HARTOMO

DEVELOPMENT OF ERGONOMIC-AXIOMATIC DESIGN PARAMETERS FOR VIRTUAL ENVIRONMENT

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UNIVERSITY OF MALAYA
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<u>ORIGINAL LITERARY WORK DECLARATION</u>

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Field of Study: **Industrial Ergonomics**

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ABSTRACT

Ergonomic design of virtual environment will enhance the effectiveness of communication between the users and the virtual world, as well as avoiding the unwanted side effects, especially those affecting vision. Thus, it is highly essential to ensure that a set of design parameters of virtual environment should satisfy the ergonomic requirements and the user's criteria. The objective of this study is to develop the ergonomic design parameters to design the virtual environment and to propose the methodology to invent ergonomic design parameters.

Axiomatic design method is applied to map the physical domain that satisfies the functional domain and the functional domain that satisfies the customer domain. This process should be referred to the independence axiom. The implementation of ergonomic concept is considered as a basis of mapping process to develop the design parameters of virtual environment and the methodology proposed. "Fitting the task to the man" is the main principle in ergonomic design.

Survey by using questionnaire was conducted to identify the customer's criteria and investigate the visual disorder on the users. A field study was completed to obtain the criteria needed by the customer in the virtual environment. Meanwhile, an experimental study was done as the empirical evidence on visual symptoms experienced by user's vision when interacting with the virtual environment. Thus, virtual robot manufacturing system, as the case study, was developed as virtual stimulus by using *Direct X* and *C#* programming. Also, Autodesk 3 DS Max software was used to build the virtual objects. This experimental study was divided into two activities. The first was to investigate the ergonomic attributes and the second was for validation.

Statistical test by using non-parametric statistical method that includes descriptive test, reliability test, factorial analysis test, and chi-square test of independence were applied to find out some valid customer's criteria to be considered in designing the ergonomics virtual environment. Then, binomial test was used to determine the effect of several attributes identified to the visual symptoms. In addition, Mann-Whitney U test was used to validate the effectiveness of the developed ergonomics design parameters.

The results of this study have found that there were eight customer criteria which need to be considered in designing the virtual environment. The criteria are user friendly (89.7%), easy to use (88.6%), easy to learn (90.3%), easy to memorize (88.6%), flexible (90.8%), visual comfort (91.4%), non-glaring (84.9%), and resembling the real environment (84.9%). This study also showed that there were significant effects between the ergonomic attribute of virtual environment on user's vision at 5% significance level especially in the form of eyestrain, blurred vision, dry and irritated eyes, and light sensitivity symptoms. These attributes are virtual colour background, virtual lighting, field of view, flow rate of virtual objects, speed of virtual object's motion, screen resolution, and contrast ratio. Furthermore, the result of this study also showed that there was no significant different in criteria between surveyed customers and experimental study using the ergonomic design parameters developed i.e. medium slate blue for virtual background colour, 50% of brightness level, field of view of 85^o, flow rate of five second per piece, low speed motion of virtual objects, high resolution (1280 x 800), and 24.58% of contrast. Thus, it showed that the ergonomic design parameters developed were valid to satisfy the customer's visual comfort at 5% significance level and more effective to alleviate the user's visual symptoms. Subsequently, the methodology proposed was also valid and viable to be used in designing other ergonomic virtual environment. These were the significant finding of this research which may be as guide line of virtual product design.

ABSTRAK

Reka bentuk ergonomik persekitaran maya akan meningkatkan keberkesanan dalam komunikasi antara pengguna dan dunia maya, dan juga mengelakkan kesan sampingan yang tidak diingini terutama yang menjejaskan penglihatan. Oleh itu, ianya sangat penting untuk memastikan bahawa satu kumpulan parameter reka bentuk persekitaran maya harus memenuhi keperluan ergonomik dan kriteria pengguna. Objektif kajian ini adalah untuk membangunkan parameter reka bentuk ergonomik untuk mereka bentuk persekitaran maya dan mencadangkan kaedah untuk mencipta parameter reka bentuk ergonomik.

Kaedah reka bentuk aksioman digunakan untuk memetakan domain fizikal yang memenuhi domain fungsi dan domain fungsi yang memenuhi domain pelanggan. Proses ini perlu merujuk kepada aksioman kebebasan. Perlaksanaan konsep ergonomik diguna sebagai asas proses pemetaan untuk membangunkan parameter reka bentuk persekitaran maya dan metodologi yang dicadangkan. "Sepadan tugasan kepada manusia" adalah prinsip utama dalam reka bentuk ergonomik.

Kaji selidik dengan menggunakan soal selidik dilakukan untuk mengenalpasti kriteria pelanggan dan untuk menyiasat gangguan visual kepada pengguna. Kajian lapangan dilakukan untuk mendapatkan kriteria yang diperlukan pelanggan untuk persekitaran maya. Sementara itu, uji kaji dilakukan sebagai bukti empirikal mengenai gejala visual yang berlaku semasa berinteraksi dengan persekitaran maya kepada deria penglihatan pengguna. Sistem pembuatan robot maya, sebagai kajian kes, dibangunkan sebagai rangsangan maya dengan menggunakan *Direct X* dan pengaturcaraan *C#*. Perisian *Autodesk 3 DS Max* juga digunakan untuk membina objek maya. Uji kaji ini

dibahagikan kepada dua bahagian, iaitu pertama untuk menyiasat ciri-ciri ergonomik dan kedua bertujuan untuk pengesahan.

Ujian statistik dengan menggunakan kaedah statistik bukan parametrik yang digunakan merangkumi ujian deskriptif, ujian kebolehpercayaan, ujian analisis faktorial, dan ujian khi-kuasa dua untuk kebebasan bagi mengetahui beberapa kriteria pelanggan yang sah yang perlu dipertimbangkan dalam reka bentuk ergonomik persekitaran maya. Seterusnya ujian binomial digunakan untuk mengetahui kesan beberapa ciri-ciri yang dikenal pasti pada gejala visual. Disamping itu, ujian *Mann-Whitney U* digunakan untuk mengesahkan keberkesanan parameter reka bentuk ergonomik yang dibangunkan.

Keputusan kajian ini mendapati terdapat lapan kriteria pelanggan yang perlu dipertimbangkan dalam merekabentuk persekitaran maya. Kriteria tersebut adalah mesra pengguna (89.7%), mudah untuk digunakan (88.6%), mudah untuk dipelajari (90.3%), mudah untuk dihafal (88.6%), fleksibel (90.8%), keselesaan kepada penglihatan (91.4%), tidak silau (84.9%) dan menyerupai keadaan sebenar (84.9%). Kajian ini juga menunjukkan bahawa terdapat kesan yang signifikan antara ciri ergonomik persekitaran maya pada penglihatan pengguna pada kadar signifikan 5% terutamanya dalam bentuk ketegangan mata, kabur penglihatan, mata kering dan gatal-gatal, dan gejala kepekaan cahaya. Ciri ergonomik tersebut adalah warna latar belakang maya, pencahayaan maya, bidang pandangan, kadar aliran objek maya, kelajuan pergerakan objek maya, resolusi skrin, dan nisbah kontras. Tambahan pula, hasil daripada kajian ini juga menunjukkan bahawa tidak ada perbezaan yang signifikan mengenai kriteria di antara kaji selidik pelanggan dan kajian eksperimen dengan menggunakan parameter reka bentuk ergonomik yang dibangunkan iaitu biru sabak sederhana untuk warna latar belakang maya, 50% daripada kadar kecerahan, 85 darjah keluasan bidang pandangan, kadar aliran lima saat bagi setiap keping, gerakan rendah kelajuan objek maya, resolusi tinggi (1280 x 800), dan 24.58% kontras. Oleh itu, ia menunjukkan bahawa parameter reka bentuk ergonomik yang dibangunkan adalah sah untuk memenuhi keselesaan visual pengguna pada kadar signifikan 5% dan lebih berkesan untuk mengurangkan gejala visual pengguna. Kemudiannya, metodologi yang dicadangkan juga adalah sah dan sesuai untuk digunakan dalam bentuk kes-kes yang lain bagi bidang reka bentuk lingkungan maya ergonomik. Kajian ini mendapati penemuan yang signifikan untuk digunakan sebagai garis panduan rekabentuk product maya.

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LIST OF EQUATIONS

LIST OF SYMBOLS

n = Sample size required

p = Approximate proportion in population

d = Margin of error or absolute precision desired

$Z_{1-\alpha/2}$ = Reliability coefficient for a certain confidence level

α = Cronbach's alpha

B = Number of success

= Sample variance

p_i = Proportion receiving a score of 1

$1-p_i$ = Proportion receiving a score of zero

p_o = Specified number or proportion

f_e = Expected frequency

f_l = Column frequency

f_b = Row frequency

N = Sample size

U = U-value of Mann-Whitney test

$P(x,n)$ = Probability x for n sample

$n1$ = Sample size for sample 1

$n2$ = Sample size for sample 2

Rx = Sum of ranks in sample x

LIST OF ABBREVIATIONS

AD : Axiomatic Design

ANSI : American National Standard Institute

C# : C-Shaft

CA : Customer Attributes

CAD : Computer Aided Design

CC : Costumer Criteria

CRT : Cathode Ray Tube

DESA : Design Equation for Systems Analysis

DP : Design Parameter

EC : Ergonomic Criteria

EDP : Ergonomic Design Parameter

EP : Ergonomic Process

EPV : Ergonomic Process Variable

ER : Ergonomic Requirement

ES : Ergonomic Specification

EVE : Ergonomic Virtual Environment

FOV : Field of View

FRs : Functional Requirement

FR : Flow Rate

HFES : Human Factors and Ergonomic Society

HMD : Head Mounted Display

KMO : Kaiser-Meyer-Olkin

LCD : Liquid Crystal Display

PV : Process Variable

R&D : Research and Development

RE : Real Environment

SLU : Storage Loading and Unloading

SPSS : Software Package of Statistics Science

TFT : Thin Film Transistor

UA : User Action

USAF : United States Air Force

VE : Virtual Environment

VDU : Video Display Unit

VDT : Video Display Terminal

VR : Virtual Reality

VS : Visual Symptoms

VS_E : Visual Symptoms Eyestrain

VS_{BV} : Visual Symptoms Blurred Vision

VS_{DI} : Visual Symptoms Dry and Irritated Eyes

VS_{LS} : Visual Symptoms Light Sensitivity

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CHAPTER 1 INTRODUCTION

1.1 Background

Virtual environment (VE) is a sophisticated and innovative virtual technology that has potential for application in several fields, such as education, medical, entertainment, military, engineering, social-economics, and others. The aim of the application is for evaluation and analysis, physical therapy, design, game, training, military-strategic development, simulation, and teaching-learning process.

Wilson (1997;1999) defined VE as a computer-generated three-dimensional model environment, in which a user feels as if he or she is present in the environment and the user can interact intuitively with the objects contained within the model. The model is advantageous in experiencing new environment without having to build the real situation, and the experience comes with some side effects for some users. It has been reported that when interacting with VE through output and input devices, some users experienced negative side effects by being immersed into the graphically-rendered virtual worlds. One of the side effects is known as cyber sickness particularly affects the vision i.e. visual symptoms (Stanney *et al*, 1998; Barret, 2004). The user experienced this condition because the viewing demand of the task exceeds the user's visual abilities (Anshel, 2005).

The incidence of visual symptoms on VE may be influenced by a large number of factors, which involve individual limitation and ability especially on the eyes, where the limitation include accommodation, adaptation, visibility, visual acuity, binocular vision, eye movement skill or flexibility, eye recovery from glare, and eyes coordination

(Anshel, 2005). Stanney *et al* (1998) mentioned that for VEs to be effective and well received by their users and at the same time avoiding unwanted side effect, human being's limitation needs to be considered during the design stage of VE. It is highly essential to ensure that advances in VE technology will not be at the expense of human well-being.

Ergonomics is a branch of science that concerns with the achievement of optimal relationship between workers and their work environment (Tayyari & Smith, 1997). Since human being's limitation is crucial in the design process of a virtual environment, intervention of ergonomics will give an optimal VE experience for users. Good design that incorporates ergonomic considerations will enhance the communication between the user and the virtual world. Several ergonomic factors contribute to good VE design, and there is a need to investigate what are the critical ergonomic design parameters.

Most ergonomic researches are related to ergonomic design parameters, but the majority focus on physical ergonomics such as visual display terminal/unit design parameters (Stewart,1995; Menozzi, *et al,* 1999; Nichols, 1999; Shieh & Lin, 2000; Lin, 2003; ANSI/HFES100, 2007; Amick III, *et al*, 2012). Their research produced some design parameters related to office workstation (chair, table, keyboard height), type of display (LCD, CRT, HMD), and position of display monitor. Meanwhile, ergonomic research related to virtual environment have also been conducted in the past, but the focus of the research was only on the use of VE as a tool in ergonomic analysis, such as participatory ergonomic using VR, evaluating ergonomic and safety by using virtual humans and prototypes, ergonomic evaluation of virtual assembly tasks and process, and ergonomic measurements in VE and RE (Shaikh, *et al*, 2004; Colombo & Cugini, 2005; Pappas, *et al*, 2005; Dukic, *et al,* 2007; Hu, *et al*, 2011).

