spectral colour purity of the display and the glasses. The study ranked the following displays from best to worst for anaglyph image quality: 3-chip LCD projector, CRT display, LCD display.

Therefore, based on these studies, the author has decided to use a Red and Green anaglyphs for the purpose of the project and project the image on a standard CRT display.

CHAPTER 3
METHODOLOGY AND PROJECT WORK

Generally, the procedure of the project is being carried out in 2 major phases, which is in the FYP 1 and FYP 2 semester. The duration of the project is 2 semesters; therefore the author has divided the procedure of work according to the semesters. Roughly the first semester is to carry out the requirements and research work, while the second semester is to carry out the system development and experimentation. A more detailed explanation of the methodologies is provided more in this section. Below is the methodology flowchart of the project.

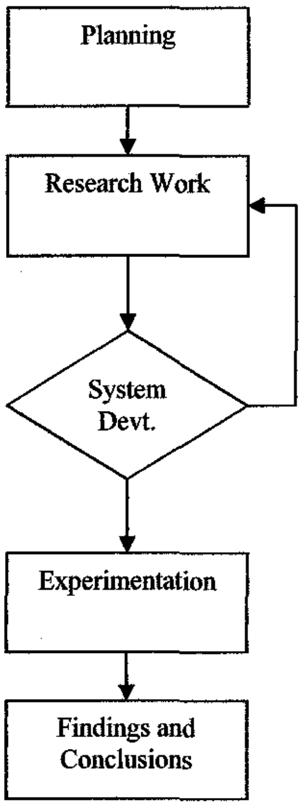


Figure 3.1 Methodology Flowchart

3.1 PLANNING

This phase involves the planning of how to carry out the project. It includes the identification of the data and information that is need to be researched and the relevant previous studies that has been done. This phase also involves the outlining of the project objectives, problem statement and scope of study. The possible tools and equipments are also identified in this phase.

3.2 RESEARCH WORK

In this phase, the author has focused on doing research work about stereoscopic technology and understanding the overall concept. It also involves the research about the factors that has been affecting the projection of stereoscopic, and its relations with realism and presence in VR. Information is gathered from previous works that has been done by scholars and also information from the Internet, journals and books. This phase is one of the essential phases of the project, because the system development and experimentation is done based on the findings in this phase. Theoretically the phase is being carried out during the first semester, but practically it is done throughout the duration of the project. This is because the author needs to refer to many literatures and information throughout the whole period of the project.

3.3 SYSTEM DEVELOPMENT

System development is done mostly during the second semester of the project. The development is heavily based on the research that has been done earlier. That is why in the flowchart this phase has a connection with the Research Work node.

3.3.1 Application Development Tools and Hardware

Basically the system is an application that is developed using **Microsoft Visual Basic.NET** and uses the **C++** language with **OpenGL** as the graphics engine. The reason why the author chooses OpenGL is because it provides vast options for graphics programming; by using the libraries or even independent object modelling. Plus, the author also already has an exposure of how to use the engine from lessons learned in core courses. Besides the computer, the hardware that is being used in this project is the Anaglyph with Red and Green filters.

3.3.2 Application Coding

For the application, the author actually does not develop from a scratch. From the research, the author has found out a useful sample code that can be used as a guide and kick-start to develop the application. The code was originally written by Walter Vannini[18], but is freely distributable without licensing fees and is provided without guarantee or warrantee expressed or implied. From there, the user has done modifications to cater to the system requirement. Vannini's sample code is really helpful in terms of the programming of the stereo rendering, and the author has taken some time to understand the coding before doing modifications. Most of the modifications have been done in the scene rendering.

For the stereo rendering, the application makes use of the function glColorMask. glColor Mask is a function that enables the masking of color buffers, thus enables to apply layers of RGB colors to the objects. By applying two layers of glColorMask, which is Red and Green, when the image is viewed using Anaglyphs, the colors will be filtered by the respective color filters for each eyes and then generates the depth perception. In other words, glColorMask is used to control the update of the red and green channel.

The projection that is being used in this application is the perspective projection. The function glFrustum is used to setup two different view frustums for each eye based on eye separation value. Eye separation is the value that corresponds to the ability of the eyes to focus on different images before sending it to the brain to be processed.

For the scenes, the author has made use of the keyboard keys to switch from one scene to another. Below is the table of keyboard functions and its scenes:

Keyboard Functions	Scene
1	Two objects without movement
A	Two objects with movement
2	One object without movement
B	One object with movement
3	Cube
C	Sphere
D	Dodecahedron
4	High Brightness
5	Low Brightness
6	Three icosahedrons with different distance from users

Table 3.1 Keyboard functions and Corresponding Scenes

Each scene has its own attributes and is used for the purpose of experiments. Each scene is also meant to represent different conditions and is expected to give different perspective to the subjects. The procedure of experiment will be explained in the next section.

3.4 EXPERIMENTATION

This phase involves the experimentation activity that is done using the system that has been developed.

3.4.1 Subjects

The subjects for this test were 10 young adults (19-22 years old), mainly science students from areas of studies that is not specifically related to the current work area. None of them has long term experience with stereoscopic displays in the past.

3.4.2 Apparatus

The experimental environment was based on a computer workstation that is able to run the application. The subjects are seated in front of the monitor while viewing the application through an anaglyph glasses. The external conditions (lighting conditions, viewing distance and viewing direction) are kept constant as experiment is done in the same place and in the same workstation. The anaglyph is a glasses that has Red and Green filters, and the application is also programmed to project Red and Green to the respective filters. Figure below illustrates the experimental apparatus.

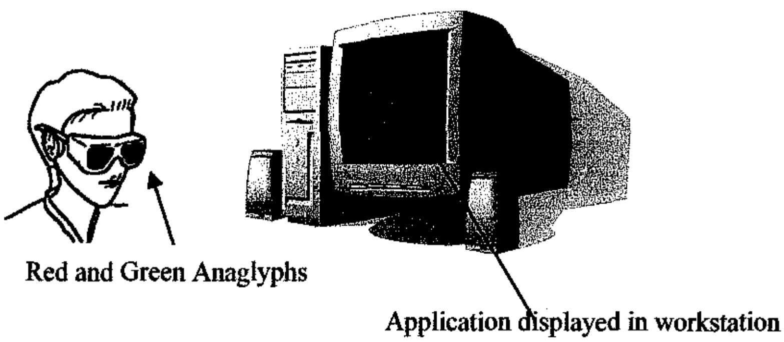


Figure 3.2 Experimental Apparatus

3.4.3 Experimental Procedure

The procedure of experiment is a simple view-and-comment method. The subjects are asked to sit in front of the monitor and view the scene that is given one at a time. Then they are asked to answer the questionnaires related to the scene that they are viewing. The author also acts as a facilitator during the experiment whereby their side comments are stated down and their enquiries are answered. They are allowed to rest for a moment during the experiments to prevent them from eye fatigue.

The first step is to let the user sit down and view the objects with the anaglyphs to make them more familiar with the apparatus. Then the users are given one scene at a time for them to evaluate. Each attributes that is being experimented is considered as one separate experiment.

A) Experiment 1: Movement

This experiment is to see whether the introduction of movement enhance or disturb the perception of depth of the specified objects. For this experiment, users are exposed to 2 categories of scene, one for 2 objects and another for a single object. The movement that is applied to the object is the rotation of the Z-axis and it is moving in an idly manner (continuous). The function IdleFunc() is used in the coding to enable this.

Constants: Object type, size, positioning, colour

Variables: Movement, depth perception

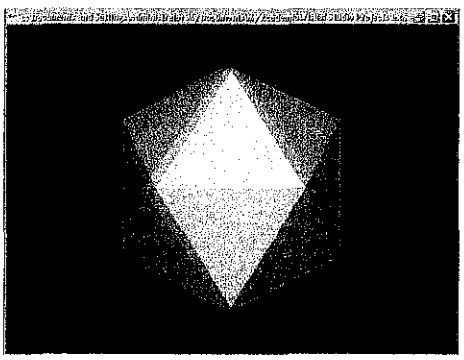


Figure 3.3 (a) Single object without movement

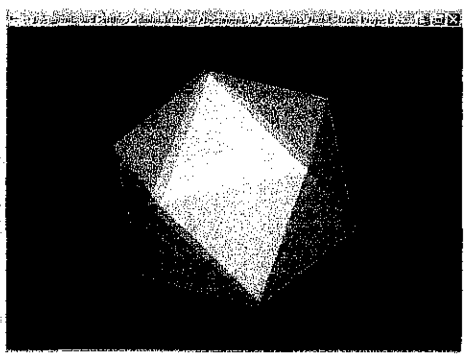
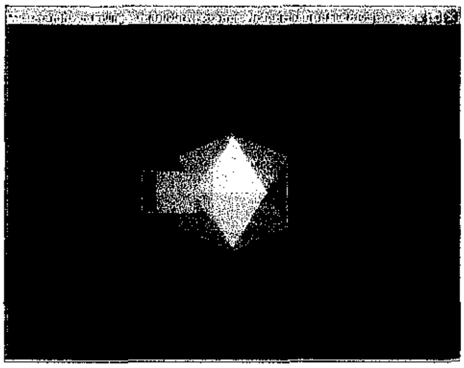


Figure 3.3 (b) Single object with movement



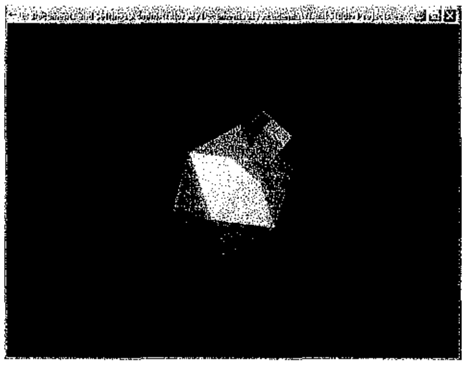


Figure 3.4 (a) Two objects without movement

Figure 3.4 (b) Two objects with movement

The users are presented with the single object scenes first and then the two object scenes. Then, they are questioned about the degree of depth that they can perceive in the 2 scenes of each category and then compare it with each other. They are also asked whether they are comfortable with the presence of movement when they are using Anaglyphs, and whether the movement helps them with the depth perception. The questionnaire sample of the experiments can be found in Appendice I.

B) Experiment 2: Edges

This experiment is intended to see whether edges give impact on the perception of depth. For this experiment, the user is asked to compare the degree of depth that they can perceive in 3 objects, which is a cube, a sphere and a dodecahedron. Each object has its own edge attributes.

Constant: Object colour, position, size

Variables: Object type, no of edges, depth perception

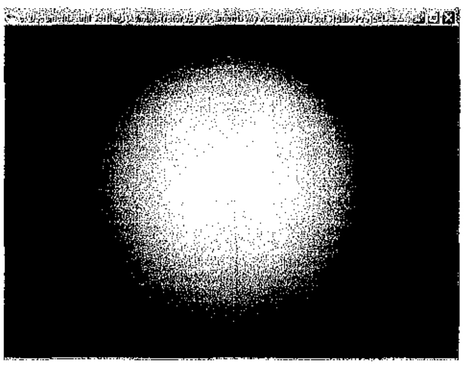


Figure 3.5 (a) Sphere, smooth edges

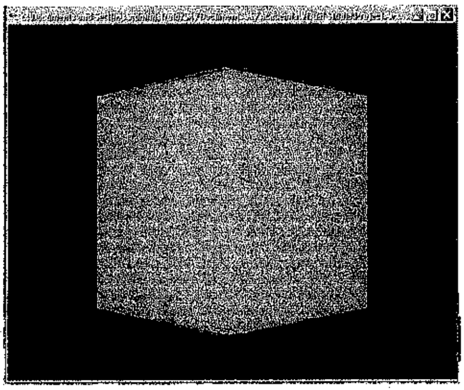


Figure 3.5 (b) Cube, 12 edges

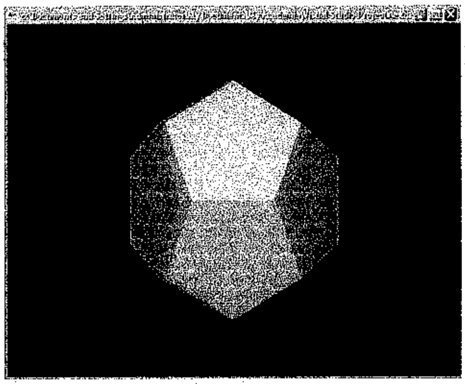


Figure 3.5 (c) Dodecahedron, 30 edges

After viewing each object, the users are asked to rank which object has the most depth and which is the less. Questionnaire is available in Appendice II.

C) Experiment 3: Background Brightness

This experiment is intended to see whether the brightness of background or environment affects the depth perception. Because of the limitations of colours in anaglyphs, the brightness level is adjusted at the background. There are 2 scenes that are presented to the subjects, which is scene with high brightness and a scene with a lower brightness.

Constants: Object type, colour, size

Variables: Background brightness, depth perception

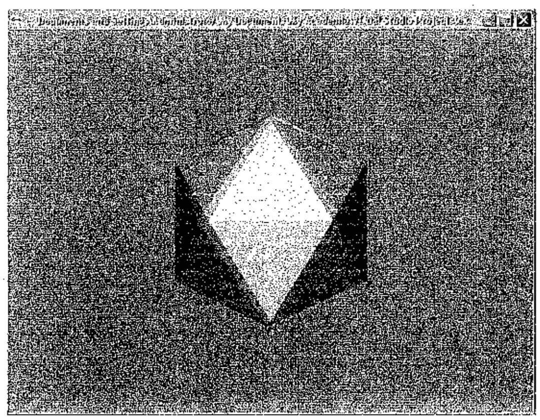


Figure 3.6 (a) Icosahedron on a bright background

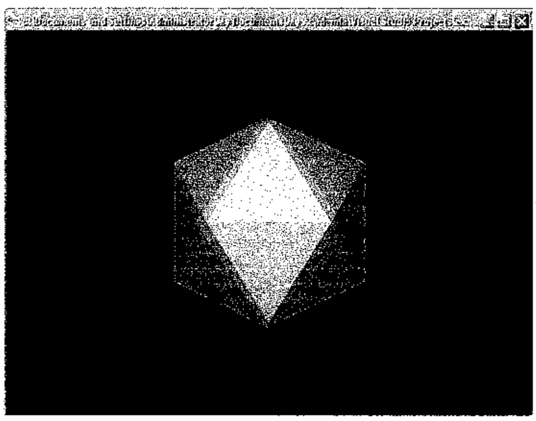


Figure 3.6 (b) Icosahedron on a dark background

After viewing each scene, the users are asked how well their depth perception in each scene. They are also asked about which scene that gives most eyestrain to them and which scene is the most comfortable looking at. Questionnaire is in Appendice III.

D) Experiment 4: Distance of objects from users

This experiment is to see whether the distance between object and user affects the depth perception or not. There is only one scene to be viewed, but there are 3 icosahedrons that are projected near, far and farther away from user. The distances of the object are varied by changing the values of the x, y and z coordinate and putting them in different parallax regions.

Constants: Object type, colour, size

Variables: Object position, depth perception

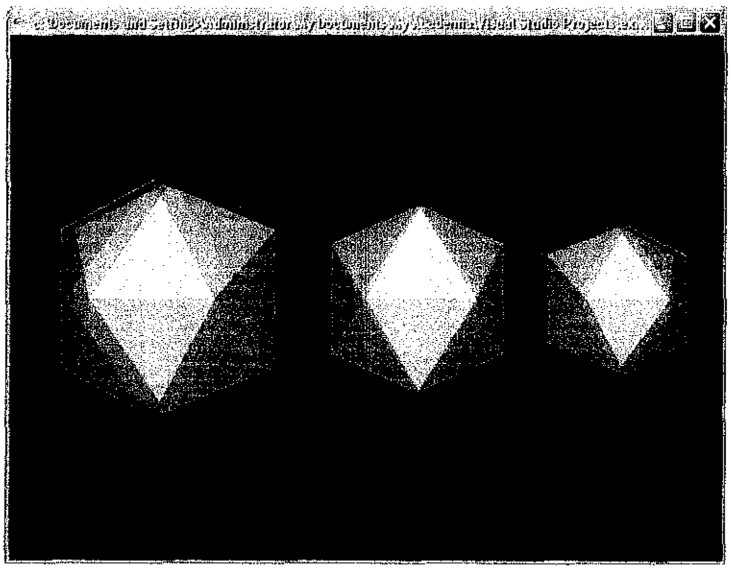


Figure 3.7 Icosahedrons with different positions. Each icosahedron has different distance from users.

After viewing the scene, the users are asked to compare the depth of the 3 objects and rank the depth. They are also asked which object is the most comfortable to be perceived. Questionnaire is in Appendice IV.

3.4.4 Data Analysis

After doing all the experiments, the data that would be analyzed the subject's depth perception. Based on the experiments, the possible strongest factor that affects the degree of depth perception is identified.

CHAPTER 4

RESULTS AND DISCUSSIONS

This chapter includes the results from the research that has been done as well as results and discussions of the experiments that is explained in the previous chapter.

4.1 RESEARCH RESULTS

From the research that has been done, the author has found and gained more knowledge about the issues surrounding the projection of a stereoscopic image. Basically the research has yielded the technical and natural aspects of the human and system that gives effect to the projection of a stereoscopic image. The research shows that realism and presence of a virtual environment is related with a good stereo projection.

4.1.1 Realism, presence and the relations to stereoscopic displays

Research shows that in order to generate a sense of presence in the users of virtual environment, it is crucial to achieve a certain amount of realism in the images generated. The higher the degree of realism in the image produced, the higher the tendency for the users to feel present in the environment.

The question is how can designers of VE achieve the realism? After research work, the author can conclude that the major elements that contributes to the realism is the stimulation of the senses of human, which also plays a vital role in the real life; it enables human to feel, touch, see, hear and the most of all, experience. In this project however, the author focuses on the visual capability of a human, the visual sense. Therefore, by stimulating the visual sense properly, it is possible to achieve realism in the VE. The way is to generate stereoscopic scenes to the users, which makes use of the natural perception capability in human, stereopsis.

Another question is, how can the designers generate the most ideal environment or object that will resemble the real thing as maximum as possible? Here, the factors and issues that surround the projection of the stereoscopic image must be taken into account.

There are many issues and factors related to the projection of stereoscopic images. It is not only limited to the issues regarding the hardwares and softwares, but also the capabilities and attributes of the human itself.

4.1.2 Factors affecting stereoscopic projection

Below is the summary of the factors that contributes to the quality of a stereoscopic projection. The author has divided the factors into 2 categories, which are the human aspects and the technical aspects.

Factors	Remarks
Colour	Colours of the image may effect the amount of ghosting in an image, it is said that the amount of Green in a image gives impact to ghosting because it produces the longest afterglow [13]
Brightness/Image Intensity	The degree of brightness in an image may hinder or enhance the perception of depth.
Focal Distance	Changing viewing distance strongly affects the visual stimulus and may affect the depth perception [13] Frequent cuts in stereo movie/animation forces the viewer to adjust to the different focal lengths. Frequent cuts to scene with very different content and focal length will quickly introduce stress on the visual system. [14]
Field-of-View (FOV)	Increasing the FOV is linked to an increase in the subjective sense of presence. To increase FOV is often based on the argument that closely matching the human FOV improves the sense of immersion[9]
Spatial resolution	The number, angular size and spacing of the pixels. Increased resolution causes images to appear clearer, sharper and more in-focus[9]
Ghosting and Flicker	Ghosting may be caused by contrast in the images and the eye separation value in the parallax region. Regions

	of high contrast may produce a higher ghosting effect [14] The alternating display of 2 images also causes ghosting. Flicker is most common in the case of a time-sequential hardware, especially when the switching rate is too slow. [13]
High Contrast	Higher contrast may cause higher ghosting effects [14] that may hinder the depth perception.
Screen Border	Objects in the negative parallax region (in front of the screen) will present conflicting cues to the visual system if they are cut by the border of screen, a region that is clearly at zero parallax. [14]
Occlusion by other viewers	The effect of the line of site being blocked by other members of the audience can lead to conflicting cue if the blocking object is at similar or greater depths than the stereo content. [14]
Motion Cues	Motion cues is the next strongest cues that enhances the depth perception [14]
Vertical Structure	Parallax information requires vertical structure. Therefore, introducing vertical structures in an image may enhance depth perception, compared to non-textured image or a fuzzy/blurred texture. [14]
Noisy Texture	Noisy textures on surfaces will result in poor depth perception if the frequency is so high that there effectively isn't matching visual information between the stereo pairs.[14]
Positive Parallax	Positive parallax (objects behind the screen) is in general easier to look at and minimises eye strain. [14]
Stereo image presentation	Presenting binocular disparity information by displaying separate images for each eye[14]

Table 4.1 Technical (Hardware and Software) Issues

Human Issues

User's perceptual, cognitive and motor abilities also play a role in perceiving depth.

- **Subject Stereoacuity**

  Stereoacuity is the capability of a person to fuse 2 images that is presented to separate eyes. This attribute varies in individuals. There are people who can fuse objects excellently but there are also people who cannot fuse at all. Variability in stereoacuity may influence results of stereo perception [14]

- **Susceptibility to motion sickness[11]**

  Degree of susceptibility to motion sickness also may hinder the depth perception because sometimes motion is introduced into the image. Certain person may have different thresholds to the sickness.

- **Practice**

  It is known that practice can help in improving stereoacuity. For an observer who has little experience with stereoscopic effects, they might take sometime to get a stereo perception. However, the learning process occurs rapidly. [14] Prior experience and expectations towards mediated experiences also affects the depth perception. [11]

- **Willingness to suspend disbelief**

  This issue is psychological; perhaps it means that when a user is willingly to suspend their disbelief the sense of presence may occur faster.

4.2 EXPERIMENT RESULTS

4.2.1 Experiment 1: Movement

Design

Objective : To see the impact of motion cues (movement) on depth perception

Constants : Object type, size, positioning, colour

Variables : Movement, depth perception

This experiment is divided into 2 categories. Category 1 is Movement with single object (Experiment 1a), and category 2 is Movement with 2 objects (Experiment 1b). Subjects are firstly presented with Experiment 1(a) and then Experiment 1(b).