To create a virtual environment that is acceptable from the ergonomic point of view, Suh (2007) stated that the functional requirements (FRs) and constraints related to ergonomic issues must be identified and defined from the beginning of design process, where the design parameter (DPs) must be determined to satisfy the FRs independently. Axiomatic design (AD) constitutes a formalized methodology that can be used to represent a variety of design problems (National Academy of Engineering, 2002). Helander (1995; 2007) had conceptualized the use of AD procedures in ergonomic study and proposed design parameters in human computer interaction. In addition, Quill (2001), Helander and Lin (2002), and Lo and Helander (2007) introduced AD as the foundation in ergonomics design such as visual information, microscope workplace and hand tool design and also to analyze the complexity in human machine system. AD method provides a scientific basis, and logical and rational thinking process for the ergonomic design (Suh, 2001; 2007).

Thus, the integration of ergonomic principles and application of axiomatic design method could reasonably be a significant concept in this study in order to develop ergonomic design parameters for virtual environment, and also to propose a methodology in the field of ergonomic design.

1.2 Problem Statement

Based on the background above, the problems in this research are:

1. What are the critical ergonomic design parameters of the virtual environment?
2. What is the methodology to develop the ergonomic design parameters for virtual environment?

1.3 Objective of the Research

The main objectives of this research are:

1. To investigate the customer's criteria and ergonomic specification in designing virtual environment.
2. To develop ergonomic design parameter in designing virtual environment using axiomatic design method and to validate the effectiveness of the ergonomic design parameter of virtual environment
3. To develop a methodology for identifying the ergonomic design parameter in designing a virtual environment.

1.4 Significance of the Research

The results of the ergonomic design parameters and methodology allows the development of ergonomic design parameters for virtual environment. Ergonomic consideration consists of an important criterion during the virtual environment design stage so that the design is effective and well-received by users. Application of the axiomatic design provides a methodology to design the virtual environment and a scientific basis that is acceptable from the ergonomic point of view (Suh, 2001; 2007).

However, this research combined two main principles, namely ergonomics principle and axiomatic design principle as a new methodology in identifying the design parameters for the VE design that reduces the negative side effect. Thus, the research provides a significant contribution for designers to produce an ergonomic VE design. Furthermore, the research also provides a contribution in the development of science, especially in ergonomics and product design.

1.5 Scope of the Research

The research is confined to the development of ergonomic design parameters for virtual environment based on visual ergonomics principles. Ergonomics itself is multi-disciplinary in nature that covers psychology, physiology, biomechanics, sociology, anthropology, industrial engineering, and philosophy. Hence, it is necessary to limit the scope of the research to accomplish the aforementioned objectives. The application of axiomatic design principles also focuses on the first axiom, which is the independence axiom. It does not involve the second axiom (information axiom). It is because this axiom is only used for determining or deciding the best design among the developed independent designs. Furthermore, information axiom is not relevant with the objective of this study. Thus, the development of methodology emphasizes on the integration of two design principles, which are visual ergonomics and independence axiom design.

The research is also confined to subjective response, especially on visual comfort. Moreover, due to so many factors and response involved, it is difficult to measure them objectively, as well as testing the validity in a limited time given.

For the case study of virtual environment, the research focused on the simple operation in manufacturing. It uses a virtual robot manufacturing system.

1.6 Organization of Thesis

The thesis consists of nine chapters. The first chapter is the introduction of the problems that will be discussed. It encompasses the background of research, problem statement, objectives of research, significance of research, scopes of research, as well as organization of thesis.

Chapter 2 is the literature review that explains the result of some existing research projects related with the application of ergonomic principle to develop the design parameters of virtual environment. The implementation of independence axiom method to create the design that is acceptable from ergonomics point of view is also presented. Thus, it can be expected that the literature review may increase the area and deepen the process of developing independence ergonomic design parameters, as well as developing the methodology or solving the problems faced.

Chapter 3 consists of the research methodology. This chapter describes the process of data collection which comprises survey and empirical study method and the process of data analysis that covers non-parametric statistical analysis. The visual ergonomic principles and axiomatic design method will also be explained in this chapter.

Chapter 4 presents the results of customer survey related to the criteria that customer requires in the virtual environment design. This chapter includes the result of descriptive analysis and reliability test, as well as hypotheses test on two different independent samples using Binomial test, Chi-square test and Mann-Whitney test.

The next chapter is Chapter 5 that describes the application of the axiomatic design concept to develop the ergonomic design parameter for virtual environment. This chapter will explain the mapping process that involves customer domain (CA), functional domain (FR), and physical domain (DP). This chapter will also explain the result of empirical study related to visual comfort. It investigates the effect of attributes of virtual environment on the incidence of visual symptoms.

Chapter 6 contains the design of VE based on the ergonomic design parameters developed for validation. This chapter also presents the validation test on the effectiveness of the ergonomics design parameters developed. The development of the proposed methodology for inventing the ergonomics design parameters for virtual environment is presented as well.

The discussion is presented in Chapter 7. The content of this chapter shows data analysis that covers the analysis of customers' voice, ergonomic criteria, and design process of the virtual environment design. The analysis of validation test and the methodology developed will also be presented.

Finally, Chapter 8 is the conclusion and recommendation for future research. The conclusion is summary of results that satisfy the objectives of the study. Recommendations are also given for the success of further research. In addition, major contribution of this research will also be presented.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

This chapter presents a review of the literature on the ergonomics design parameters for virtual environment. Its aim is to investigate existing research on ergonomic design parameters and methodologies to design virtual environment. Chapter 2 encompasses five sections. Section 2.2 presents a review on virtual environment design. Section 2.3 is reviews the ergonomic design parameters and virtual environment, while Section 2.4 reviews the application of axiomatic design principles in ergonomic design. Finally, section 2.5 is the conclusion of the literature review.

2.2 Virtual Environment Design

Virtual environment (VE) can be defined as a computer generated three dimensional model environment, where a user feels as if he or she is present in the environment and the user can interact intuitively with objects contained within it (Wilson, 1999). Virtual environment and virtual reality are usually used synonymously as three-dimensional data set describing an artificial environment that the user interacts with (Blade & Padgett, 2002). Whyte (2002) in Figure 2.1 explains the component of a VR system consisting of computer hardware and software, input and output devices, data and user. The input and output devices are used to interact more intuitively with virtual environment. The simplest input devices are conventional keyboard or mouse, trackball or joystick. These devices allow the tracking of the position of virtual object in three positions (X, Y, Z) and three orientations (roll, pitch, and yaw). Meanwhile, the common output device is visual display of virtual environment. These devices can be stereoscopic with different pictures viewed through each eye, or monoscopic, where both eyes seeing the same picture. Head mounted display is immersive visual display, while the desktop monitor is non-immersive visual display.

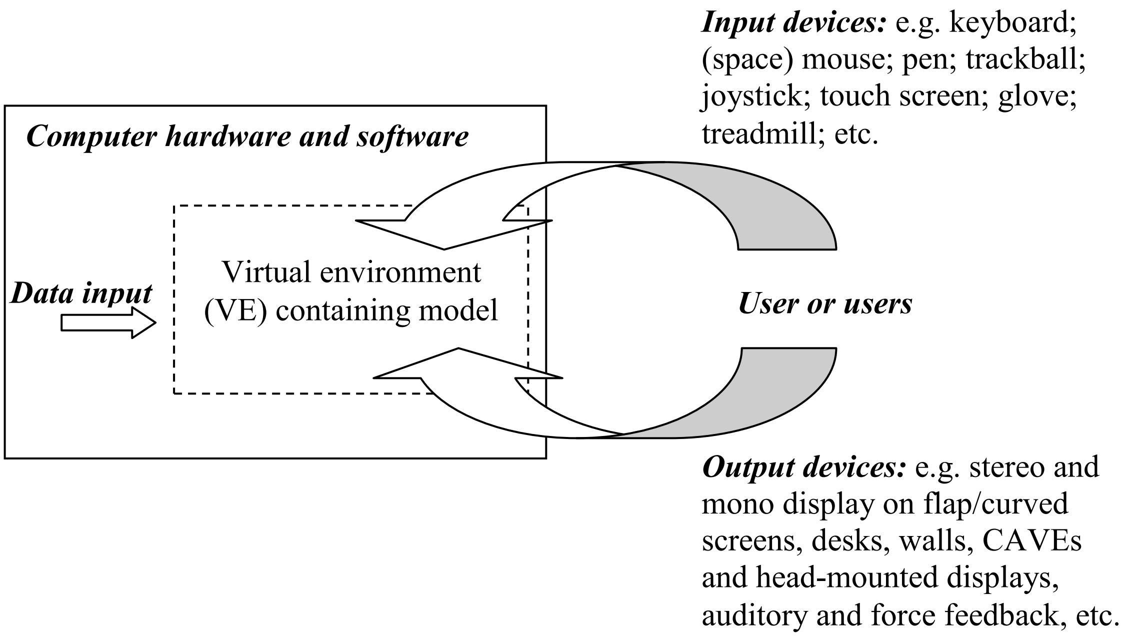


Figure 2.1 Components of virtual reality system (Whyte, 2002)

Whyte (2002) further explained that in computer hardware and software, the data input is the key part of VR system. Models can be built within the virtual environment, but it may also be imported from computer-aided design (CAD), therefore users can interact with data. However, this research focuses on the virtual environment as previously mentioned.

Virtual environment has been implemented in many applications such as tool for testing, simulation, training, analysis and evaluation, as well as teaching-learning process, such as in medicine, engineering, military, education, entertainment, architecture, and others. It is advantageous in experiencing new environment without having to build the real situation. However, it has been reported that some users experienced negative side effects by being immersed in the graphically rendered virtual worlds when interacting with VE through output and input devices. One of the side effects is known as cyber sickness i.e. the vision of the person is affected (Stanney *et al*, 1998; Nichols & Patel, 2002; Barret, 2004). Stanney *et al* (1998) further mentioned that for VEs to be effective and well received by their users, and at the same time avoiding unwanted side effects, human being's limitation needs to be considered during the design stage of VEs. It is highly essential to ensure that advances in VE technology will not be at the expense of human well-being.

2.3 Ergonomic Design Parameter and Virtual Environment

Ergonomics is a branch of science that is concerned with the achievement of optimal relationship between workers and their work environment (Tayyari & Smith, 1997). Since human being's limitation is crucial in the design process of a virtual environment, implementation of ergonomics will bring about an optimal VE experience for users. Good design incorporating ergonomic considerations will enhance the communication between the user and the virtual world. Since several ergonomic factors contribute to good VE design, there is a need to investigate what the critical ergonomic design parameters are.

2.3.1 Review on Ergonomic Research and Virtual Environment

Ergonomics research related to virtual environment has been conducted in the past, but the focus of the research is only on the use of VE as a tool in ergonomics analysis and problem solving (Gill & Ruddle,1998; Shaikh, *et al*, 2004; Pappas, *et al*, 2005; Colombo & Cugini, 2005; Caputo, *et al* (2006); Dukic, *et al,* 2007; Honglun, *et al*, 2007; Jung, *et al*, 2009; Hu, *et al*, 2011). Gill and Rudles (1998) investigated the feasibility of integrating virtual human into design of virtual environment to solve real ergonomic problems. An industrial case study was used in the ergonomic evaluation. The result of this study showed that the ergonomics assessment utilizing virtual human was beneficial and has a potential in further development of virtual environment/reality.

Shaikh *et al.* (2004) presented a study on participatory ergonomics using virtual reality system. This study integrated an interactive immersive simulation tool and a commercial human modelling simulation system to demonstrate virtual assembly system. Through this integration, ergonomic analysis was conducted by providing a dynamic analysis of posture for human modelling system. The study found that the use of immersive system would help towards designing better workplaces and developing optimum product development cycle. Pappas *et al.* (2005) also investigated the ergonomic evaluation of virtual assembly tasks by using virtual reality and human simulation technology. In this study, the execution of assembly task was evaluated in terms of ergonomic through the developed virtual workstation and human modelling. This enables the identification of critical points in the assembly procedure, where re-design of the assembly procedure was required for better ergonomic and efficiency.

Colombo and Cugini (2005) investigated an approach on the use of virtual humans and prototypes to evaluate product ergonomics and safety. The research involved two case studies to demonstrate the validity of this approach; virtual interior of cars and virtual workstation of a riveting system. The results of this work showed that virtual human was an important tool to improve functionalities of virtual prototype, as well as to increase ergonomics and the safety of the product. Caputo *et al.* (2006) developed a method to study the ergonomics optimization of a work cell in automotive manufacturing system. This study simulated human performances during the execution of assembly operation in a virtual environment involving digital human models and VR technique. The results showed that the proposed methodology can be used to evaluate the performance of workers in a workplace before it is implemented in the real situation.

Meanwhile, Dukic *et al.* (2007) researched the use of virtual tool to evaluate the ergonomics of a pre-production phase by verifying the manual assembly of a car model. The results showed that virtual development process using computer manikin was a viable tool to verify ergonomics in the early development process and as an aid to detect some problems prior to physical manufacturing. Honglun *et al.* (2007) studied on virtual human in ergonomics simulation to evaluate and validate the virtual product development. In this study, the ergonomic virtual human was developed based on biomechanics/physiology model, anthropometrics model, posture and motion model, task model, human reactions and decision making model, and human factor analysis model. The result of this ergonomics simulation was an important part of virtual product development and can be brought into life cycle product development. As for Jung, *et al* (2009) they proposed a method of digital human model generation as tool for ergonomic design and evaluation of product and workplaces in virtual environment. This study applied this method into a web-based system for interior design of passenger car, and the result showed that the proposed method was an effective tool that is capable of generating a group of digital human models representing the target population with different nationality, gender, and accommodation percentage.