Experiment 1(a) stimulus:

- Scene 1: Single icosahedron without movement about z-axis
- Scene 2: Single icosahedron with movement about z-axis

Experiment 1(b) stimulus:

- Scene 1: Two objects (cube and icosahedron) without movement about z-axis
- Scene 2: Two objects (cube and icosahedron) with movement about z-axis

For each category, subjects are presented with both scenes subsequently. Subjects are then required to answer questions related to their depth perception. Questions are provided in a specific questionnaire (Appendice I).The depth perception is measured based on how well the user can see the 3Dness of the object.

Results and Discussion

The results of the experiment for all 10 subjects are formulated into the figures below:

Experiment 1 (a):

i) Most 3D scene

Subjects compare both scenes and choose which scene that looks the most 3D to them.

Scene	Respond
Scene 1	0
Scene 2	7
Both scenes	3

Table 4.2 Most 3D Scene (Exp. 1a)

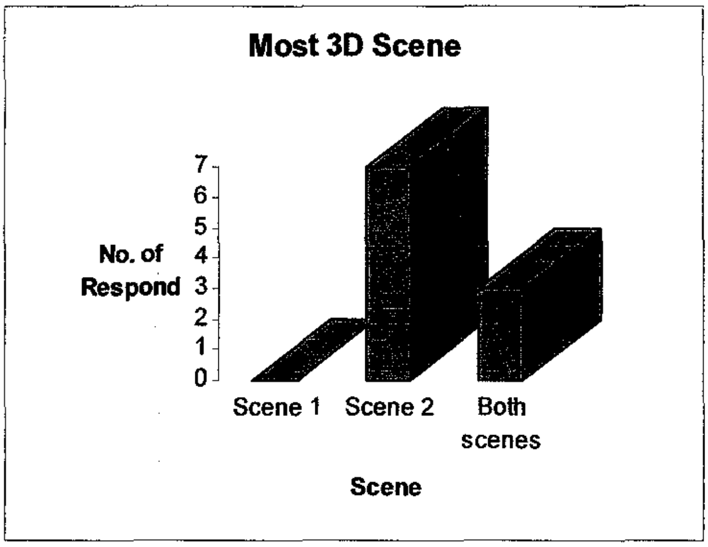


Figure 4.1 Most 3D Scene (Exp 1a)

From the chart above, it can be seen that 7 out of 10 subjects (70%) chooses Scene 2 (object with movement) as the most 3D scene. 3 out of 10 subjects (30%) says that both scenes looks the same to them. None of them chose Scene 1 (without movement) as the most 3D scene. Those who chose Scene 2 said that the object looks a lot more realistic when movement is present. Those who choose both scenes as the same said that they perceive the depth of object just the same even when movement is present. Based on the figure, it can be implied here that majority of the subjects feel that a scene with movement looks more 3D and realistic to them.

ii) Scene Ranking

Subjects are required to rank each scene with a predetermined degree of 3D (poor, average or excellent), based on how well they perceive depth in each scene.

Scene 1	Respond
Poor	1
Average	7
Excellent	2

Scene 2	Respond
Poor	0
Average	1
Excellent	9

Table 4.3 Scene Ranking (Exp. 1a)

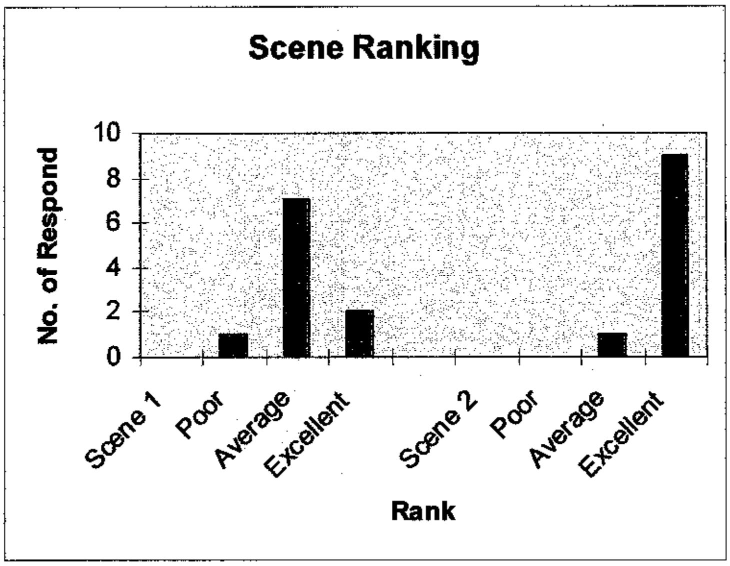


Figure 4.2 Scene Ranking (Exp 1a)

The result has yielded that for Scene 1 (without movement), 7 out of 10 (70%) subjects have rated it Average, 1 out of 10 (10%) subjects rate it as Poor and 2 out of 10 (20%) subject rated it as Excellent. Most of the subjects said that Scene 1 still produces depth perception, but very minimal compared to Scene 2. Those who rate Excellent for Scene 1, also rates Excellent for Scene 2, as they do not see any difference in both scenes. For Scene 2 (with movement), 9 out of 10 subjects (90%) rated is as Excellent and only 1 subject (10%) rated is as Average. Subjects have responded that Scene 2 looks livelier and more realistic to them, which are why they rate it as Excellent. Based on the prevailing of the Average rate in Scene 1 and the prevailing rate of Excellent in Scene 2, it is implied from here that majority of the subjects perceive Scene 2 as more in depth perception and realistic, compared to Scene 1.

iii) Movement helps depth perception

Subject are questioned whether the movement in the scene helps them with their depth perception of both scenes.

Yes	6
No	4

Table 4.4 Movement and Depth Perception (Exp 1a)

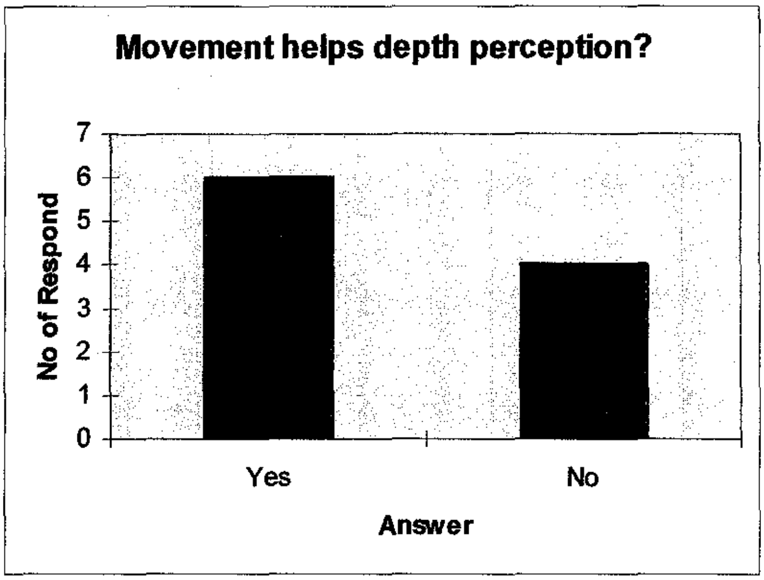


Figure 4.3 Movements and Depth Perception (Exp 1a)

From the chart above it can be seen that 6 out of 10 (60%) subjects answered Yes, while 4 out of 10 subjects (40%) answered No. Subjects have responded that movement makes the object looks more realistic to them. Based on the response and figure, it can be said that majority of the subjects thinks that for a single object environment, movement or motion cues helps them in achieving a better depth perception.

Experiment 1(b):

i) Most 3D scene

Subjects compare both scenes and choose which scene that looks the most 3D to them.

Scene	Respond
Scene 1	0
Scene 2	10
Both Scenes	0

Table 4.5 Most 3D Scene (Exp. 1b)

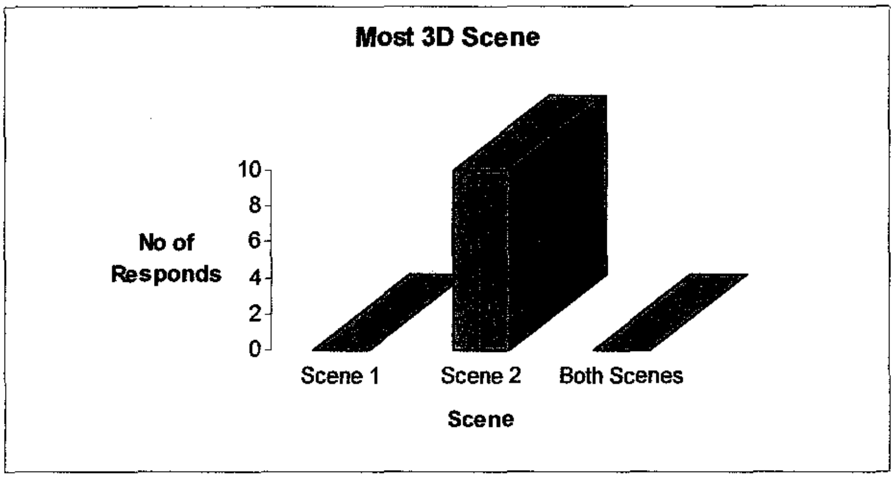


Figure 4.4 Most 3D Scene (Exp 1b)

The results for this section yields that for a scene of 2 objects, 10 out of 10 (100%) of the subjects has pointed out that Scene 2 (with movement) is more 3D compared to the other scene. All subjects have commented that Scene 1 (without movement) gives them poorer depth perception; some of them even cannot see the cube very well. They have also said that Scene 2 gives them more depth perception because they are able to see both objects very well, along with its depth relation. Therefore from here it can be implied that Scene 2 (with movement) gives an excellent depth perception to the users, and the movement has given a positive impact on the viewers.

ii) Scene Ranking

Subjects are required to rank each scene with a predetermined degree of 3D (poor, average or excellent), based on how well they perceive depth in each scene.

Scene 1	
Poor	2
Average	8
Excellent	0

Scene 2	
Poor	0
Average	0
Excellent	10

Table 4.6 Scene Ranking (Exp. 1b)

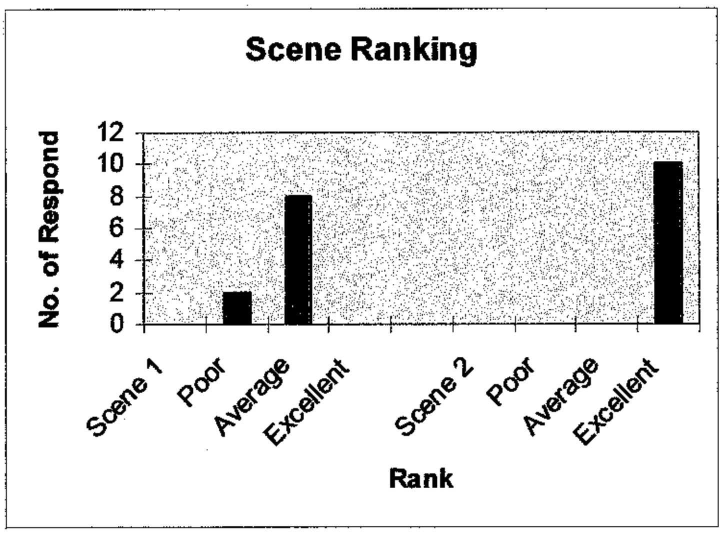


Figure 4.5 Scene Ranking (Exp 1b)

For this experiment, the figure shows that for Scene 1 (without movement), 2 out of 10 (20%) subjects rated it as Poor, while 8 out of 10 (80%) subjects rated it as Average. For Scene 2 (with movement), 10 out of 10 subjects (100%) rated it as Excellent. Here it can be seen that majority of the subjects finds out that Scene 1 only give them an Average quality of depth perception, while Scene 2 gives them a very good depth perception. In relation between the two scenes, it can be implied here that Scene 2 definitely gives a better depth perception than Scene 1. These results have supported the results in the previous section, and therefore it can be implied that movement does give a better depth perception to the users.

iii) Movement helps depth perception

Subject are questioned whether the movement in the scene helps them with their depth perception of both scenes.

Yes	10
No	0

Table 4.7 Movement and Depth Perception (Exp. 1b)

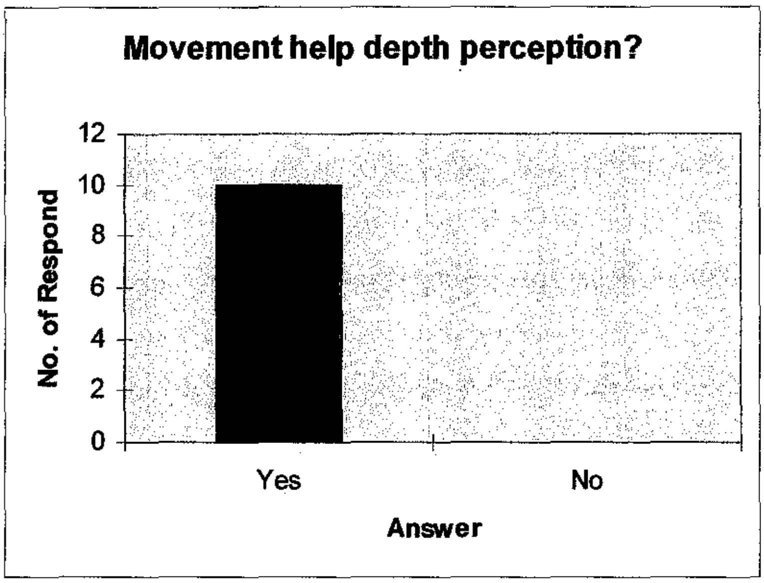


Figure 4.6 Movements and Depth Perception (Exp 1b)

For this part, the results have shown that 10 out of 10 (100%) subjects have answered Yes to the question. None of them answered No to the question. It can be seen here that apparently for a scene with more than 1 object (2 objects), subjects finds that the motion cues provided from the object movement really boosted their depth perception. Most of them said that when there is movement, they can see the relation between the objects better than a scene without motion cues. Therefore it is also proven that motion cues assist users in the perception of depth.

iv) Comfort with Movement and Depth Perception

Subjects are questioned whether they are comfortable viewing 3D scenes with motion cues or not. This includes dizziness, eyestrain or motion sickness.

Yes	10
No	0

Table 4.8 Comfort with 3D and Movement

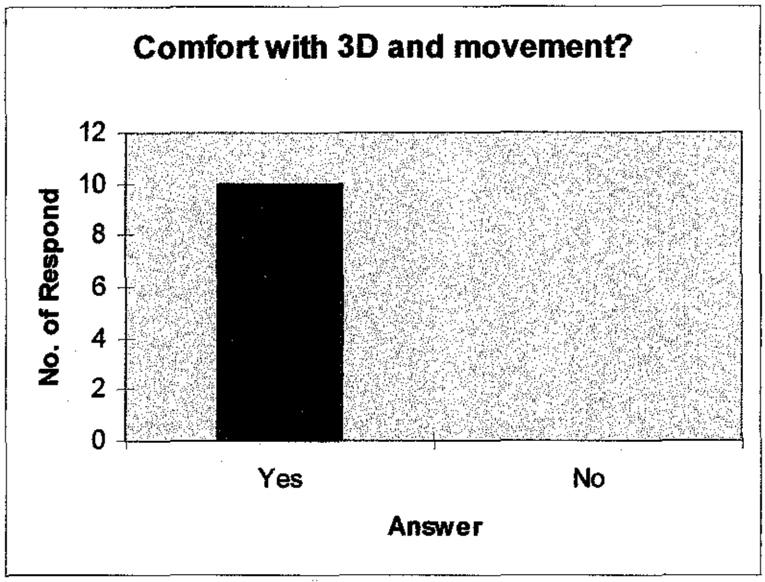


Figure 4.7 Comforts with 3D and Movement

This section represents the results of the question that relates subjects comfy with depth perception and movement. From the results, it has shown that 10 out of 10 (100%) subjects answered Yes to the question, which means that all of them thinks that they do not have problems when viewing the presented moving 3D scene. All of them are apparently happy with the introduction of movement, because of the same reason stated in the previous section. In this context, it is safe to say that for a simple scene with a simple movement, users may have no problems in viewing it. From research, it was found out that depth perception also depends on the human's susceptibility to motion sickness. These results do not prove that all users will not have problems viewing moving 3D objects. Another experiment with different types of motions can be designed to prove this theory.

Results from Experiment 1(a) and Experiment 1(b) has shown that movement or motion cues gives positive impact on the viewers depth perception. The introduction of movement to the 3D scenes has little or no effect to the comfort of the viewers. It helps the viewers achieve a better depth perception, and makes the objects look more realistic. Therefore, it can be ruled out that for a scene with a single or more objects, movement or motion cues gives positive impact on the depth perception of users. It causes the objects to look more realistic and therefore increases the chance of achieving realism and sense of presence. Therefore, designers may want to add more animations into 3D scenes that is being designed so that it could make the scene looks more realistic and increases the chances of the users to achieve a sense of presence.

4.2.2 Experiment 2: Edges

Design

Objective : To see the impact of edges in objects on depth perception

Constants : Object colour, size, positioning

Variables : Object type, number of edges, depth perception

For this experiment, the subjects are presented with 3 different objects with different number of edges as the stimulus. The objects are:

- Sphere : Smooth edges
- Cube : 12 edges
- Dodecahedron : 30 edges

Each object has different number of edges and the numbers of edges that can be viewed by the subjects are also different. After being presented with each stimulus, the subjects are required to rank each object with the predetermined degree of 3D (poor, average and excellent), based on how well they perceive each object. The sample questionnaire is provided in Appendice II.

Results and Discussion

Results and discussions for all 10 subjects are provided below:

Rank	Respond		
	Sphere	Cube	Dodecahedron
Poor	7	3	0
Average	3	7	0
Excellent	0	0	10

Table 4.9 Ranking of Object's 3D

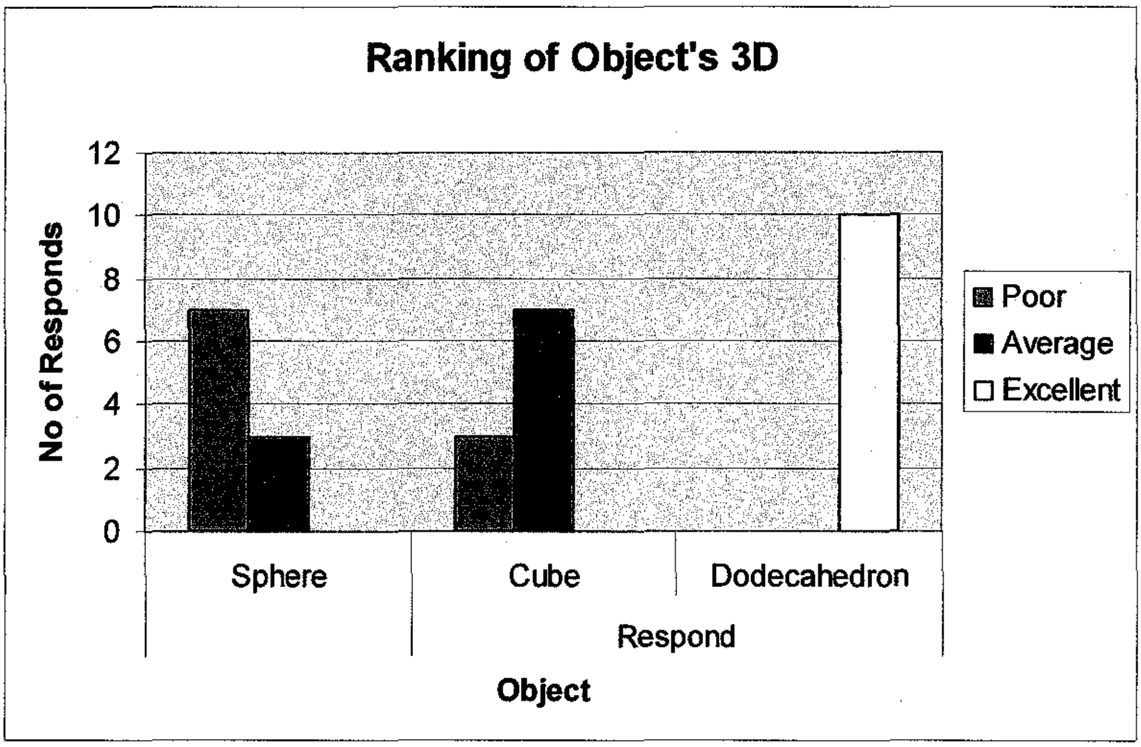


Figure 4.8 Ranking of Object's 3D

Based on the chart above, it can be seen that for:

Sphere (smooth edges)

- 3 out of 10 (30%) subjects rate as Average
- 7 out of 10 (70%) subjects rate as Poor

Cube (12 edges)

- 3 out of 10 (30%) subjects rate as Poor
- 7 out of 10 (70%) subjects rate as Average

Dodecahedron (15 edges)

- 10 out of 10 (100%) subjects rate as Excellent

Most of the subjects said that the dodecahedron has the most 3D effect to them, which means that they can see the dodecahedron as the most realistic one compared to others. Most of them also think that the cube and sphere does not give them much depth perception. Some of them also see that the cube and sphere both has the same quality of depth perception. From the results, it is proven that edges could give impact on the depth perception. However, because the cube and the sphere give the same impact to the subjects, it cannot be verified exactly how much does it affects the depth perception. A more precise and detailed study is needed to cater to this. Perhaps from further studies, more evidence can be found to prove this theory.

4.2.3 Experiment 3: Background Brightness

Design

Objective : To see the impact of scene brightness on depth perception

Constants : Object type, size, positioning, colour

Variables : Background brightness, depth perception

From the research, it is found out that brightness also plays a role in creating a good stereoscopic image. However, a specific way of setting the brightness and how does it impacts the depth perception is not expressed. For this experiment, an attempt is made to see whether the brightness of a scene can give impact on the subject's depth perception. Because the hardware that is being used is Anaglyph, the limitation is that the author does not have control over the brightness of the objects. Therefore, adjustments are made to the background of the scene, by presenting the subjects with 2 scenes with different brightness as the stimulus. The scenes are:

- Scene 1: Object with a high brightness background (Neon Green)
- Scene 2: Object with a low brightness background (Black)

After subjects are being presented with the scenes, they are required to rank each scene with the same predetermined degree of 3D (Poor, Average or Excellent).They are also asked about which scene that provides the most eyestrain to them. The sample questionnaire can be found in Appendice III.