Hu, *et al* (2011) presented a study on whether the ergonomic measure from a virtual environment might represent the real environment or not. The preliminary experiment was conducted for some typical “drilling” task and ergonomic assessment was carried out in both VE and RE. The result indicated that discomfort and fatigue experienced by subject was quicker in VE than in RE, but it was found that there were linear correlations between them.

2.3.2 Ergonomics Design Parameters for Virtual Environment Design

Ergonomic design parameters are the most important requirement that should be considered in the design of a VE so that it does not result in negative effects on users, especially on vision. Many research related to ergonomic design parameters have been conducted, but these studies only focused on physical ergonomics of human-computer interaction, such as visual display terminal (VDT). Stewart (1995) exhibited the importance of ergonomic standards for computer equipment (ISO 9241), and the necessity in understanding how to use them when designing visual display unit (VDU) equipment and systems**.** The standard provides the type of information to be considered and used when designing the ergonomics aspect or properties of a system.

Ziefle (1998) presented an experimental study concerning the effect of display resolution on visual performance. Two (60 and 120 dpi) and three (62, 69 and 89 dpi) resolution of cathode ray tube (CRT) were examined on proofreading speed, accuracy and eye movement parameters in a visual search task. This study found that the use of high resolution display might optimize the visual performance, which makes viewing more comfortable and avoid visual fatigue. Menozzi, *et al* (1999) conducted studies to compare the suitability of CRT display and liquid crystal display (LCD) in visual tasks of VDU. It was found that LCD provided better viewing conditions compared to CRT display.

Nichols (1999) investigated the design of VR equipment with respect to physical ergonomics such as head mounted display (HMD) and hand-held input devices, as well as the problems associated with the design. However in 1996, Rinalducci, *et al* conducted a study on the use of HMD in virtual environment. The study investigated the use of a physiological method to determine the horizontal and vertical field of view (FOV) of an HMD. It focused on designing a simple equation to determine the basic dimension of the display.

Shieh and Lin (2000) investigated the effect of screen type, ambient lighting and colour combination of VDT on visual performance, and they found that those factors affected VDT performance. Lin (2003) studied the effects of contrast ratio and text colour on visual performance using TFT-LCD, and it was determined that the contrast ratio significantly affected visual performance.

Several other studies related to design parameters of workstation of VDT/VDU have also been conducted. One of the studies was conducted by Straker and Mekhora, (2000). This study investigated the effect of visual display unit monitor placement on the gaze, head, neck and trunk posture. The experiment was carried out by using two VDU monitor placement conditions; high and low monitor position. It was found that low monitor position caused greater discomfort on gaze, head, neck and trunk than high position. According to this study, it was suggested that users may use high monitor position during work because it could produce less flexion on head, neck and trunk posture. Rempel, *et al* (2007) also investigated on visual display unit and focusing on the effect of the distance of visual display on the visual and musculoskeletal system, especially on neck comfort. The result of this study recommended that the position of the computer monitor should be between near (52cm) and middle (73cm) distance from eyes if the size of the character on the computer screen was close to the visual acuity limits.

Ntuen, *et al* (2009) conducted two experiment to assess the difference between 2 D & 3 D modes of auto stereoscopic display on the effect of viewing field and illumination on performance and visual fatigue. The results showed that there was no difference between 2D and 3D modes in auto stereoscopic display, based on visual fatigue and performance.

In 2007, after being approved by ANSI on 14th November, Human Factor Engineering Society published a new national standard for human factor engineering of computer workstation (ANSI/HFES100), which eventually became the comprehensive ergonomic guideline for the design of a VDT. Meanwhile in 2012, Zunjic *et al* had developed a useful tool for assessment of VDT regarding health and safety.

To create a design of virtual environment that is acceptable from the ergonomic point of view, Suh (2007) stated that the functional requirements (FRs) and constraint related to ergonomic issues must be identified and defined from the beginning of the design process, where the design parameter (DPs) must be determined to satisfy the FRs independently.

2.4 Application of Axiomatic Design Principles to Ergonomics Design

Axiomatic design principle is a method that provides a scientific basis for design and improvement of design activities based on logic and rational thought process and tools by clearly formulating the design objectives through the establishment of functional requirement and constraint (Suh, 1990; 2001). Furthermore, Suh (2001) explained that the goals of axiomatic design principle are:

- To make human designers more creative;
- To reduce the random search process;
- To minimize the iterative trial–and–error process;
- To determine the best design among those proposed; and
- To endow the computer with creative power.

To achieve those objectives, the concept of domain that provides an important foundation of axiomatic design needs to be understood as this concept creates demarcation line between four different kinds of design activities. The structure of the domain can be seen in Figure 2.2. It consists of customer domain, functional domain, physical domain, and process domain, where the domain on the left represents "what we want to achieve" and the domain on the right represent the design solution "how we propose to satisfy the requirements specified in the left domain" (Suh, 1990, 2001).

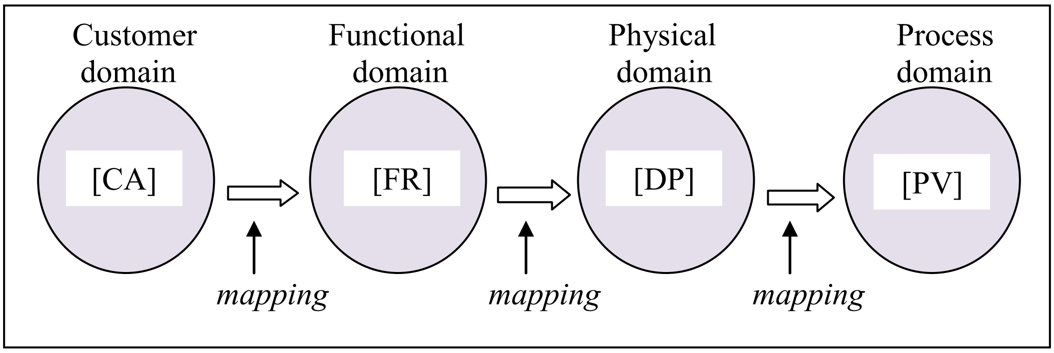


Figure 2.2 Four domains of design process (Suh, 1990, 2001)

Customer domain is related with the criteria of the product (virtual environment) that the customer requires. The criteria (CAs) are specified in terms of functional requirement (FRs) in the functional domain. In the physical domain, design parameters are realized to satisfy the specified FRs. Finally, it is developed into the process (PVs) to produce the product in terms of DPs.

This method has been applied in a variety of research fields such as product design, system design, manufacturing system design, software design, organization, and decision making, as well as evaluation system (Kulak, *et al*, 2010). Thielman and Ge (2006) applied the axiomatic design theory to evaluate and optimize the large-scale engineering systems. In this study, they proposed a systematic methodology for implementing Suh's axiom in a case study of a nuclear reactor system. An R/S analysis using surrogate modelling and optimization was used to achieve a less functional couple design. The results showed that the use of the proposed methodology provides an efficient approach to evaluate and optimize a large scale engineering system against multiple design objectives.

There have also been quite a number of researches in the ergonomics field that are related to the application of AD, either theoretical or empirical studies. Helander (1994, 1995) proposed the use of AD procedures in ergonomics to avoid costly experimentation, where this procedure was applied by top-down approach. According to the author, the design process could be conceptualized as four consecutive steps: costumer requirements (CRs), functional requirements (FRs), design parameters (DPs), and process variables (PVs), where synthesizing process for DPs specification was developed based on designer's knowledge and creativity (Figure 2.3). Therefore, a designer should be able to develop a process based on his knowledge, experience, and associations to propose a new design. In the study, the design of height adjustability of a microscope workstation was used as an example of this procedure. The developed design parameters (DPs) satisfied the functional requirement (FRs), which implies uncoupled design was a one-to-one correspondence between height adjustable foot rest (DP1) and support the feet (FR1), height adjustable table (DP2) and table height at sitting elbow height (FR2), and height adjustable of separate microscope table (DP3) and eyepieces at eye level (FR3).

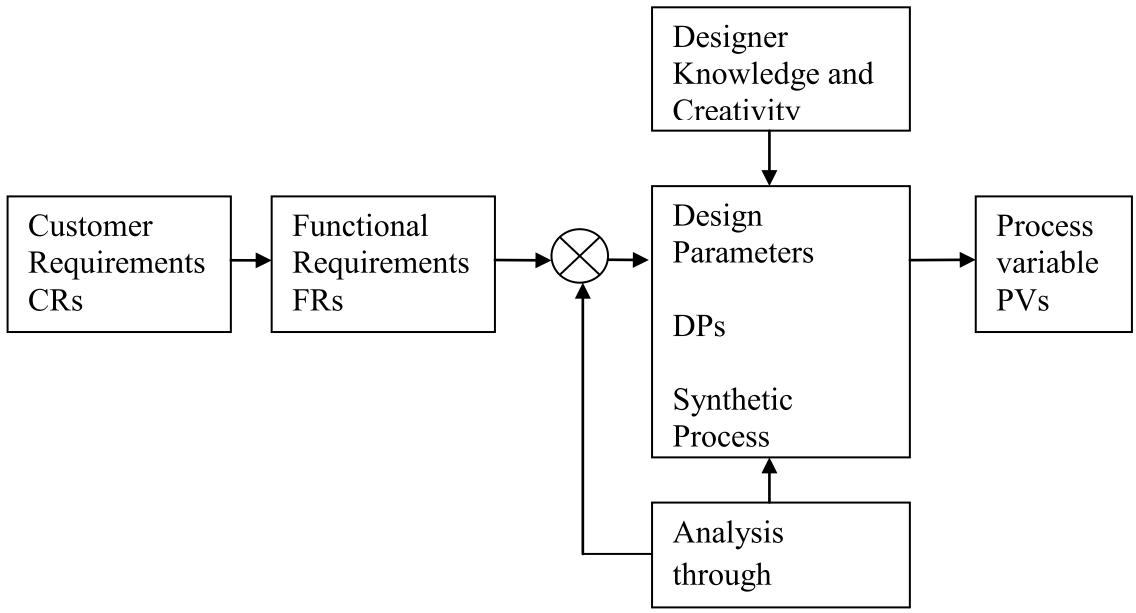


Figure 2.3 Conceptualization of design process (Helander, 1994; 1995)

Quill *et al* (2001) applied AD to integrate the information visualization method into a USAF R&D design during several development phases. According to this study, the quality of user displays might be improved and the design modification could be minimized through information visualization techniques and the use of system development process.

Furthermore, Helander and Lin (2002) introduced AD as a foundation in ergonomics design, where an anthropometric design of microscope workplace and biomechanical design of hand tools were designed to demonstrate the use of this approach. The study used the independent axiom to structure the design activity that could avoid time-consuming iterative improvement of design solution and the information axiom for anthropometric design of a workplace as a new way to determine the information content. The case studies demonstrated the strong potential for the application of AD in ergonomics.

Karwowski (2003) conceptualized four domain of AD for ergonomics design purposes. They are: 1) customer domain described in terms of human factor engineering requirement; 2) functional requirement and constraints expressed in terms of human capabilities and limitation; 3) physical domain in terms of design of compatibility, expressed through the human system interaction and specific work system design solution; and 4) process domain defined as management compatibility (Figure 2.4). In 2005, Karwowski introduced an axiomatic approach to ergonomics design and a universal measure of system-human incompatibility.

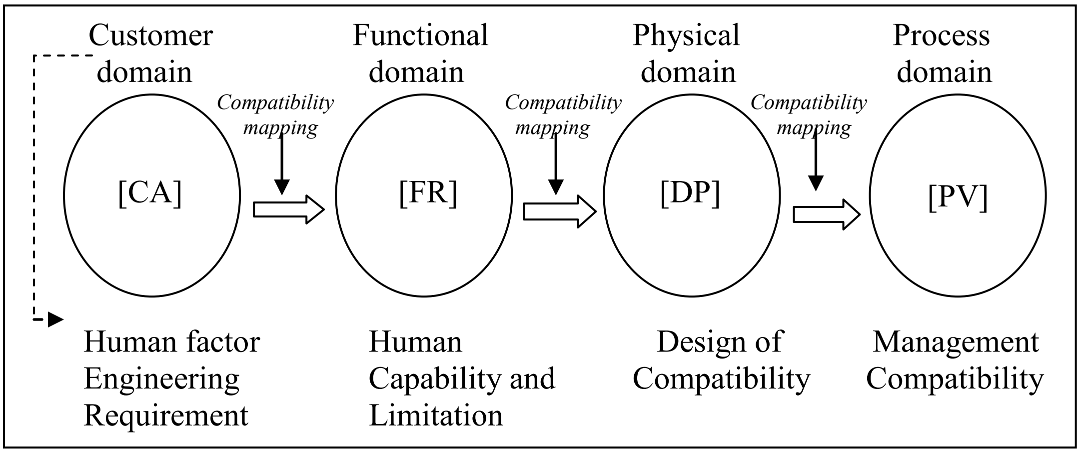


Figure 2.4 Conceptualization of four domains of AD for ergonomic design purposes (Karwowski, 2003)

Suh (2007) proposed the application of AD and complexity theory in ergonomics design to improve the robustness and efficiency for satisfying the functional requirement. According to these theories, AD established the criteria for the best design, whereas complexity theory reduced complexity in human machine interaction. In the study, the uncoupled design was the best from the ergonomic point of view as it did not have imaginary complexity, hence relieving unnecessary work.