Results and Discussion

Results for this experiment as in the figures provided below:

i) Ranking for Scene 1

Subjects are required to rank the scene with Poor, Average or Excellent.

Rank	Respond
Poor	3
Average	6
Excellent	1

Table 4.10 Scene 1 Ranking (Exp 3)

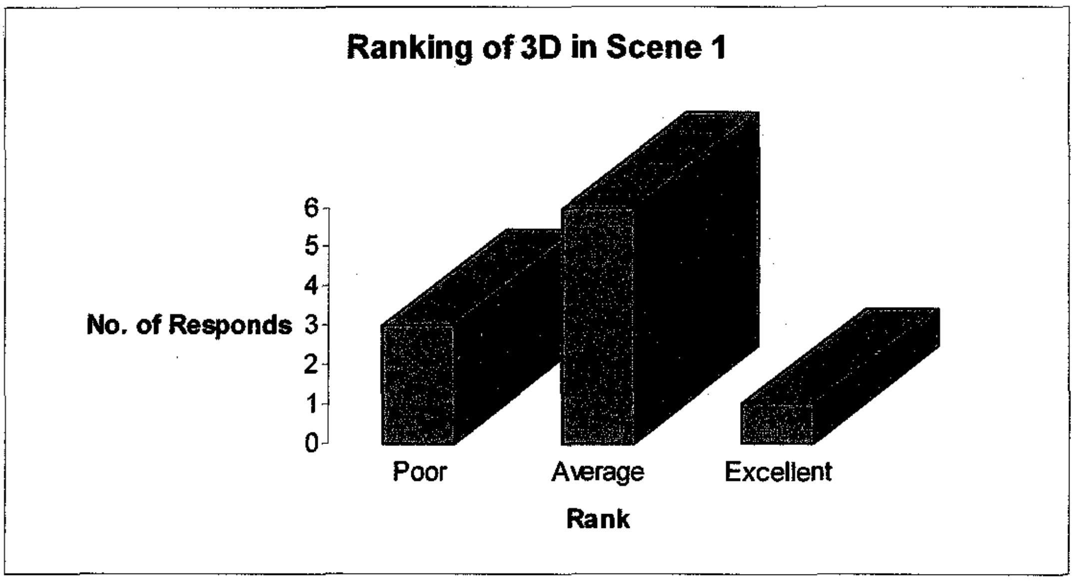


Figure 4.9 Scene 1 Ranking (Exp 3)

Here, the results have yielded that for Scene 1 (high brightness), 3 out of 10 (30%) subjects have rated as Poor, 6 out of 10 (60%) subjects have rated it as Average and only 1 out of 10 (10%) rated it as Excellent. Therefore it can be seen here that most of the subjects finds out that Scene 1 does not give a very good depth perception to them. Most of them commented that they can still see the depth of the object, but they cannot see it very well because of the bright background.

ii) Ranking for Scene 2

Subjects are required to rank the scene with Poor, Average or Excellent.

Rank	Respond
Poor	0
Average	2
Excellent	8

Table 4.11

Scene 2 Ranking (Exp. 3)

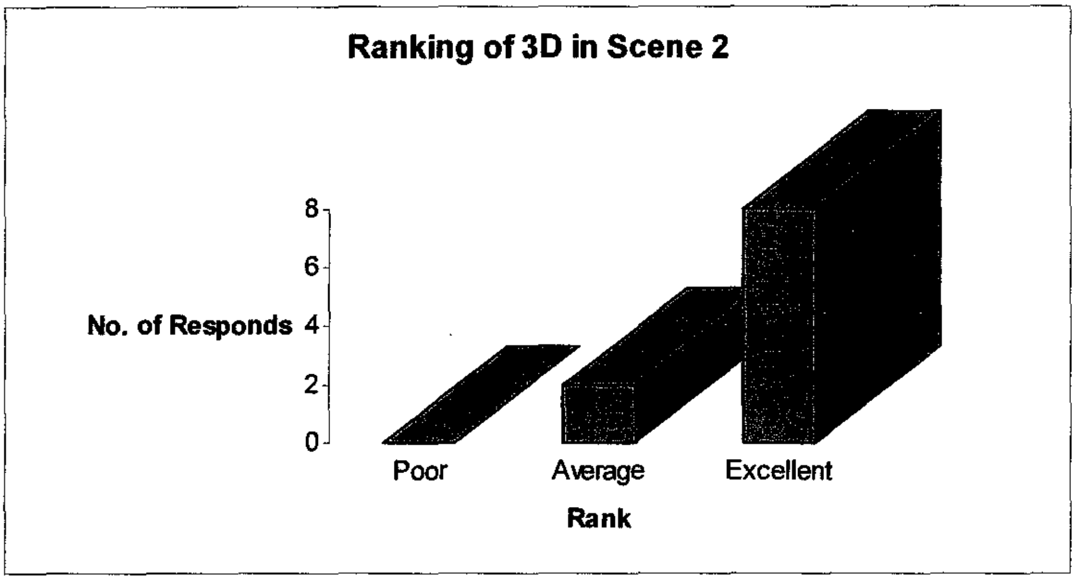


Figure 4.10 Scene 2 Ranking (Exp 3)

Here the results have yielded that 2 out of 10 (20%) subjects rate the scene as Average, while 8 out of 10 (80%) subjects rated is as Excellent. Therefore it can be seen that for Scene 2 (low brightness), most of the subjects can achieve a better depth perception. Most of them have commented that they can view the scene better because of the black background. There are also those who view Scene 1 and Scene 2 as the same, and they have commented that both scenes do not have very great difference.

iii) Comfortable and Straining Scenes

Subjects are required to choose which scene is comfy and which scene is straining to their eyes.

Rank	Scene	
	Scene 1	Scene 2
Comfortable	0	10
Straining	10	0

Table 4.12 Comfortable and Straining Scenes (Exp 3)

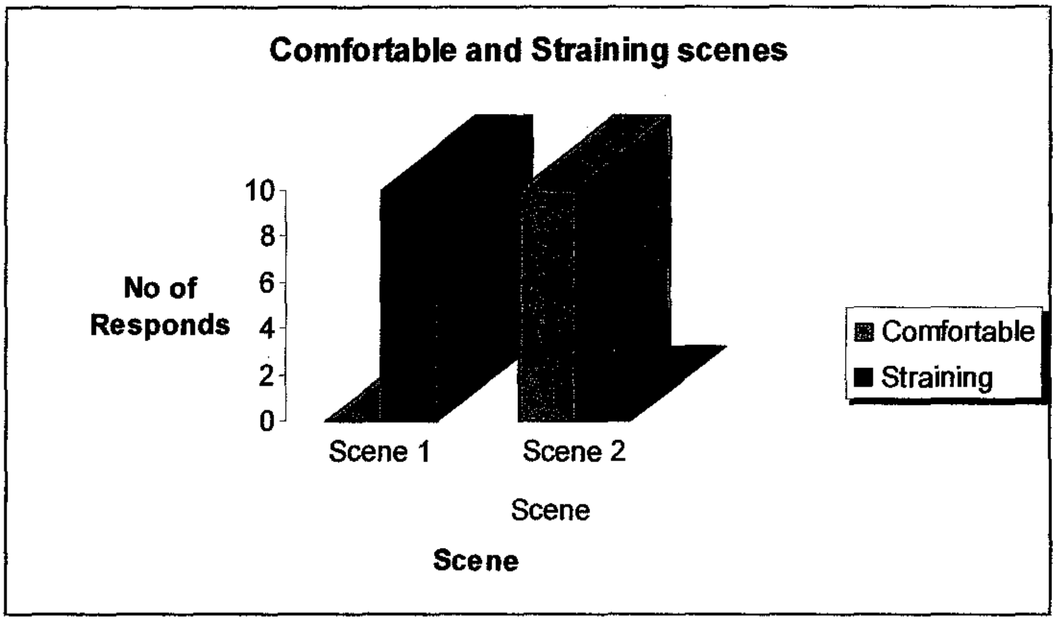


Figure 4.11 Comfortable and Straining Scenes (Exp 3)

Here it can be seen that 10 out of 10 subjects (100%) have rated that Scene 1 (high brightness) is the most straining scene while Scene 2 (low brightness) is the most comfortable scene to view. As expected, most subjects think that background with high brightness give them a poor depth perception. They have commented that they are distracted with a bright background. Scene 1 also gives them a lot of eyestrain because of the very bright background colour. Scene 2 in the other hand, gives them less distraction and enables them to view the object better.

From the results of this experiment, it can be said that a scene with a bright background does not give a very good depth perception to the user. Users are strained with the background and it disables them to view the objects properly. Therefore in designing a good scene, a too bright scene should be avoided. A moderate background colour should be maintained so that it would not distract the users. However, this experiment cannot determine whether brightness of objects could or could not affect the depth perception. A separate experiment with different scene or environment is needed to prove the theory, and it can be done with Colour Anaglyphs to overcome the problem of lack of control over object colours.

4.2.4 Experiment 4: Distance of objects from users

Design

Objective : To see the impact of distance to the depth perception

Constants : Object type, colour, size

Variables : Object position, depth perception

For this experiment, subjects are presented with only one scene, but with 3 objects in it as the stimulus. The difference between the objects is that the position is different with each other. All objects have the same size, but because of the different positions, they look relatively dissimilar in size. With the different positions, it means that the objects are also put in different parallax region as illustrated below:

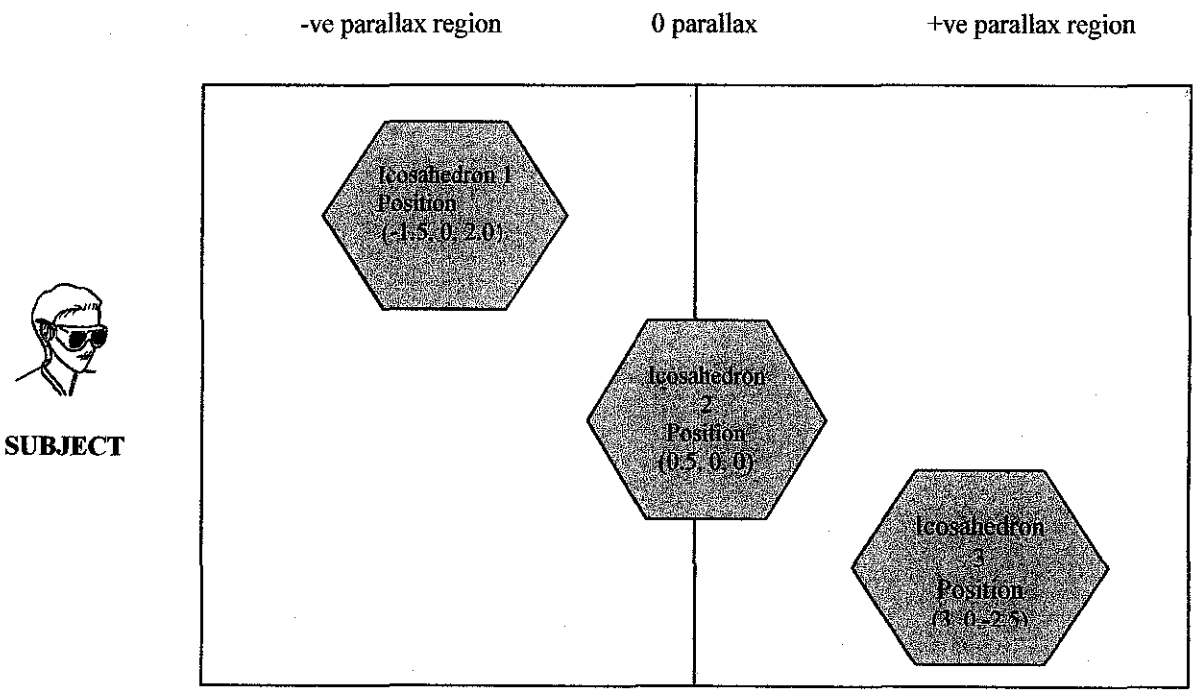


Figure 4.12 Parallax Region and Objects (Exp 4)

The object that is closest to the subject (Icosahedron 1) is in the negative parallax region, the object that is on the origin (Icosahedron 2) is in the 0 parallax region, and the object that is the farthest from the subject (Icosahedron 3) is in the positive parallax region.