Helander (2007) presented a study to identify the sources of couplings and proposed new design parameters that uncoupled the design in human-machine interaction. In this study, a method for human factor design was developed by referring to the independent axiom called Design Equation for Systems Analysis (DESA). It was exemplified by some case studies to illustrate the implementation of DESA that is useful for analyzing existing design and synthesizing new design alternatives. The study concluded that DESA was a new design method in ergonomics combined the features of uncoupled design and minimum information design.

Lo and Helander (2007) conducted a study to analyze the complexity in human-machine system and developed a methodology for eliminating the couplings. In this study, design domain (goal domain, functional domain, physical domain, and action domain) were used to construct a model of human-machine interaction. The design equation was also applied in the mapping process among these domains, which provides qualitative metric for characterizing the degree of coupling. Functional model of the system was represented by the goal and action domains, while structural model of the system was represented by the functional and physical domains (see Figure 2.5). Several examples were presented for illustrating the proposed methodology.

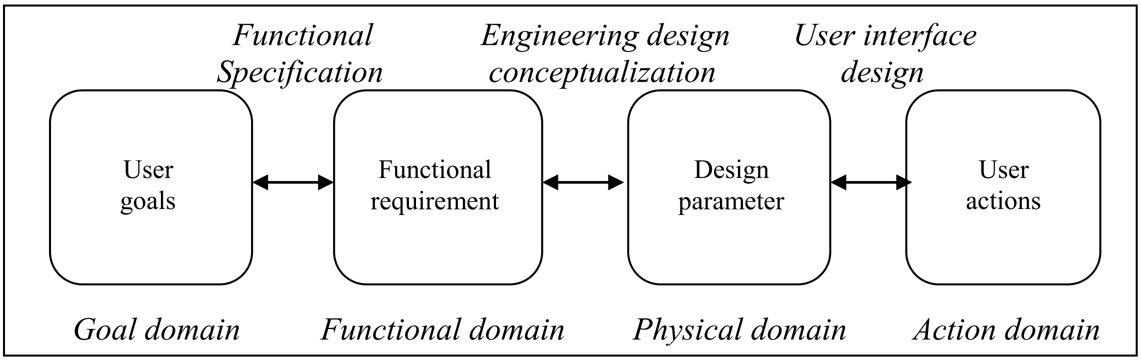


Figure 2.5 Design equations for systems analysis' framework consists of four design domains (Lo & Helander, 2007)

2.5 Conclusion

It is concluded that there is an absence of ergonomics design parameters in the design of a virtual environment. There is also no methodology to develop the ergonomics design parameters for a virtual environment. Therefore, there is a need for identifying the parameters and developing a methodology for ergonomic design of a virtual environment.

CHAPTER 3 RESEARCH METHODOLOGY

3.1 Introduction

This chapter describes the research design and the methods used to collect and analyze data as well as to test the hypotheses and validate the effectiveness of ergonomic design parameters. Section 3.2 presents the research framework and the flow diagram of the research. Section 3.3 presents the visual ergonomics principles, and the axiomatic design procedure is explained in Section 3.4. Section 3.5 and Section 3.6 present the methods of survey and empirical study, respectively. The apparatus of research is described in Section 3.7 that covers population and sample, questionnaires and virtual stimulus developed. Section 3.8 presents statistical method for data analysis. Finally, the conclusion is presented in section 3.9.

3.2 Research Framework and Flow Diagram

This study applies the method of inductive study, where empirical evidence from previous study was used to develop a general concept. The framework of this study began with a customer survey. Then, the experiments were conducted, where the ergonomic design parameters of the virtual environment were identified. Finally, a methodology was proposed after the evidence of the empirical study has been validated.

Ergonomics, especially the visual ergonomic principle, was used as the basic knowledge to develop ergonomics design parameters. The independence axiomatic design method is an approach to map ergonomic domains. Figure 3.1 presents the framework of the study.

The flow chart of the research activities can be seen in Figure 3.2, which consists of three parts. The first part of the research began with a literature review. The literature review was conducted to identify existing research related to ergonomic criteria or parameters in virtual environments (VE) design and methods used to identify it. Next, the problem and the research objective were developed.

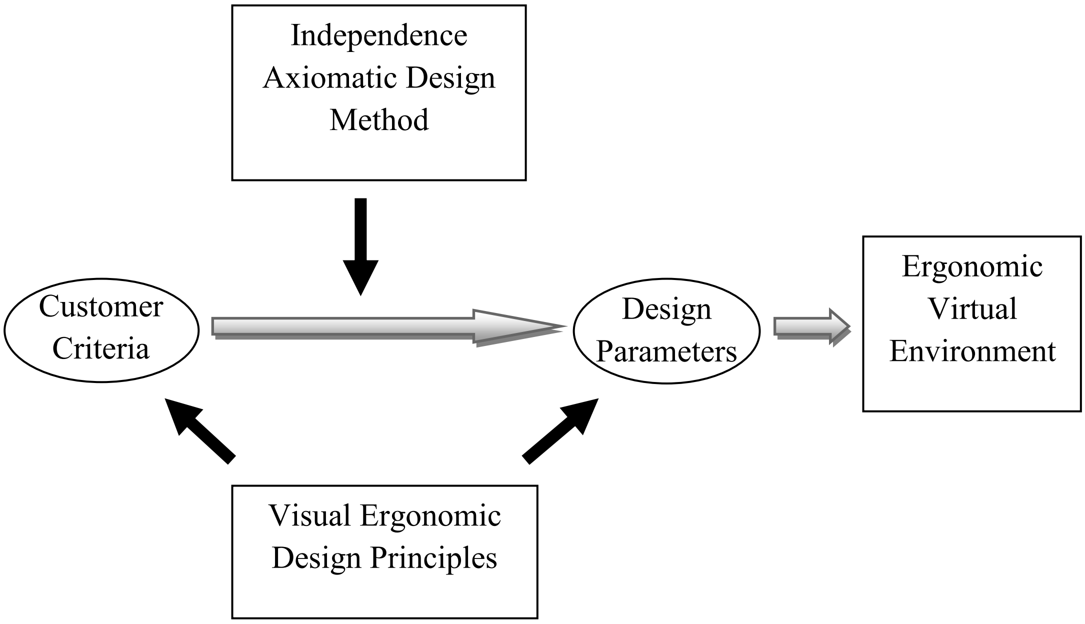


Figure 3.1 The Research framework

Questionnaires were developed to identify the attributes that customers looked for in the virtual environment, as well as visual symptoms. The experimental procedure was also designed. A paper-based survey was conducted to identify customers' requirements of a virtual environment.

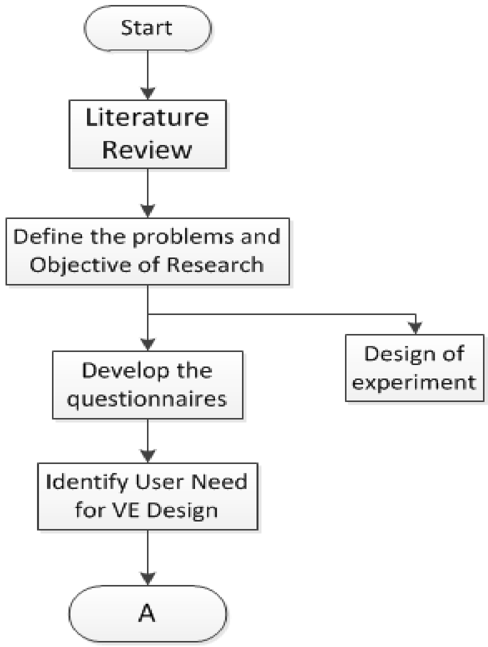


Figure 3.2 Flow chart of research part 1

Figure 3.3 presents the flow chart of part 2 of the research, where the variables or attributes of virtual environment that affected visual symptoms based on the experiment were identified. This is an empirical study to prove the effect of some attributes of virtual environment identified from visual symptoms by applying statistical test.

In the next part of the research (see Figure 3.4), the axiomatic design principles were applied to determine the ergonomics design criteria or parameters of the virtual environment design. The flow started by specifying functional requirement (FR) and constraints, and mapping the FRs to design parameters (DP). In this part, validation was also conducted.

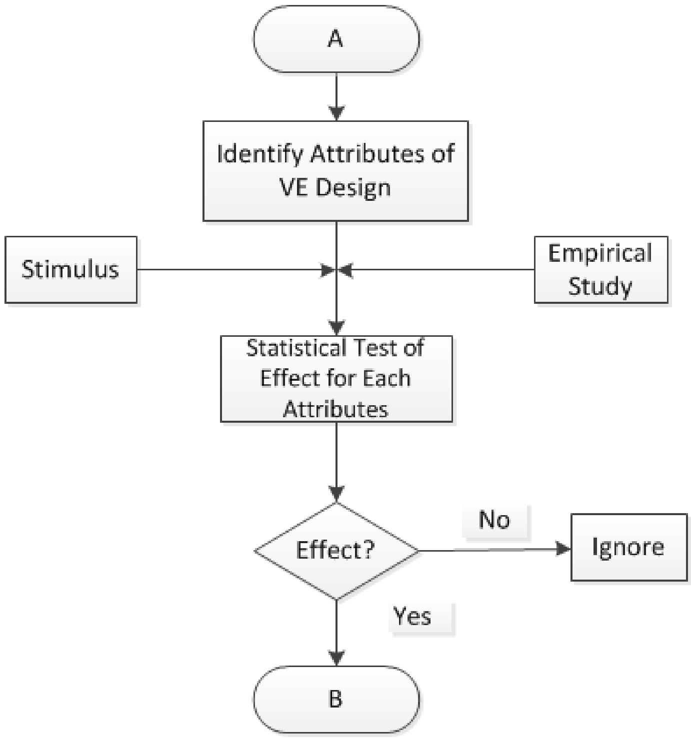


Figure 3.3 Flow chart of research part 2

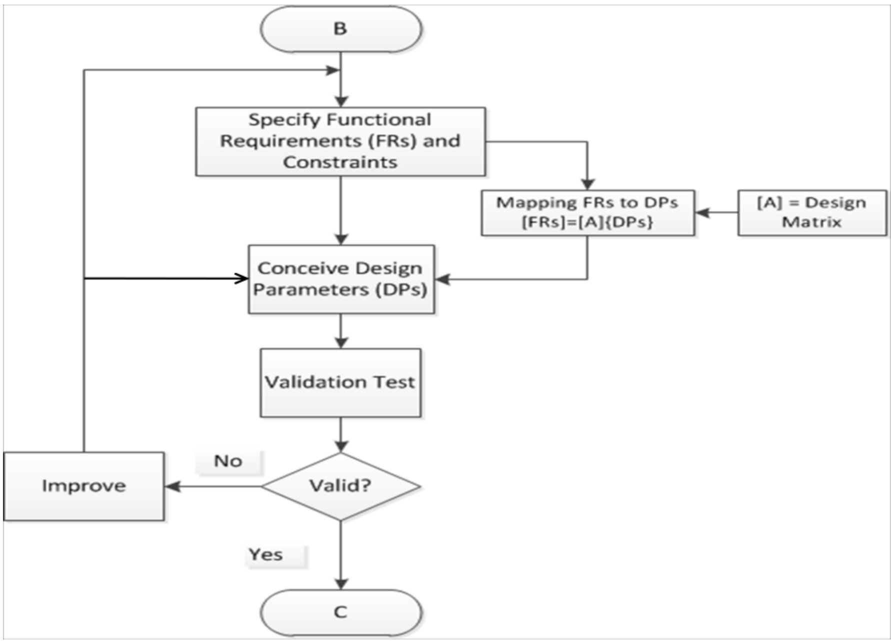


Figure 3.4 Flow chart of research part 3

3.3 Principle of Visual Ergonomic Design

"Fitting the Task to the Man" is a general principle and substantial in the ergonomic design. This principle explains that the design of the product (Task) should take into consideration the limitations of the user (Man) so that it is able to ensure the comfort, safety and health of the users (Granjdean, 1986). Thus, an understanding of human limitation is a critical point in designing the ergonomic product.

In the concept of visual ergonomic, this limitation is related to human vision (eyes), which includes the limited ability of the eyes to see an object clearly (visual acuity), the limited ability of the eye to adjust to changing light condition (adaptation), the limited ability of the eyes to see an object in certain distance (visibility), the limited ability of the eyes to see visible area (visual field/FOV), the limited ability of the eye's lens to change its focal length or to focus on near and far objects (accommodation), and others (Tayyari & Smith, 1997). The design which is not able to meet these limitations may result in visual syndrome or symptoms on the sense of vision. Anshel (2005) mentioned that visual symptoms varies but mostly include eyestrain, headaches, blurred vision (distance or near), dry and irritated eyes, slow refocusing, neck and backache, light sensitivity, double vision, and colour distortion. Thus, a virtual environment should alleviate or minimize, or even relieve these symptoms.

3.4 Axiomatic Design Principle

In his book, Suh (1990, 2001) explained that design involves a continuous interplay between *"what we want to achieve"* and *"how we want to achieve it"*. Subsequently, Suh (2001) expressed that the concept domain is to systemize the thought process involved in this interplay. This concept creates demarcation lines between four different kinds of design activities that embody the customer domain, which are the CAs (customers attributes) for a design; the functional domain, which are the FRs (functional requirements) that satisfy the CAs; the physical domain, which are the DPs (design parameters) that satisfy the FRs; and the process domain, which are the PVs (process variables) to produce the design specified in terms of the DPs (see Figure 3.5).

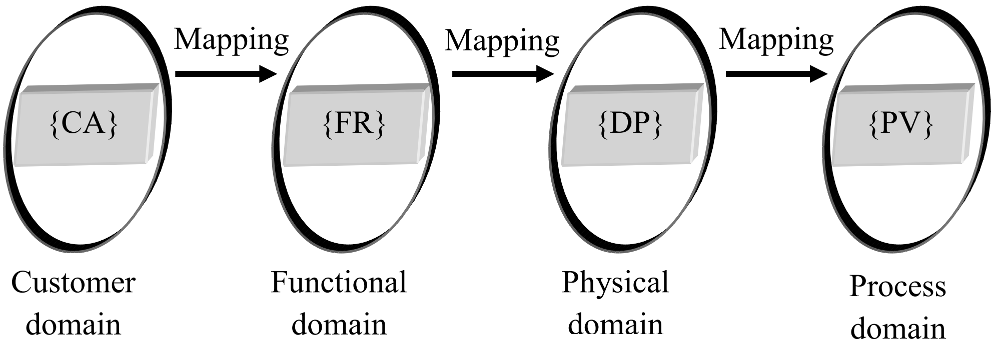


Figure 3.5 Four domains in axiomatic design framework (Suh, 2001)

In the mapping process from domain to domain, Suh (2001) recommended to conduct the process within a *"solution-neutral environment"*. This means that mapping must be defined without thinking about something that has already been designed. Once the CAs has been identified and defined, these attributes must be translated into FRs and map them into specific DPs satisfying the FRs, and also into PVs that can satisfy the DPs specified. This process began as one of many processes in a hierarchy way that is also called zigzag or decomposition process, by referring to two axioms: the independence axiom (axiom 1) and the information axiom (axiom2).

Axiom 1 states that the independence of FRs is not affected by others FRs. Thus, a correct set of DPs has to be selected to satisfy the FRs that maintains the independence

(Suh, 2001). This mapping process can be formulated mathematically as mentioned by Suh (2001):

(3.1)

Where is a design matrix that relates FRs and DPs. Figure 3.6 shows three types of design matrix of the uncoupled design or the diagonal matrix, which is an ideal design with each of the DPs controls only one of the FRs (Figure 3.6 (a)). Next, the decoupled design or a triangular matrix is shown in Figure 3.6 (b). If the independence of FRs cannot be satisfied by an uncoupled, the independence of FRs can be met if and only if the DPs are determined in a proper sequence. In accordance with Suh (2001), when a matrix produces a coupled design or a full matrix (Figure 3.6 (c)), then it may result in many problems in the design process. Therefore, the coupled design is not robust and should not be considered as DPs. To satisfy the independence axiom, Suh (2001) suggested that the design matrix must be a diagonal matrix or triangular matrix.

(a) (b) (c)

Figure 3.6 Three types of design matrix; (a) uncoupled design, (b) decoupled design, and (c) coupled design (Suh, 2001)

Axiom 2 states that the design with the smallest information content is the best design among those designs that satisfy the independence axiom (Suh, 2001). In this research, axiom 2 is not considered since it is not part of the objective for this research.

Moreover, only axiom 1 is required to develop design parameters of virtual environment based on ergonomic principles.

3.5 Survey

A paper-based survey was conducted within a specified period. The survey encompassed three main objectives. The first objective was to identify some attributes that customer are looking for in the virtual environment. In this survey, questionnaires were distributed randomly to more than one hundred respondents. Only questionnaires with valid feedback were considered in the next analysis. The second step was to investigate the effect of virtual environment attributes to visual symptoms. This survey identified visual symptoms that user's experienced when interacting with the virtual environment. Here, the participant was asked to complete a certain questionnaire. Lastly, the third step was to validate the effectiveness of the ergonomics design parameters developed. This survey identified the suitability of the design parameters developed to the customer's criteria of virtual environment, as well as the level of visual symptom experienced.

3.6 Empirical Study

The objective of the empirical study was to analyze the effect of virtual environment attributes on the visual symptoms and to validate the design parameters for designing of virtual environment.

3.6.1 Experimental Design

The experiments were conducted at the ergonomic-virtual reality laboratory, which consists of two experiments in a sitting posture and no any changing on posture during completing the task. The first experiment was to study the ergonomics attributes and the other was for validation.

In the first experiment, the subject sits (maintain in sitting posture) at a distance of 15 – 25 cm from the back edge of the table to complete the task (see Figure 3.7). The activity was to operate a virtual robot in the VE using an infrared mouse (wireless mouse) and the motion was observed on the wide screen display. The digital projector was positioned on a table of 75 cm in height and with an inclination angle between 5^{o} -10^{o} with respect to the horizontal axis. The projector was connected to a laptop with a display set to 1280 x 800 pixels. The distance from the front edge of the table or the digital projector to the centre of the wide screen was 300 cm. The size of wide screen display was 170 cm in length and 155 cm in width. The bottom edge of the wide screen display was measured at 94 cm above the floor. Prior to conducting the experiment, the subjects adjusted their seating positions to make them as comfortable as possible.

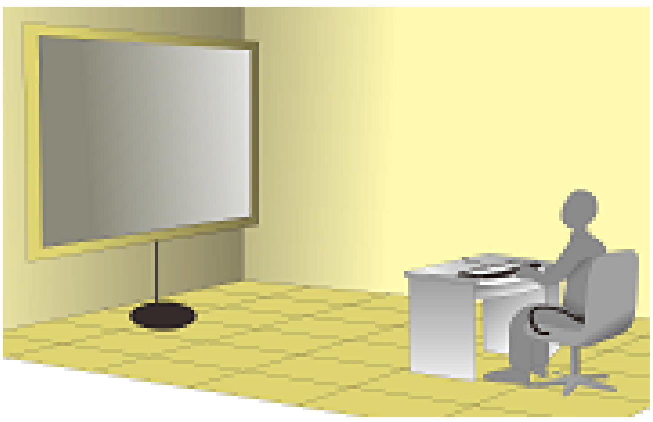


Figure 3.7 A snapshot of a design of the first experiment

Meanwhile, Figure 3.8 describes the second experiment where all variables were similar to the previous experiment, except for the use of screen. This experiment used a 21 inches liquid crystal display (LCD) monitor and located on a table with a normal position. This was based on user preferences obtained from the survey, where 80.54% of users preferred LCD monitor to other displays (i.e. CRT and wide screen display).

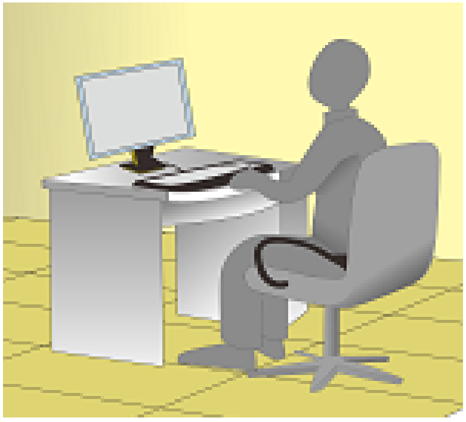


Figure 3.8 A snapshot of a design of the second experiment

3.6.2 Virtual Task Design

A simple virtual task, storage loading and unloading activities (SLU) was conducted in this research, where the user picks up a virtual material on a rack and put it on a conveyor, and subsequently to also picks up a virtual product on the conveyor and stores it in another rack. The activity was performed for 10 minutes.

3.6.3 Experimental Procedure

The subjects were provided with information describing the aims of the study and how the experiment would be conducted. Their health condition and medical history were also identified and their anthropometric data were measured. Colour blind test was then conducted before proceeding to colour selection and the experiment. If a subject could not complete the test, it means that the subject has some visual problems and was unable to continue the experiment.

Prior to performing the experiment, subjects were trained on how to use the wireless mouse in order to operate the virtual robot in VE to complete the virtual task. In the experiment, subjects were exposed to the virtual environment to view and operate a virtual robot by using a wireless mouse; to pick up a virtual material in a rack and put it on a conveyor and subsequently to pick up a virtual product on the conveyor and store in another rack, as shown in Figure 3.9. The activity was performed for 10 minutes for every subject. All subjects were required to sit in an upright posture and also in a comfortable posture while completing the virtual task. Participants were also instructed to complete the questionnaire immediately after finishing the virtual task.

3.7 Apparatus

3.7.1 Population and Sample

The subjects were male and female university students familiar with virtual world. The age range of the subjects was between 17 to 40 years old. Samples were taken randomly to identify customer's needs for the virtual environment design survey. Eight samples were chosen to identify the attributes of VE and twenty one samples for the validation of each university students participated in the empirical study, where none of the participants suffered from any vestibular dysfunction or were taking any medication during the experiment. Participants were tested individually during the entire experiment session and they were given token of appreciation for their participation.

3.7.2 Questionnaire Development

A qualitative assessment was conducted by using questionnaire. Three set of questionnaires were developed. The first questionnaire was used to identify the attributes or variables that a customer looks for in the virtual environment design (see Appendix A). This questionnaire consists of two parts; personal background and virtual environment characteristics.

The second was a questionnaire to investigate the effect of the attributes/variables of the virtual environment on user's vision (i.e. visual symptoms) (see Appendix B). The questionnaire consists of two principal parts. The first part contained questions with seven response option. This questionnaire was aimed to identify visual problems experienced during or after interacting with VE. The second part contained questions to identify the level of symptoms experienced based on the answers of the previous part. The answers to the questions in the second part were ordinal data type. Finally, two types of questionnaires were utilized to validate the effectiveness of the developed ergonomics design parameters (see Appendix C). The first type contained questions to identify the level of criteria of virtual environment, and the second type contained questions to identify the level of visual symptoms experienced.

3.7.3 Virtual Stimulus Design

The virtual stimulus system used was a virtual robot manufacturing system (henceforth will be referred only as the virtual environment (VE)). This virtual environment presents a virtual robot activity for storage loading and unloading (SLU) process (shown in Figure 3.9). It was developed using *Direct X* and Dark Basic Professional, as well as C# programming. Autodesk 3DS Max software was used to build the virtual object. VE was displayed through a projector on a wide screen display and 21 inches LCD monitor. The projector was connected via cable to a laptop and the virtual environment was controlled by a keyboard and a mouse. The wide screen display and LCD monitor allow the projection of stereoscopic images, where each eye would see slightly shifted images.

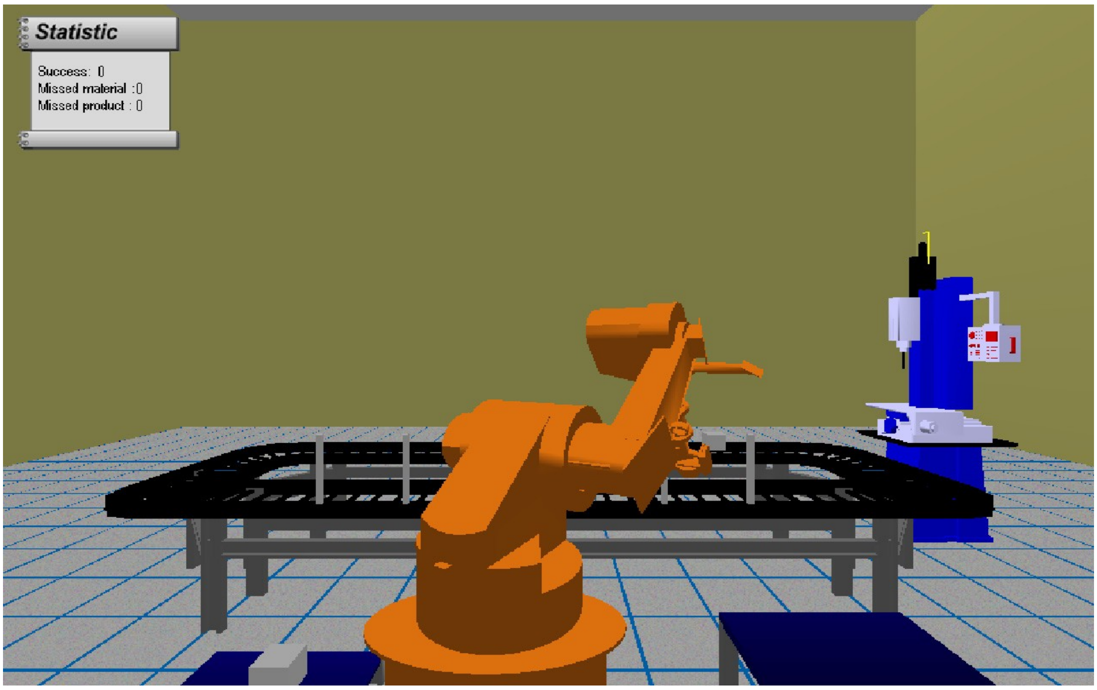


Figure 3.9 A snapshot of virtual robot manufacturing system

3.8 Data Analysis Methods

The non-parametric statistical method is a statistical procedure that requires few assumptions about the underlying population from which the data were obtained, and it is also called free distribution. The approach is a highly efficient technique applicable to a wide variety of situations (Hollander & Wolfe, 1999).