After presenting the scene to the subjects, they are then asked to rank each object with a predetermined degree of 3D (Poor, Average and Excellent) based on how well they perceive each object. They are also required to point out the object that gives them the most and least eyestrain. A sample questionnaire is in Appendice IV.

Results and Discussion

Results of this experiment are based on the figures provided below:

i) Ranking of Object's 3D

Subjects are required to rank the object's 3Dness with Poor, Average or Excellent.

Rank	Object		
	Ico 1 (-1.5, 0, 2.0)	Ico 2 (0.5,0,0)	Ico 3 (3,0,-2.5)
Poor	5	4	1
Average	1	6	3
Excellent	4	0	6

Table 4.13 Ranking of Object's 3D (Exp 4)

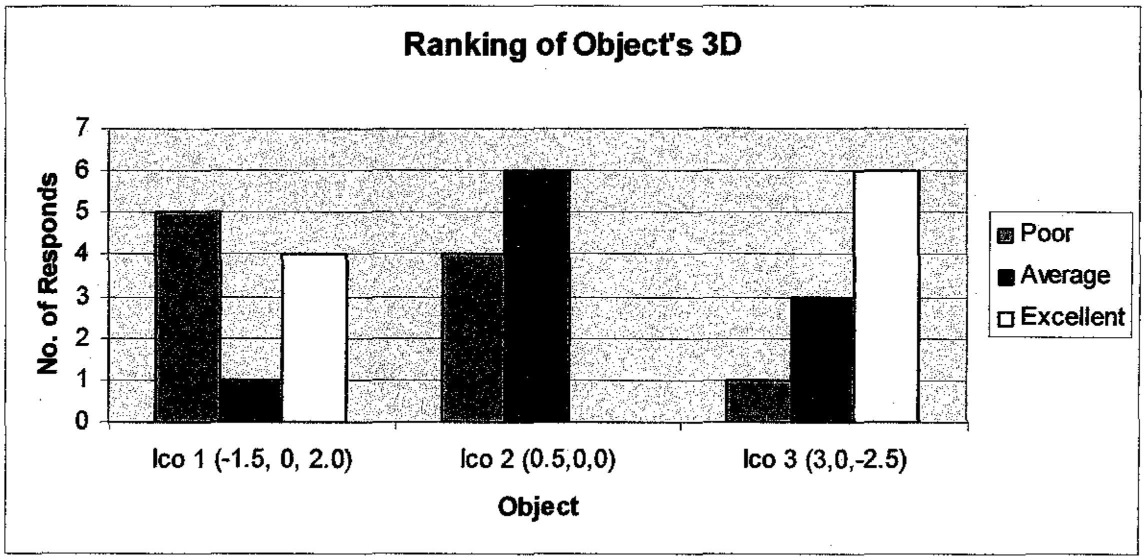


Figure 4.13 Ranking of Object's 3D (Exp 4)

The results for this section yield that for:

Icosahedron 1 (-1.5, 0, 2)

- 5 out of 10 (50%) subjects rate as Poor
- 1 out of 10 (10%) subjects rate as Average
- 4 out of 10 (40%) subjects rate as Excellent

Icosahedron 2 (0.5, 0, 0)

- 4 out of 10 (40%) subjects rate as Poor
- 6 out of 10 (60%) subjects rate as Average
- 0% subjects rate as Excellent

Icosahedron 3 (3, 0,-2.5)

- 1 out of 10 (10%) subjects rate as Poor
- 3 out of 10 (30%) subjects rate as Average
- 6 out of 10 (60%) subjects rate as Excellent

From the results it can be seen that Icosahedron 1 gives the poorest depth perception to subjects, Icosahedron 2 give and average depth perception to subjects and Icosahedron 3 gives the best depth perception to users. In this experiment, most users commented that the closest icosahedron (Icosahedron 1) have the most shadow and does not look good to their eyes. However, eventhough it produces the most ghosting, Icosahedron 1 still looks more 3D than the one in the middle (Icosahedron 2). That explains why some subjects still rate Icosahedron 1 as Excellent. Icosahedron 2 is only rated as poor and average because the subjects have commented that it does not give more depth perception to them compared to Icosahedron 1 and Icosahedron 3. Icosahedron 3 is the most preferred as Excellent by the subjects because they think that it gives the best depth perception to them and look good to the eyes.

The reason why Icosahedron 1 produces the most shadow is that because it has an eye separation value that is too high for the standard eyes. It is because it resides in the negative parallax region, whereby the separation value can go up to infinity [14]. Therefore, because of the excessive value, subjects cannot see the object properly. Icosahedron 2 in the other hand has a too small value of eye separation, because it resides on the 0 parallax region. The value is not enough for the brain to fuse the images and enable a good depth perception. Therefore, subjects do not prefer it as the best 3D object and ranked it as Poor and Average only. Icosahedron 3 has the most optimum value of eye separation, as it resides on the positive parallax region. It gives enough information to the human brain to fuse it nicely and produce a good 3D image. That is why most of the subjects rank it as Excellent.

Therefore, from all these results, it can be implied that objects the farthest from the user, or objects that resides in the positive parallax region, may convey the best depth perception to the users.

ii) Least and most eyestrain objects

Users are required to choose which object that gives the least and the most eyestrain to them.

	Ico 1	Ico 2	Ico 3
Most eyestrain	9	0	1
Least eyestrain	1	4	5

Table 4.14 Most and Least Eyestrain Objects (Exp 4)

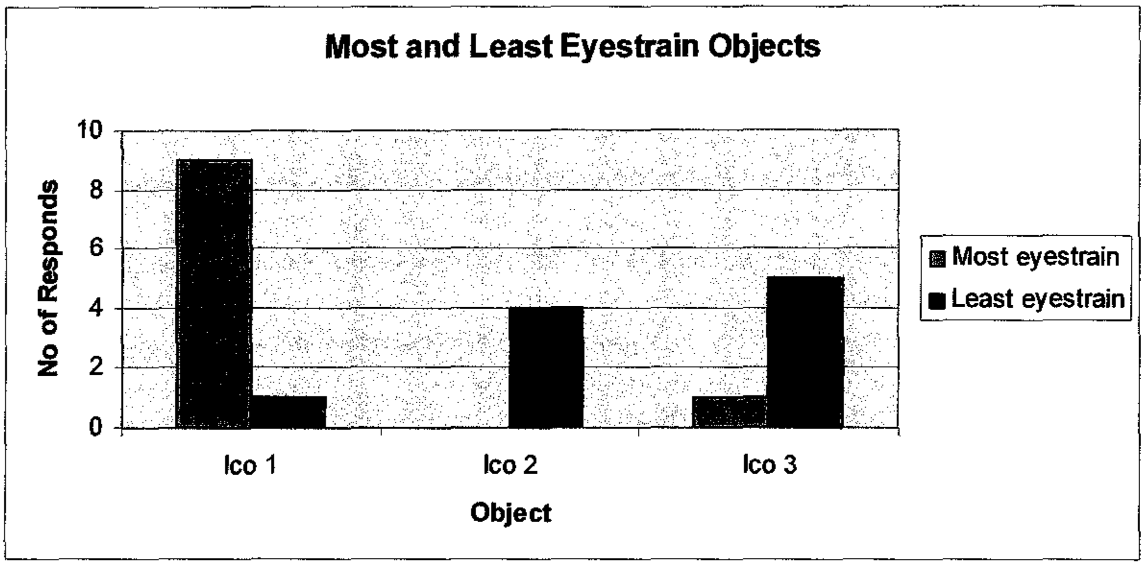


Figure 4.14 Most and Least Eyestrain Objects (Exp 4)

Here it can be seen that for:

Icosahedron 1

9 out of 10 (90%) subjects rate as having the most eyestrain

1 out of 10 (10%) subjects rate as having the least eyestrain

Icosahedron 2

0% subjects rate as having the most eyestrain

4 out of 10 (40%) rate as having the least eyestrain

Icosahedron 3

1 out of 10 (10%) subjects rate as having the most eyestrain

5 out of (50%) 10 subjects rate as having the least eyestrain

From the results it can be seen that the object that gives the user the most eyestrain is Icosahedron 1, while the object that gives the least eyestrain is Icosahedron 3, followed by Icosahedron 2. Eventhough most subjects can see the depth of Icosahedron 1; they find out that the object also gives the most strain to their eyes. Therefore from here, it can be implied that the farther the object is from the user, the less strain it gives to their depth perception. This corresponds to the theory that is given by Bourke, saying that an object that resides in the positive parallax region is in general easier to look at and minimises eye strain. [14]

From all the results that are obtained from this experiment, it is shown that distances between object and user gives an impact to the depth perception. The farther an object is from the user, the easier it is to look at and give a better depth perception. The closer it is to the user, the higher the chances it is to produce a poor depth perception and high eyestrain. Therefore, in designing a good scene for stereoscopic viewing, designers must take in this factor as a consideration. Perhaps designers can specify a suitable viewport that will give an optimum projection so that users can see all the objects in the scene without much disturbance.

4.3 EXPERIMENT SUMMARY

After all experiment has been done, the author was able to find out what factors from all 4 that gives the most impact to the depth perception. Below is the table that summarizes the findings that have been made.

Parameter	Impact on Depth Perception	Results
Movement / Motion Cues	Positive	Introduction of movement or motion cues to the objects enhances the depth perception and therefore increases the realism effect. In designing a 3D scene, designers could include animations to give a better effect.

Edges	Inconclusive	Numbers of edges that can be seen on an object are proven to give impact to the depth perception, but how much does it affects the perception is inconclusive. Further studies are needed to prove the theory.
Background Brightness	Positive	Bright background may produce distractions to the user, causing them to fail to view the objects depth properly. Generally a less bright scene gives a better perception. Therefore, when designing a scene, designers must be aware to use a moderate background colour. Not too bright to cause distractions, but still caters to the requirements.
Distance of object from users	Positive	The further an object is from the user, the better the user perceive the depth. Objects that are further away also cause less eyestrain to users, proving Bourke's theory [14]. Generally objects that resides in the positive parallax region results to the condition said above. Therefore in designing a 3D scene, designers may want to adjust the location of the objects so that it resides in the positive parallax region, or perhaps avoid from setting the objects in a locations that may cause strain and poor depth quality.