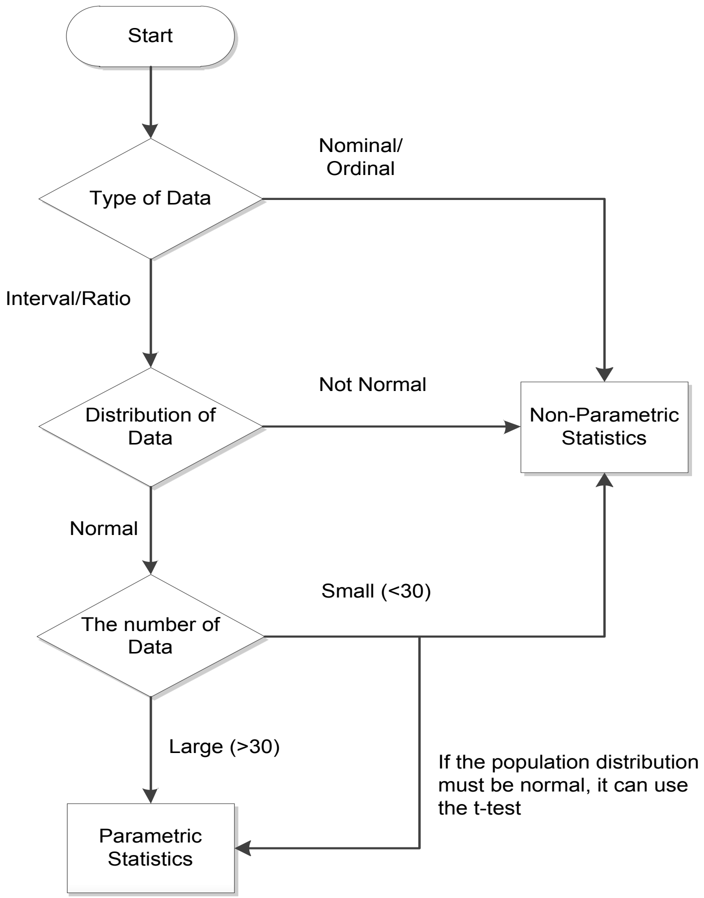


Figure 3.10 Procedure for selecting statistical method (Santoso, 2001)

Figure 3.10 explains the procedure for selecting the statistical method to test of the hypotheses or data analysis, either parametric method or non parametric method. Parametric statistical method is used if the type of data is interval or ratio, the distribution of data is normal, and the number of data is more than thirty (>30). If the type of data is nominal or ordinal and/or distribution is not normal, and/or the number of data is small or less than thirty (<30), then a non-parametric statistical method is used. The non-parametric statistic implemented in this research consists of descriptive statistic, reliability test, factorial analysis test, binomial test, chi-square test, and Mann-Whitney U test. The statistical analysis was conducted using the SPSS 19 software.

3.8.1 Descriptive Statistical Method

Descriptive statistics is a summary describing the important information for a group of data, such as mean or modus and median, standard deviation, variance of data, and frequency of data, as well as proportion of data.

3.8.2 Adequacy Test Method for Sample Size Required

Assuming that the population is not limited (infinite) and the sampling distribution is normal, the sample size required can be estimated by the following formula (Lemeshow *et al.*, 1990; Levy & Lemeshow, 1999):

(3.2)

Where;

n = Sample size required

p = Approximate proportion in population

d = Margin of error or absolute precision desired

$Z_{1-\alpha/2}$ = Reliability coefficient for a certain confidence level (i.e. 95%)

3.8.3 Reliability Method

Reliability refers to the consistency of a measure, where the study is able to produce consistent results under consistent conditions (Piaw, 2012). This measure is determined by using the internal consistency approach, which is statistically calculated from the pair-wise correlations between items. Cronbach's alpha is used the measure the reliability, and the general formula is as follows (Cronbach, 1951):

(3.3)

Where n is the number of items, p_i is the proportion receiving a score of 1, $1 - p_i$ is the proportion receiving a score of zero on the item, is the sample variance of test score, and i represent an item.

Internal consistency ranges between zero and one, with values close to 1.00 indicating high consistency. A commonly accepted rule of thumb for describing internal consistency can be seen in Table 3.1.

Table 3.1 Cronbach's alpha criteria for internal consistency (Cronbach, 1951)

Cronbach's alpha	***Internal consistency***
$\alpha \geq .90$	Excellent
$.90 > \alpha \geq .80$	Good
$.80 > \alpha \geq .70$	Acceptable
$.70 > \alpha \geq .60$	Questionable
$.60 > \alpha \geq .50$	Poor

Piaw (2012) mentioned that a grade of alpha .65 or .70 to .95 was considered satisfactory but lower (< .70) or higher (> 0.95) values are not necessarily desirable. This indicated that the items might be entirely redundant (no ability or overlapping).

3.8.4 Factorial Analysis Method

Factorial analysis consists of procedures to identify, reduce and construct items of questionnaires into several groups. According to Piaw (2009), ordinal scale data can be used in this method with a minimum scale of measurement of four or more. There are three steps in factorial analysis. The first step is to identify a correlation among factors, the second step is to extract the factors, and the third step is to rotate the factors.

3.8.5 Statistical Binomial Test Method

Non-parametric statistic was implemented for one sample test involving statistical binomial test. In this test, the data consists of two categories, which are the probability of success (p) and failure (1-p), where the probability can be calculated by the following formula:

(3.4)

Thus binomial test was used to test the hypothesis of a sample data that $p = p_o$ where p_o is a specified number or proportion. The procedure of the binomial test is as follows:

To test H_o: $p = p_o$,

where p_o is some specified number, $0 < p_o < 1$, set

$$B = \text{number of success}$$

versus

$$H_1: p > p_o \text{ , for one-sided upper-tail test}$$

or

$$H_1: p < p_o \text{ , for one-sided lower-tail test}$$

or

$$H_1: p \neq p_o \text{ , for two-sided test}$$

This research classifies the category of "success" if there is "effect" and the category of "failure" as there is "no effect". Hence, binomial test was used to test for the hypothesis on the effect of each attributes or variables of the virtual environment on the incidence of visual symptoms.

3.8.6 Statistical Chi-square Test of Independence Method

Chi-square test is one of the nonparametric statistical methods used for analyzing the correlation between two or more categories of two variables in the nominal and ordinal scale (Piaw, 2012). Two types of the methods are known as the chi-square test for goodness of fit and for independence or test of homogeneity. This study only applied chi-square test of independence, which is formulated as follows:

$$\frac{\quad}{\quad} \tag{3.5}$$

Where, f_e = Expected frequency

f_l = Column frequency

f_b = Row frequency

N = Sample size

The hypothesis of research developed was there is difference between two categories.

3.8.7 Statistical Mann-Whitney U Test Method

Mann-Whitney test is a kind of non-parametric test with the same aim as *t*-test on parametric, which is to understand which two independent samples come from the same population. The procedure is as follows:

- First: Two independent data were combined and sorted from smallest to highest. Then, the rank of such data was determined.
- Second: The value of rank for the same sample was summed on the basis of rank number.
- Third: *U*- value for each sample was calculated by the following formula:

$$-\qquad (3.6)$$

- Conclusion was deduced based on the result.

In this research, Mann-Whitney U test was used to test the hypothesis on the difference average response between male and female participants, and validation of the ergonomic design parameters. The hypothesis developed is:

- H_o: no difference on the average response of VE attributes between male and female needs.

Validation test was conducted to test for the hypothesis on the effectiveness of the ergonomics design criteria or parameters to design the virtual environment. The effectiveness was validated to prove that the design parameter (DP) developed has satisfied the functional requirement (FR) and customer attributes (CA). Thus, the hypothesis developed is:

- H_o: the ergonomics design parameter has satisfied the functional requirement and the customer needs.

3.9 Conclusion

In conclusion, the methodology proposed in this research involved two primary principles; visual ergonomic and axiomatic design principles. It also includes survey and experimental study by using questionnaire designed for collecting data. Statistical non-parametric analysis was used to test the hypothesis.

CHAPTER 4 CUSTOMER SURVEY

4.1 Introduction

This chapter presents the result of customer survey. The aim of this survey was to identify the criteria that the customer was looking for in the virtual environment. Based on the Likert scale, a questionnaire was developed and randomly distributed to respondents. Chapter 4 contains four sections including the introduction in the first section. Section 4.2 presents the characteristic of the participating subjects. Section 4.3 presents results of the survey, and this section consists of four sub-sections. Sub-section 4.3.1 presents the result of the adequacy test of sample required, Sub-section 4.3.2 shows the result of the reliability test, while Sub-section 4.3.3 presents the result of the factorial analysis test to group the criteria. Sub-section 4.3.4 presents the hypothesis test on the relationship between the two categories of variables related with the homogeneity response. Lastly, the conclusion is presented in Section 4.4.

4.2 Subject Characteristics

There were 94 male and 91 female university students (users/customers) participated in the survey. The subjects were also known as respondents. 4.26% of male users and 12.09% of female users have experienced the interaction with the virtual world in the last 1 year. 35.11% of male and 27.47% of female users had experienced with the virtual world in the last 2 – 4 years, while the remaining 60.64% of male and 60.44% of female users have interacted with the virtual world for more than 5 years.

Most interaction was done using computer (79.21% and 94.51% were male and female users, respectively) and only a few users (7.92% male and 4.4% female) have used simulators. Others have interacted with the virtual world through television (9.90% males and 12.09% females), cinema (0.99% males and 4.4% females) and others (5.94% males and 1.1% females). The most popular virtual world for interaction was virtual game. Table 4.1 shows the types of virtual world that were used by respondents to interact. The anthropometric data of the respondents is described in Table 4.2.

Table 4.1 Most popular types of virtual world preferred by respondents

No.	Type of Virtual World	Proportion of Users (%)	
		Male	Female
1.	Virtual sport	82.98	51.65
2.	Virtual boxing	11.70	6.59
3.	Virtual fighting	42.55	36.26
4.	Virtual driving	34.04	31.87
5.	Virtual airplane	17.02	12.09
6.	Virtual train	7.45	5.49
7.	Virtual Robot	8.51	6.59
8.	Virtual manufacturing	13.83	7.69
9.	Others	9.57	15.38

Table 4.2 Anthropometric data of respondents

Gender	Sample Size (number)	Mean Age (years)	Standard Deviation	Min. Age (years)	Max. Age (years)
Male	94	19.12	1.51	17	27
Female	91	20.14	2.37	17	30

4.3 Survey Results

A paper-based survey was conducted by distributing some questionnaires to respondents who were familiar with the virtual world. Approximately, over two hundred questionnaires were distributed, and only 185 of them responded (94 males and 91 females).

The results of the survey can be seen in Table 4.3. It presents the perceived level of importance of the criteria by users or customers of virtual environment design. The criteria identified were ergonomics criteria. An ordinal scale was used to rank the level of importance perceived by the user.

In this study, five levels of importance were divided into two groups. The first group combined strongly important/strongly agree (5), important/more agree (4) and moderate/agree (3) responds as being generally important. The other group combined less important/somewhat disagree (2) and strongly not important/strongly disagree responds as being not important. The following are the discusses of the first group.

Table 4.3 Survey results for the criteria that customers looked for in virtual environment design.

Criteria of The VE	Level of Importance	Customer Criteria					
		Male (94)		Female (91)		Comb. (185)	
		Freq.	%	Freq.	%	Freq.	%
Useful	*5. Strongly Important*	29	30.9	35	38.5	64	34.6
	4. Important	6	6.4	19	20.9	25	13.5
	3. Moderate	43	45.7	30	33.0	73	39.5
	Sum	***78***	***83.0***	***84***	***92.3***	***162***	***87.6***
	2. Less Important	8	8.5	4	4.4	12	6.5
	1. Strongly Not Important	8	8.5	3	3.3	11	5.9
Easy to Use	*5. Strongly Important*	26	27.7	35	38.5	61	33.0
	4. Important	20	21.3	26	28.6	46	24.9
	3. Moderate	34	36.2	23	25.3	57	30.8
	Sum	***80***	***85.1***	***84***	***92.3***	***164***	***88.6***
	2. Less Important	8	8.5	4	4.4	12	6.5
	1. Strongly Not Important	6	6.4	3	3.3	9	4.9
Simple Design	*5. Strongly Important*	18	19.1	31	34.1	49	26.5
	4. Important	26	27.7	29	31.9	55	29.7
	3. Moderate	33	35.1	24	26.4	57	30.8
	Sum	***77***	***81.9***	***84***	***92.3***	***161***	***87.0***
	2. Less Important	11	11.7	3	3.3	14	7.6
	1. Strongly Not Important	6	6.4	4	4.4	10	5.4
User Friendly	*5. Strongly Important*	23	24.5	34	37.4	57	30.8
	4. Important	32	34.0	29	31.9	61	33.0