Table 4.15 Summary of Findings

The results and findings above are of course, only applicable to the same environment that is used in the experiment. This means that when designers are designing a 3D scene, the parameters that can be considered above are only applicable when they are using the similar hardware and software setting. The findings are also applicable to 3D scenes that are viewed using Red and Green Anaglyphs only. It cannot be assumed that the same parameters could definitely give the same impact on different stereoscopic display methods.

CHAPTER 5
CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

After all that has been done, the author feels that this study is only complete at a preliminary stage. There are actually many other issues that need to be studied more deeply to continue with the study and help strengthen the findings that have been made. From a personal point of view, the research that has been done has given much information that gives the author understanding of the issues surrounding the projection of stereoscopic images. It includes the basic understanding of stereoscopic concept itself, the application of the concept in VR technology, and its relations with realism and sense of presence. The author also has been able to understand more about one of the popular hardware that is being used to view stereoscopic images, which is the Anaglyph.

The project was able to meet the objectives successfully. The first objective, which is to find out what are the factors that affects the realism of the projected image in stereoscopic displays, have been achieved through the intensive research and readings of previous literatures. From there the author has compiled and summarized the proven issues and factors that have been known as having an affect on the projection of stereoscopic images.

The research also enables the author to know which factor and issues that can be controlled over and be used in designing a good stereoscopic image. Then the author have chosen the suitable parameters that can be experimented with, to see how much the parameters does affects the depth perception of users. This is being done through the experimentation.

From the experiment, the author has then able to achieve the second objective of the project, which is to identify image parameters that give the most impact to user's depth perception of a 3D scene. The experiment have shown the parameters that gives the most effect to the users depth perception, which then leads to a better realism effect. When this condition is achieved, it means that the projection of the image is also of good quality. The findings from the experiments have ruled out that the parameter that gives the most impact on user's depth perception for Anaglyph 3D scenes are motion cues, distances of object from user and background brightness. The number of edges on objects is also found out as affecting the depth perception, but further studies is needed to prove how much does the effect goes.

5.2 RECOMMENDATIONS FOR FUTURE STUDIES

Here are few recommendations from the author for the purpose of expansion and continuation of the research.

5.2.1 Enlarge the scope of experiments

Here it is meant that the experiment scope could be enlarged to get more varied results and then get a stronger conclusion. The enlargement is applicable to the subjects, whereby in the future studies, more diverse subjects could be used to be experimented on. This is because depth perception is very subjective, and it is expected that it could differ in different people. When more diverse subject is being used, more findings could also be achieved.

The objects that are being used in the experiment could also be varied in the future. For example in terms of number of edges, more objects with a varied number of edges could be use to see the difference. The results would also perhaps be more concise.

5.2.2 Experiment with more parameters

Future studies may also include experimentations on more parameters. For example, it could include experiments on different object textures and colour. Perhaps different texture and colours could also give impact on the depth perception. Other technical parameters like screen resolution and field of view could also be used for experimentation.

5.2.3 Research expansion that covers more on human issues

Besides technical issues, perhaps future studies could also include studies on human issues that affect the depth perception. Human issues are something that is more subjective, but a research that focuses on it could be very beneficial as well, because human issues are also found out to play a vital role in stereoscopic viewing.

5.2.4 Implementation of Colour Anaglyphs

In terms of hardware, future studies may also include a research that is done using Colour Anaglyphs, which is slightly different from the one used in this project. Colour anaglyphs are more flexible and useful because it overcomes the limitations of the conventional anaglyphs. Perhaps findings for colour anaglyphs would be different at all, and therefore can determine whether colour anaglyphs are better to use or not.

All in all, the project has been able to draw a platform to start a research on the parameters that affects the user's depth perception and the quality of the images projected for Anaglyphs. As said earlier, the project is only complete on a preliminary stage, and the author believes that more efforts can be done to continue this research. The project was accomplished in time and able to achieve its goals successfully.

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APPENDICES

APPENDICE I: EXPERIMENT 1 QUESTIONNAIRE

EXPERIMENT 1: MOVEMENT **Date:**

Name:

Age:

Remarks:

a) Movement with a single object

i) Which scene projects object with the most depth / 3D?

- ☐ Scene 1
- ☐ Scene 2

ii) Rate the degree of depth for each scene:

Scene 1

Poor Average Excellent

Scene 2

Poor Average Excellent

iii) Does movement helps your depth perception for this object?

- ☐ Yes
- ☐ No

b) Movement with 2 objects

i) Which scene projects object with the most depth / 3D?

- ☐ Scene 1
- ☐ Scene 2

ii) Rate the degree of depth for each scene:

Scene 1

Poor | Average | Excellent

Scene 2

Poor | Average | Excellent

iii) Does movement helps your depth perception for this object?

- ☐ Yes
- ☐ No

iv) Are you comfortable with movement in 3D scenes?

- ☐ Yes
- ☐ No

APPENDICE II: EXPERIMENT 2 QUESTIONNAIRE

EXPERIMENT 2: EDGES **Date:**

Name:

Age:

Remarks:

Rank objects with their degree of 3D:

Rank	**Object**		
	Sphere	*Cube*	*Dodecahedron*
Poor			
Average			
Excellent			

* Tick at the appropriate boxes

APPENDICE III: EXPERIMENT 3 QUESTIONNAIRE

EXPERIMENT 3: BACKGROUND BRIGHTNESS **Date:**

Name:

Age:

Remarks:

i) Rank how well do you perceive depth in Scene 1

Poor Average Excellent

ii) Rank how well do you perceive depth in Scene 2

Poor Average Excellent

iii) Which scene gives more strain / ghosting to your eyes?

- ☐ Scene 1
- ☐ Scene 2

iv) Which scene you are most comfortable looking at?

- ☐ Scene 1
- ☐ Scene 2

APPENDICE IV: EXPERIMENT 4 QUESTIONNAIRE

EXPERIMENT 4: DISTANCE OF OBJECTS FROM USER **Date:**

Name:

Age:

Remarks:

---

i) Rank objects with their degree of 3D:

Rank	Object		
	Icosahedron 1	*Icosahedron 2*	*Icosahedron 3*
Poor			
Average			
Excellent			

* Tick at the appropriate boxes

ii) Which objects gives the most and less eyestrain to you?

Rank	Object		
	Icosahedron 1	*Icosahedron 2*	*Icosahedron 3*
Most eyestrain			
Least eyestrain			

* Tick at the appropriate boxes

APPENDICE V: APPLICATION CODE

```
/* redblue_stereo.c - demo of stereo for red/blue filter stereo glasses
*/

/* by Walter Vannini (walterv@jps.net, waltervannini@hotmail.com) */

/* In stereo mode, the object is drawn in red for the left eye
   and blue for the right eye.  Viewing the scene with red/green
   filter stereo glasses should give a sense of stereo 3D.
   glColorMask is used to control update of the red and green
   channel.  glFrustum is used to setup two different view frustums
   for each eye based on eye separation. */

/* Copyright (c) Walter Vannini, 1998.  */

/* This program is freely distributable without licensing fees and is
   provided without guarantee or warrantee expressed or implied. This
   program is -not- in the public domain. */

#include <stdlib.h>
#include <math.h>
#include <GL/glut.h>

#ifndef M_PI
#define M_PI 3.14159265358979323846
#endif

void init(void);
void KeyboardFunc(unsigned char key, int x, int y);
void MenuFunc(int value);
void IdleFunc(void);
void ReshapeFunc(int w, int h);
void DisplayFunc(void);



struct ProgramState
{
 int w;
 int h;
 GLdouble RotationY;
 double eye;
 double zscreen;
 double znear;
 double zfar;
 double RotationIncrement;
 int solidmode;
};
struct ProgramState ps;

const double PIXELS_PER_INCH = 100.0;

void init(void)
{
 GLfloat mat_ambient[] = {0.2,0.2,0.0,1.0} ;
```

```
 GLfloat mat_diffuse[] = {0.7,0.7,0.0,1.0} ;
 GLfloat mat_specular[] = {0.1,0.1,0.0,1.0} ;
 GLfloat mat_shininess[]={20.0};

 GLfloat light_position[]={0.0,5.0,20.0,1.0};

 GLfloat light_ambient0[]= {1.0,0.0,0.0,1.0};//red lights
 GLfloat light_diffuse0[]= {1.0,0.0,0.0,1.0};
 GLfloat light_specular0[]={1.0,0.0,0.0,1.0};

 GLfloat light_ambient1[]= {0.0,1.0,0.0,0.0};//green lights
 GLfloat light_diffuse1[]= {0.0,1.0,0.0,0.0};
 GLfloat light_specular1[]={0.0,1.0,0.0,0.0};

 glDisable(GL_DITHER);
 glClearColor(0.0, 0.0, 0.0, 1.0);//bg
 glShadeModel(GL_SMOOTH);
 glEnable(GL_DEPTH_TEST);
 glEnable(GL_NORMALIZE);
 glEnable(GL_CULL_FACE);
 glLightModeli(GL_LIGHT_MODEL_LOCAL_VIEWER, 1);


 glMaterialfv(GL_FRONT, GL_AMBIENT, mat_ambient);
 glMaterialfv(GL_FRONT, GL_DIFFUSE, mat_diffuse);
 glMaterialfv(GL_FRONT, GL_SPECULAR, mat_specular);
 glMaterialfv(GL_FRONT, GL_SHININESS, mat_shininess);

 glLightfv(GL_LIGHT0, GL_POSITION, light_position);
 glLightfv(GL_LIGHT0, GL_AMBIENT, light_ambient0);
 glLightfv(GL_LIGHT0, GL_DIFFUSE, light_diffuse0);
 glLightfv(GL_LIGHT0, GL_SPECULAR, light_specular0);

 glLightfv(GL_LIGHT1, GL_POSITION, light_position);
 glLightfv(GL_LIGHT1, GL_AMBIENT, light_ambient1);
 glLightfv(GL_LIGHT1, GL_DIFFUSE, light_diffuse1);
 glLightfv(GL_LIGHT1, GL_SPECULAR, light_specular1);
 glEnable(GL_LIGHTING);

 ps.eye=0.50;//eye separation value
 ps.zscreen = 10.0;
 ps.znear = 7.0;
 ps.zfar = 13.0;
 ps.RotationY = 0.0;
 ps.RotationIncrement = 0.05;
 ps.solidmode = 1;
}

void KeyboardFunc(unsigned char key, int x, int y)
{
 switch(key)
 {
 case 27:  /* escape */
 case 'q':
 case 'Q':
  exit(0);
  break;
```

```
 case 's': /* stereo */
  ps.eye = 0.50;
  break;
 case '1':
  ps.solidmode = 1;
  glFrontFace(GL_CCW);
  break;
  case 'a':
  ps.solidmode = 'a';
  glFrontFace(GL_CCW);
  break;
 case '2':
  ps.solidmode = 2;
  glFrontFace(GL_CCW);
  break;
  case 'b':
       ps.solidmode = 'b';
     glFrontFace(GL_CCW);
       break;
 case '3':
  ps.solidmode = 3;
  glFrontFace(GL_CCW);
  break;
 case 'c':
       ps.solidmode = 'c';
     glFrontFace(GL_CCW);
       break;
 case 'd':
       ps.solidmode = 'd';
     glFrontFace(GL_CCW);
       break;
  case '4':
  ps.solidmode = 4;
  glFrontFace(GL_CCW);
  break;
 case '5':
  ps.solidmode = 5;
  glFrontFace(GL_CCW);
  break;
 case '6':
  ps.solidmode = 6;
  glFrontFace(GL_CCW);
  break;
 case 'm': /* mono */
  ps.eye = 0.0;
  break;
 }
}

void MenuFunc(int value)
{
  KeyboardFunc(value, 0, 0);
}

void IdleFunc(void)
{
 ps.RotationY += ps.RotationIncrement;
```

```
 glutPostRedisplay();
}

void ReshapeFunc(int w, int h)
{
 glViewport(0,0,  w,  h);
 ps.w = w;
 ps.h = h;
}
void drawBackground()
{ glBegin (GL_POLYGON);
      glColor3f (1,1,1);
            glVertex2f (0,0);
            glVertex2f (0,10);
            glVertex2f (-10,10);
            glVertex2f (-10,0);
      glEnd();
}
void drawSphere(void)
{
      float t, dt, p, dp, pi = 3.141592654, divide = 10.0;
    float X, Y, Z, x1, x2, y1, y2, z1, z2;

      dt = pi/divide;
      dp = pi/divide;

    glBegin(GL_QUADS);
      for (t = 0; t < 2.0*pi; t += dt)
            for (p = -pi/2.0+dp; p < pi/2.0; p += dp)
            {
                  x1=   cos(p+dp)*cos(t+dt)-cos(p)*cos(t+dt);
                  y1=   sin(p+dp)-sin(p);
                  z1=cos(p+dp)*sin(t+dt)-cos(p)*sin(t+dt);
                  x2=   cos(p)*cos(t)-cos(p)*cos(t+dt);
                  y2=   sin(p)-sin(p);
                  z2=cos(p)*sin(t)-cos(p)*sin(t+dt);
                  X = y1*z2-z1*y2; Y = x2*z1-x1*z2; Z = x1*y2-x2*y1;

      //          glNormal3f(X,Y,Z);

                  glVertex3f(cos(p)*cos(t),sin(p),cos(p)*sin(t));
                  glVertex3f(cos(p)*cos(t+dt),sin(p),cos(p)*sin(t+dt));

      glVertex3f(cos(p+dp)*cos(t+dt),sin(p+dp),cos(p+dp)*sin(t+dt));

      glVertex3f(cos(p+dp)*cos(t),sin(p+dp),cos(p+dp)*sin(t));
            }
      glEnd();

   glBegin(GL_QUADS);
      for (t = 0; t < 2.0*pi; t += dt)
            for (p = -pi/2.0; p < -pi/2.0+dp; p += dp)
            {
                  x1=   cos(p+dp)*cos(t)-cos(p+dp)*cos(t+dt);
                  y1=   sin(p+dp)-sin(p+dp);
                  z1= cos(p+dp)*sin(t)-cos(p+dp)*sin(t+dt);
                  x2=   cos(p)*cos(t+dt)-cos(p+dp)*cos(t+dt);
```

```
                y2=   sin(p)-sin(p+dp);
                z2= cos(p)*sin(t+dt)-cos(p+dp)*sin(t+dt);
                X = y1*z2-z1*y2;Y= x2*z1-x1*z2 ;Z=x1*y2-x2*y1;

                glNormal3f(X,Y,Z);

                glVertex3f(cos(p)*cos(t),sin(p),cos(p)*sin(t));
                glVertex3f(cos(p)*cos(t+dt),sin(p),cos(p)*sin(t+dt));

        glVertex3f(cos(p+dp)*cos(t+dt),sin(p+dp),cos(p+dp)*sin(t+dt));

        glVertex3f(cos(p+dp)*cos(t),sin(p+dp),cos(p+dp)*sin(t));
            }
        glEnd();
}


void DisplayFunc(void)
{
 double xfactor=1.0, yfactor=1.0;
 double Eye =0.0;
 int i;

 if(ps.w < ps.h)
 {
  xfactor = 1.0;
  yfactor = ps.h/ps.w;
 }
 else if(ps.h < ps.w)
 {
  xfactor = ps.w/ps.h;
  yfactor = 1.0;
 }

 glClear(GL_COLOR_BUFFER_BIT);
 for(i=0;i<2;i++)
 {
  glEnable(GL_LIGHT0 + i);
  glClear(GL_DEPTH_BUFFER_BIT);
  if(i==0) /* left eye - RED */
  {
   Eye = ps.eye;
   glColorMask(GL_TRUE,GL_FALSE,GL_FALSE,GL_TRUE);
  }
  else /* if(i==1) right eye - GREEN */
  {
   Eye = -ps.eye;
   glColorMask(GL_FALSE,GL_TRUE,GL_FALSE,GL_TRUE);
  }

  glMatrixMode(GL_PROJECTION);
  glLoadIdentity();
  glFrustum(
   (-(ps.w/(2.0*PIXELS_PER_INCH))+Eye) *(ps.znear/ps.zscreen)*xfactor,
   (ps.w/(2.0*PIXELS_PER_INCH)+Eye)    *(ps.znear/ps.zscreen)*xfactor,
   -(ps.h/(2.0*PIXELS_PER_INCH))*(ps.znear/ps.zscreen)*yfactor,
   (ps.h/(2.0*PIXELS_PER_INCH))*(ps.znear/ps.zscreen)*yfactor,
```

```
 ps.znear, ps.zfar);
glMatrixMode(GL_MODELVIEW);
glLoadIdentity();
glTranslatef(Eye,0.0,0.0);
glTranslated(0,0,-ps.zscreen);




switch(ps.solidmode)
{
case 1://motion cues scene 1 - without mvmnt // 2 objects
 {
    glClearColor(0.0, 0.0, 0.0, 1.0);//bg

    glPushMatrix();
    //glTranslatef(0,2,0);
    glutSolidIcosahedron();
    glPopMatrix();
    glPushMatrix();
    glTranslatef(-0.7,0,2);
    glRotatef (45.0,0.0,1.0,0.0);
    glutSolidCube (0.5);
  glPopMatrix();


  break;
 }
case 'a'://motion cues scene 2 -with movement //2 objects
 {
  glClearColor(0.0, 0.0, 0.0, 1.0);//bg

    glPushMatrix();
    //glTranslated(cos(ps.RotationY*M_PI/180.0),0, -
sin(ps.RotationY*M_PI/180.0) );
  glRotated(ps.RotationY, 0.0,0.0,0.1);
  glutSolidIcosahedron();
    glPopMatrix();


    glPushMatrix();
    //glTranslated(cos(ps.RotationY*M_PI/180.0),0, -
sin(ps.RotationY*M_PI/180.0) );
  glRotated(ps.RotationY, 0.0,0.0,0.1);
    glTranslatef(-0.7,0,2);
    glRotatef (45.0,0.0,1.0,0.0);
    glutSolidCube (0.5);
  glPopMatrix();

  break;
 }

case 2: // movement 1 object // withoutmvmt
     {

    glPushMatrix();
    glScalef(2,2,2);
```

```
        //glTranslatef(3.5,0,0);
      glutSolidIcosahedron();
      glPopMatrix();
        break;
        }
  case 'b': // movemtn 1 object //with movement
        {
      glPushMatrix();
      glScalef(2,2,2);
        glRotated(ps.RotationY, 0.0,0.0,0.1);
      glutSolidIcosahedron();
      glPopMatrix();
        break;
break;
        }

  case 3://edges comparison
   {
     glClearColor(0.0, 0.0, 0.0, 1.0);//bg

      //cube
      glPushMatrix();
      //glTranslatef(-1.7,0,0);
      glRotatef (45.0,0.0,1.0,0.0);
      //glRotated(ps.RotationY, 0.0,0.0,0.1);
      glutSolidCube (3);
    glPopMatrix();

    break;
   }
  case 'c':
        {

        //sphere
        glPushMatrix();
        //glTranslatef(0,-1,0);
        //glRotated(ps.RotationY, 0.0,0.0,0.1);
        glutSolidSphere (2,20,16);
        glPopMatrix();
        break;

        }
  case 'd':
        {
        //dodecahedron
      glPushMatrix();
      glScalef(1,1,1);
        //glTranslatef(3.5,0,0);
      glutSolidDodecahedron();
      glPopMatrix();
        break;
        }

    case 4://brightness scene 1
   {
    glClearColor(0.5, 1.0, 0.0, 1.0);//bg
```

```
        //drawBackground();

      glPushMatrix();
      glScalef(1.5,1.5,1.5);
      glutSolidIcosahedron();
      glPopMatrix();



break;

    }
   case 5://brightness scene 2
    {
     glClearColor(0.0, 0.0, 0.0, 1.0);//bg

     glPushMatrix();
     glScalef(1.5,1.5,1.5);
     glutSolidIcosahedron();
     glPopMatrix();



     break;
    }
   case 6://distance scene 1
         {

       ps.eye= 0.3;

         //nearest
         glPushMatrix();
         glTranslatef (-1.5,0,2.0);
         glutSolidIcosahedron();
         glPopMatrix();

         //far
         glPushMatrix();
         glTranslatef (0.5,0,0);
         glutSolidIcosahedron ();
         glPopMatrix();

         //farthest
         glPushMatrix();
         glTranslatef (3,0,-2.5);
         glutSolidIcosahedron();
         glPopMatrix();

       break;
         }


  }
  glDisable(GL_LIGHT0 + i);
 }
```

```
 glColorMask(GL_TRUE,GL_TRUE,GL_TRUE,GL_TRUE);
 glutSwapBuffers();
}


void
VisibilityFunc(int vis)
{
  if (vis == GLUT_VISIBLE) {
    glutIdleFunc(IdleFunc);
  } else {
    glutIdleFunc(NULL);
  }
}
int main(int argc, char **argv)
{
 glutInit(&argc, argv);
 glutInitDisplayMode(GLUT_DOUBLE | GLUT_RGBA );
 ps.w = 512;
 ps.h = 512;
 glutInitWindowSize(700, 500);
 glutInitWindowPosition(100,100);

 glutCreateWindow(argv[0]);
 init();
 glutVisibilityFunc(VisibilityFunc);
 glutDisplayFunc(DisplayFunc);
 glutReshapeFunc(ReshapeFunc);
 glutKeyboardFunc(KeyboardFunc);
 /*glutCreateMenu(MenuFunc);
 glutAddMenuEntry("Stereo", 's');
 glutAddMenuEntry("Mono", 'm');
 glutAddMenuEntry("Dodecahedron", '1');
 glutAddMenuEntry("Icosahedron", '2');
 glutAddMenuEntry("Teapot", '3');
 glutAddMenuEntry("Solar system", '4');
 glutAttachMenu(GLUT_RIGHT_BUTTON);*/
 glutMainLoop();
 return 0;
}
```