	3. Moderate	26	27.7	22	24.2	48	25.9
	Sum	***81***	***86.2***	***85***	***93.4***	***166***	***89.7***
	2. Less Important	10	10.6	4	4.4	14	7.6
	1. Strongly Not Important	3	3.2	2	2.2	5	2.7
Easy to Memorize	*5. Strongly Important*	22	23.4	26	28.6	48	25.9
	4. Important	26	27.7	28	30.8	54	29.2
	3. Moderate	31	33.0	31	34.1	62	33.5
	Sum	***79***	***84.0***	***85***	***93.4***	***164***	***88.6***
	2. Less Important	11	11.7	4	4.4	15	8.1
	1. Strongly Not Important	4	4.3	2	2.2	6	3.2
Flexible	*5. Strongly Important*	19	20.2	28	30.8	47	25.4
	4. Important	22	23.4	27	29.7	49	26.5
	3. Moderate	42	44.7	30	33.0	72	38.9
	Sum	***83***	***88.3***	***85***	***93.4***	***168***	***90.8***
	2. Less Important	8	8.5	5	5.5	13	7.0
	1. Strongly Not Important	3	3.2	1	1.1	4	2.2
Easy to Learn	*5. Strongly Important*	16	17.0	27	29.7	43	23.2
	4. Important	31	33.0	32	35.2	63	34.1
	3. Moderate	35	37.2	26	28.6	61	33.0
	Sum	***82***	***87.2***	***85***	***93.4***	***167***	***90.3***
	2. Less Important	9	9.6	3	3.3	12	6.5
	1. Strongly Not Important	3	3.2	3	3.3	6	3.2
Fun	*5. Strongly Important*	22	23.4	42	46.2	64	34.6
	4. Important	30	31.9	26	28.6	56	30.3
	3. Moderate	25	26.6	17	18.7	42	22.7
	Sum	***77***	***81.9***	***85***	***93.4***	***162***	***87.6***
	2. Less Important	14	14.9	4	4.4	18	9.7
	1. Strongly Not Important	3	3.2	2	2.2	5	2.7
Wonderful	*5. Strongly Important*	11	11.7	24	26.4	35	18.9
	4. Important	29	30.9	41	45.1	70	37.8
	3. Moderate	40	42.6	19	20.9	59	31.9
	Sum	***80***	***85.1***	***84***	***92.3***	***164***	***88.6***
	2. Less Important	9	9.6	5	5.5	14	7.6
	1. Strongly Not Important	5	5.3	2	2.2	7	3.8
Pleasant	*5. Strongly Important*	13	13.8	27	29.7	40	21.6
	4. Important	22	23.4	28	30.8	50	27.0
	3. Moderate	46	48.9	29	31.9	75	40.6
	Sum	***81***	***86.2***	***84***	***92.3***	***165***	***89.2***
	2. Less Important	10	10.6	5	5.5	15	8.1
	1. Strongly Not Important	3	3.2	2	2.2	5	2.7
Colourful	*5. Strongly Important*	14	14.9	21	23.1	35	18.9
	4. Important	16	17.0	28	30.8	44	23.8
	3. Moderate	42	44.7	30	33.0	72	38.9
	Sum	***72***	***76.6***	***79***	***86.8***	***151***	***81.6***
	2. Less Important	15	16.0	10	11.0	25	13.5

	1. Strongly Not Important	7	7.4	2	2.2	9	4.9
Comfort	*5. Strongly Important*	24	25.5	32	35.2	56	30.3
	4. Important	29	30.9	33	36.3	62	33.5
	3. Moderate	30	31.9	21	23.1	51	27.6
	Sum	***83***	***88.3***	***86***	***94.5***	***169***	***91.4***
	2. Less Important	8	8.5	2	2.2	10	5.4
	1. Strongly Not Important	3	3.2	3	3.3	6	3.2
Safe and Healthy	*5. Strongly Important*	24	25.5	39	42.9	63	34.1
	4. Important	17	18.1	20	22.0	37	20.0
	3. Moderate	31	33.0	20	22.0	51	27.6
	Sum	***72***	***76.6***	***79***	***86.8***	***151***	***81.6***
	2. Less Important	13	13.8	9	9.9	22	11.9
	1. Strongly Not Important	9	9.6	3	3.3	12	6.5
No Glare	*5. Strongly Important*	11	11.7	11	12.1	22	11.9
	4. Important	19	20.2	29	31.9	48	25.9
	3. Moderate	43	45.7	44	48.4	87	47.0
	Sum	***73***	***77.7***	***84***	***92.3***	***157***	***84.9***
	2. Less Important	14	14.9	4	4.4	18	9.7
	1. Strongly Not Important	7	7.5	3	3.3	10	5.4
Brightness Properly or Clear	*5. Strongly Important*	14	14.9	11	12.1	25	13.5
	4. Important	14	14.9	30	33.0	44	23.8
	3. Moderate	47	50.0	40	44.0	87	47.0
	Sum	***75***	***79.8***	***81***	***89.0***	***156***	***84.3***
	2. Less Important	17	18.1	5	5.5	22	11.9
	1. Strongly Not Important	2	2.2	5	5.5	7	3.8
Resemble the Real	*5. Strongly Important*	18	19.1	16	17.6	34	18.4
	4. Important	20	21.3	30	33.0	50	27.0
	3. Moderate	42	44.7	31	34.1	73	39.5
	Sum	***80***	***85.1***	***77***	***84.6***	***157***	***84.9***
	2. Less Important	12	12.8	9	9.9	21	11.4
	1. Strongly Not Important	2	2.1	5	5.5	7	3.8

The first criterion is "usable" or "useful", which was considered important by 87.6% of the users and not important by the remaining 12.4% users. Webster dictionary, usable is defined as "convenient and practicable for use". Thus, virtual environment designed should be convenient and practicable for use.

User-friendly in Webster dictionary is defined as a system that is easy to learn and easy to use as well as easy to memorize. 89.7 % of the users considered user-friendly to be important and 10.3% of the users think otherwise. So, the design of the VE must satisfy the user-friendly criteria, where 90.3% of users wished VE is easy to learn, 88.6% of users needed VE to be easy to use, while 88.6% of users required VE to be easy to memorize for novel users.

Flexibility is a criterion which was considered important by 90.8% of the users and not important by 9.2% of the users. This means that the design of VE should be easy to modified and adapted. 87% of the users thought a simple design of VE is important and 13% of the users thought it is not important. A simple design is a functional requirement for satisfying user friendly criteria.

Fun in Webster dictionary is the enjoyment of pleasure, and it was considered important by 87.6% of the users, and 12.4% of the users thought it was not important. 88.6% of the users assumed wonderful criteria to be important for VE design, while 11.4% of the users assumed it was not important. Another criterion is pleasantness i.e. affording pleasure, which was considered important by 89.2 % of the users and not important by 10.8% of the users. Colourfulness shows that the virtual environment is developed using more than one different combination of colours. 81.6 % of the user considered it as important, and the other 18.4% of the users disagreed that colourfulness is important.

Comfort is a criterion of VE that is related to visual comfort of user's vision. 91.4 % of the users considered it to be important and 8.6% of the users said it was not important. This indicates that the design of VE should not cause visual problems such as eyestrain, headache, etc, and can satisfy the safe and healthy criterion which was considered important by 81.6% of the users and not important by 18% of the users.

No-glaring and bright properly are two criteria which related with clearness, lighting of display, and virtual scene. 84.9% of the users deemed no glare to be important and 15.1% of the users deemed no glare were not important. Meanwhile, 84.3% of the users considered the bright properly to be important and 15.7% of the users considered the bright properly to be not important. Thus, the design of VE should not be too dark or too bright.

The last criterion is resembles the real environment. The design of a VE that resemble the real environment was considered important by 84.9% of the users and not important by 15.1% of the users.

4.3.1 Result of the Adequate Test for Sample Size

Table 4.4 presents the result of adequacy test of sample size, which describes the minimum sample size required for each different group of respondents for every criteria of the virtual environment. The test at 5% significance level and 10% margin of error shows that sixteen criteria of virtual environment require different minimum sample size. It was between the range of 40 to 75 sample size for males group and from 20 to 69 samples size for females group. The combination of males and females was between the sample size ranges of 33 to 72.

Table 4.4 Results of adequacy test for sample size

Criteria of The VE	Minimum Sample Size			Decision
	Males (94)	Females (91)	Combination (185)	
Useful	54	27	42	*Adequate*
Easy to use	49	27	39	*Adequate*
Simple	57	27	43	*Adequate*
User Friendly	46	24	35	*Adequate*
Easy to Memorize	52	24	39	*Adequate*
Flexible	40	24	32	*Adequate*
Easy to Learn	43	24	34	*Adequate*
Fun	57	24	42	*Adequate*
Wonderful	49	27	39	*Adequate*
Pleasant	46	27	37	*Adequate*
Colourful	69	44	58	*Adequate*
Comfort	40	20	30	*Adequate*
Safe and Healthy	69	44	58	*Adequate*
No Glare	67	27	49	*Adequate*
Brightness Properly	62	38	51	*Adequate*
Resemble the Real	49	50	49	*Adequate*

Significat level: 0.05 and Margin of error: 0.10

4.3.2 Results of Reliability Test

Reliability is a measure of internal consistency where it determines whether several items proposed to measure the same general construct produce similar scores or not. Table 4.5 shows the result of the reliability test where the Cronbach's alpha was used as a measure of internal consistency for the data collected. The test results showed different scores for three different groups of respondents for sixteen criteria of the virtual environment. At the bottom of Table 4.5 is the mean Cronbach's alpha for every group, which are 0.896 for males group, 0.947 for females group and 0.928 for both groups. It can be concluded from the test that the data from the overall group of respondents were reliable.

Table 4.5 Result of reliability test

Criteria of The VE	*Cronbach's* Alpha			Decision
	Male	Female	Combination	
Useful	.882	.944	.922	*Reliable*
Easy to use	.890	.942	.923	*Reliable*
Simple	.886	.942	.921	*Reliable*
User Friendly	.887	.941	.922	*Reliable*
Easy to Memorize	.892	.941	.923	*Reliable*
Flexible	.890	.941	.922	*Reliable*
Easy to Learn	.894	.941	.924	*Reliable*
Fun	.891	.943	.924	*Reliable*
Wonderful	.892	.944	.924	*Reliable*
Pleasant	.888	.942	.922	*Reliable*
Colourful	.896	.941	.928	*Reliable*
Comfort	.887	.941	.922	*Reliable*
Safe and Healthy	.889	.943	.923	*Reliable*
No Glare	.890	.944	.925	*Reliable*
Brightness Properly	.888	.949	.926	*Reliable*
Resemble the Real	.888	.947	.926	*Reliable*
Cronbach's Alpha	***0.896***	***0.947***	***0.928***	*Reliable*

4.3.3 Results of Factorial Analysis Test

Table 4.6 and Table 4.7 present the result of factorial analysis test. This test categorized sixteen criteria of the virtual environment identified into several different groups in three steps. First, the correlations among criteria were identified. This was followed by dividing the criteria into five groups. Finally, the criteria were rotated. The research hypothesis was that the identified criteria of the virtual environment were multi-dimensional (H_1), while the null hypothesis (H_o) was one-dimensional.

Table 4.6 Results of KMO and Bartlett's test

Kaiser-Meyer-OlkinMeasure of Sampling Adequacy		.910
Bartlett's Test of Sphericity	Approx. Chi-Square	1637.075
	df	120
	Sig.	.000

KMO and Bartlett's tests were used to identify whether the correlation among criteria was well-suited for factorial analysis or not. KMO measure was .910, which is greater than .5 and Sig. of Bartlett's test was .000, which is lower than .05 ($p<.05$). Thus, the criteria were suitable for factorial analysis and inter-correlation among the criteria of the virtual environment existed.

The rotated component matrix in Table 4.7 represents the correlation between the criteria and groups after *Varimax* rotation. Table 4.7 shows that group 1 contained seven criteria (useful, easy to use, simple, user-friendly, memorable, flexible, and easy to learn). Group 2 consists of comfort, and safe and health, while group 3 covers four criteria (fun, wonderful, pleasant, and colorful). Group 4 consists of two criteria, namely no glare and brightness properly. The last group (Group 5) consists of only one criterion i.e. resemble to the real.

Table 4.7 Results of rotated component matrix[a]

Criteria of the VE	*Component*				
	1	*2*	*3*	*4*	*5*
Useful	.593				
Easy to use	.749				
Simple	.783				
User Friendly	.726				
Memorable	.514				
Flexible	.680				
Easy to Learn	.653				
Fun			.720		
Wonderful			.702		
Pleasant			.438		
Colorful			.711		
Comfort		.687			
Save and Health		.822			
No Glare				.667	
Brightness properly				.726	
Resemble to the Real					.832

Extraction Method: Principal Component Analysis
Rotation Method: Varimax with Kaiser Normalization
a. *Rotation converged in 17 iterations*

4.3.4 Result of Homogeneity Test

The results of chi-square test of independence are presented in Table 4.8. The test investigates the homogeneity response between male and female respondents on the criteria required for virtual environment design. Thus, the hypothesis developed in this research is that there were differences in the responses to the criteria of virtual environment between male and female (H_1). If the result of the test at 5% significance level is hypothesis is not rejected, the response to the criteria is non homogeneity. This means that male and female respondents have different criteria for virtual environment. Therefore, the criteria should not be considered in the following study.

Table 4.8 Results of chi-square test of independence of the criteria required in virtual environment design

Customer Criteria	Person Chi-Square			Decision
	Value	Df	Asymp. Sig (2-sided)	
Useful	13.198	4	.010	*Not Reject*
Easy to use	6.520	4	.164	*Reject*
Simple	9.959	4	.041	*Not Reject*
User Friendly	5.427	4	.255	*Reject*
Easy to Memorize	4.293	4	.368	*Reject*
Flexible	5.879	4	.208	*Reject*
Easy to Learn	7.111	4	.130	*Reject*
Fun	13.770	4	.008	*Not Reject*
Wonderful	16.745	4	.002	*Not Reject*
Pleasant	11.294	4	.023	*Not Reject*
Colourful	10.405	4	.034	*Not Reject*
Comfort	6.542	4	.162	*Reject*
Safe and Healthy	9.868	4	.043	*Not Reject*
No Glare	9.204	4	.056	*Reject*
Brightness Properly	14.528	4	.006	*Not Reject*
Resemble to the Real	5.442	4	.245	*Reject*

$p < 0.05$; N = 185

4.4 Conclusion

The results of the customers' survey on the criteria of virtual environment have been explained and discussed. The number of samples has satisfied the minimum requirement. Sixteen criteria were identified to be reliable, where 8 criteria did not show different response between male and female respondents. Thus, eight criteria considered in the following study are easy to use, user friendly, easy to memorize, flexible, easy to learn, comfort on vision, no glare and resemble to the real.

CHAPTER 5 MAPPING PROCESS FOR AXIOMATIC DESIGN

5.1 Introduction

This chapter contains four main sections including the introduction in the first section. Section 5.2 presents the results of the experiments conducted. The aim of the experiments is to identify the ergonomic attributes that the customer is looking for in the virtual environment design. Based on the Likert scale, a questionnaire was developed and used to investigate the visual symptoms experienced by users for each attribute. In Section 5.3, axiomatic design theory was applied to find the ergonomics design parameters by carrying out the mapping process between Customer Criteria (CC) to Functional Requirements (FRs), and FRs to Design Parameters (DPs). Finally, a conclusion is presented in section 5.4.

5.2 Result of Empirical study

5.2.1 Characteristic of Subjects

Eight university students participated in the study. None of the participants suffered from any vestibular and visual dysfunction, and they were not under any medication during the experiments. The mean age was 21.7 years old (aged 19-23 years). Prior to the experiment, informed consent was obtained about the nature of the experiment and the objectives of the experiment, as well as participant rights were fully explained. Participants were tested individually during the entire experiment session and received with token of appreciation for their participation. Ishihara colour plates for pseudoisochromatic test were used to test normal vision of a subject. The test for colour blindness was adapted from Courtney (1986).

5.2.2 Hypotheses

The hypotheses developed were:

- H1: Background colour has effect on visual symptoms among immersive environment users.
- H2: Virtual lighting has effect on visual symptoms among immersive environment users.
- H3: Field of view (FOV) has effect on visual symptoms among immersive environment users.
- H4: Flow rate (FR) has effect on visual symptoms among immersive environment users.
- H5: Speed of virtual object's motion has effect on visual symptoms among immersive environment users.
- H6: Display resolution has effect on visual symptoms among immersive environment users.
- H7: Contrast ratio has effect on visual symptoms among immersive environment users.

The level of significance was set at $\alpha = 0.05$ for all analyses

5.2.3 Experimental Design

The experiments were conducted at the ergonomic-virtual reality laboratory. A sitting position was adopted, with the subject sitting at a distance of 15 – 25 cm from the back edge of the table while completing the task. The activity was to operate a virtual robot in the VE using an infrared mouse (wireless mouse) with the motion observed on the wide screen display.

The digital projector was positioned on a table with height of 75 cm and an inclination angle between 5^{o}-10^{o} with respect to the horizontal axis. The projector was connected to a laptop with the display set to 1280 x 800 pixels. The distance from the front edge of the table or the digital projector to the center of the wide screen was 300 cm. The size of the wide screen display was 170 cm in length and 155 cm in width. The bottom edge of the wide screen display was measured at 94 cm above the floor. Prior to conducting the experiment, subjects adjusted their seating positions to make them as comfortable as possible.

5.2.4 Experimental Procedure

The subjects were provided with information describing the aims of the study and how the experiment will be conducted. Their health condition and past experience of sickness were also identified and their anthropometric data were measured. The colour blind test was then conducted before proceeding to colour selection and the experiment. If a subject could not complete the test, it meant that the subject had some visual problems and was unable to continue the experiment.

Prior to performing the experiment, subjects were trained on how to use the input device in order to operate the virtual robot in the VE to complete the virtual task.

In the experiment, subjects were exposed to the virtual environment to view and operate a virtual robot by using the input devices, to pick up a virtual material in a rack and put it on a conveyor, and subsequently pick up a virtual product on the conveyor and store in another rack. The activity was performed for 10 minutes for each attributes of the VE. All subjects were required to sit in an upright position and also in a comfortable posture while completing the virtual task. Participants were also instructed to complete the questionnaire immediately after finishing the virtual task.

5.2.5 Effect of Background Colour on Visual Symptoms

Table 5.1 shows the results of the experiment describing the effect of colour of virtual background on visual symptoms of the subjects. There were five colours used in this experiment, which were red, fuchsia, dark sky blue, medium slate blue, and white. The colours were identified based on users' preferences. Statistical binomial test at 5% significance level showed that the overall background colour has an effect on the user, i.e. eyestrain and blurred vision syndrome. The eyestrain syndrome was experienced by 75% of the users when red and white background colours were used, while 63% users experienced eyestrain when fuchsia, dark sky blue and medium slate blue background colours were used. The blurred vision syndrome was only experienced by users when red background colour was used.

Table 5.1 Results of experiments and binomial test of visual symptoms for virtual background colour

No.	Colour	Observation Proportion (%)	Symptoms	Exact Sig. (1-tailed)	Decision
1.	Red	75	Eyestrain	0.633	Effect
		63	Blurred Vision	0.321	Effect
2.	Fuchsia	63	Eyestrain	0.321	Effect
3.	Dark Sky Blue	63	Eyestrain	0.321	Effect
4.	Medium Slate Blue	63	Eyestrain	0.321	Effect
5.	White	75	Eyestrain	0.633	Effect

$p > 0.05$; N = 8

5.2.6 Effect of Virtual Lighting on Visual Symptoms

The results of experiments on the effect of virtual lighting on visual symptoms are presented in Table 5.2. The experiment was conducted for four brightness level of virtual light from the darkest level (10% lighting) to the brightest level (100% lighting). The results of statistical binomial test at 5% significance level that showed different effects of visual symptoms experienced by users is tabulated in Table 5.2. Eyestrain symptom was experienced by 83% of the users for all level of brightness. 50% of the users experienced symptoms of dry and irritated eyes at 10% level of brightness, and light sensitivity at 100% level of brightness. At the highest level of brightness, dry and irritated eyes symptom was experienced by 67% of the users.

Table 5.2 Results of experiments and binomial test of visual symptoms for virtual lighting

No.	Level of Brightness	Observation Proportion (%)	Symptoms	Exact Sig. (1-tailed)	Decision
1.	10% level	83	Eyestrain	0.534	Effect
		50	Dry and Irritated Eyes	0.169	Effect
2.	25% level	83	Eyestrain	0.534	Effect
3.	50% level	83	Eyestrain	0.534	Effect
		100	Eyestrain	0.178	Effect
4.	100% level	67	Dry and Irritated Eyes	0.138	Effect
		50	Light Sensitivity	0.169	Effect

$p > 0.05$; N = 8

5.2.7 Effect of Field of View on Visual Symptoms

Table 5.3 presents the experimental results on the effect of field of view (FOV). There are two types of FOV, namely 120^0 and 85^0 FOV. Statistical binomial test at 5% significance level showed similar results of visual symptoms effect experienced by users but at different proportions, especially eyestrain, and dry and irritated eyes symptoms. For FOV of 120^0, 63% of the users experienced dry and irritated eyes, while only 50% of the users experienced it for 85^0 of FOV. 75% of the users experienced eyestrain symptom at FOV of 85^0, and 50% of the users experienced it at FOV of 120^0.

Table 5.3 Results of experiment and binomial test of visual symptoms of field of view

No.	Degree of FOV	Observation Proportion (%)	Symptoms	Exact Sig. (1-tailed)	Decision
1.	FOV 120^0	50	Eyestrain	0.114	Effect
		50	Blurred Vision	0.114	Effect
		63	Dry and Irritated Eyes	0.321	Effect
2.	FOV 85^0	75	Eyestrain	0.633	Effect
		50	Blurred Vision	0.114	Effect
		50	Dry and Irritated Eyes	0.114	Effect

$p > 0.05$; N = 8

5.2.8 Effect of Flow Rate of Virtual Objects on Visual Symptoms

Table 5.4 shows the results of experiments on the effect of flow rate (FR) of virtual object on visual symptoms of the subjects. There were two types of flow rate studied, five second per piece (FR 5) and ten second per piece (FR 10), which corresponds to virtual object in sight every five seconds and ten seconds, respectively. Statistical binomial test at 5% significance level showed that both types of flow rates have effect on the users, in which 75% of the users experienced symptoms of eyestrain and 50% of the users also experienced blurred vision, and dry and irritated eyes symptoms.

Table 5.4 Results of experiments and binomial test of visual symptoms for flow rate of virtual object

No.	Flow Rate (FR)	Observation Proportion (%)	Symptoms	Exact Sig. (1-tailed)	Decision
1.	Flow Rate 5	75	Eyestrain	0.633	Effect
	(FR5)	50	Dry and Irritated Eyes	0.114	Effect
2.	Flow Rate10	75	Eyestrain	0.633	Effect
	(FR10)	50	Blurred Vision	0.114	Effect
		50	Dry and Irritated Eyes	0.114	Effect

p> 0.05 ; N = 8

5.2.9 Effect of Speed of Virtual Object's Motion on Visual Symptoms

Virtual object's motion is the movement of virtual object through a virtual conveyor in a single cycle time. Table 5.5 shows the results of the experiment on the effect of speed of virtual object's motion on the subjects. Two levels of speed were investigated, which were slow motion (0.050 is five meter per minute) and fast motion (0.100 is ten meter per minute). The result of statistical binomial test at 5% significance level proved that both speeds affected the users, where both slow and fast motions caused similar visual symptoms i.e. eyestrain, blurred vision, and dry and irritated symptoms.

Table 5.5 Results of experiments and binomial test of visual symptoms for speed of virtual object

No.	Level of Speed	Observation Proportion (%)	Symptoms	Exact Sig. (1-tailed)	Decision
		83	Eyestrain	0.534	Effect
1.	Low Speed	50	Blurred Vision	0.169	Effect
		67	Dry and Irritated Eyes	0.466	Effect
		75	Eyestrain	0.633	Effect
2.	High Speed	50	Blurred Vision	0.114	Effect
		50	Dry and Irritated Eyes	0.114	Effect

p> 0.05 ; N = 8

5.2.10 Effect of Display Resolution Type to Visual Symptoms

Table 5.6 shows the results of experiments on the effect of display resolution on the subjects. Three levels of resolution were investigated for both liquid crystal display (LCD) and cathode ray tube (CRT) displays, which were high resolution, medium resolution and low resolution. The results of statistical binomial test at 5% significance level found that the overall level of resolution using either LCD or CRT displays caused eyestrain symptoms to the users, with more than 56% experiencing eyestrain. Other effects such as dry and irritated eyes symptoms were experienced by 56% of users when interacting with medium and low resolution CRT display.

Table 5.6 Results of experiment and binomial test of visual symptoms for type of display resolution

No.	Level of Resolution	Observation Proportion (%)	Symptoms	Exact Sig. (1-tailed)	Decision
			LCD		
1.	High Resolution	56	Eyestrain	0.166	Effect
2.	Medium Resolution	89	Eyestrain	0.300	Effect
3	Low Resolution	56	Eyestrain	0.166	Effect
			CRT		
4.	High Resolution	67	Eyestrain	0.399	Effect
5.	Medium Resolution	67 56	Eyestrain Dry and Irritated Eyes	0.399 0.166	Effect Effect
6.	Low Resolution	67 56	Eyestrain Dry and Irritated Eyes	0.399 0.166	Effect Effect

$p > 0.05$; N = 8

5.2.11 Effect of Contrast Ratio on Visual Symptoms

The results of the effects of contrast ratio on visual symptoms are described in Table 5.7. There were three kinds of contrast ratio investigated. They were -50.83%, +24.58%, and 0%. The ratio can vary from 100% (positive) to zero for targets darker than the background, and from zero to minus infinity (-∞) for targets brighter than the background (Grether & Baker, 1972). Statistical binomial test at 5% significance level showed that all contrast ratios caused eyestrain symptoms (75% of users). Blurred vision, and dry and irritated eyes symptoms were experienced by 63% and 50% of users at contrast ratios of -50.83% and 0% (or -0.56%), respectively.

Table 5.7 Results of experiment and binomial test of visual symptoms for contrast ratio

No.	Ratio of Contrast	Observation Proportion (%)	Symptoms	Exact Sig. (1-tailed)	Decision
1.	-50.83%	75	Eyestrain	0.633	Effect
		63	Blurred Vision	0.321	Effect
2.	+24.58%	75	Eyestrain	0.633	Effect
3.	0% (-0.56%)	75	Eyestrain	0.633	Effect
		50	Dry and Irritated Eyes	0.114	Effect

$p > 0.05$; N = 8

5.3 Result of Mapping Process for Axiomatic Design

5.3.1 Mapping Process between Customer Criteria (CCs) and Functional Requirement (FRs)

The descriptive non-parametric analysis in Chapter 4 produced five groups of customer voices, which is called customer criteria (CCs) in this study. They are:

CC_1 = Desired visual comfort when using virtual environment,

CC_2 = Use of virtual environment must be user friendly,

CC_3 = Interesting virtual environment,

CC_4 = Virtual environment is clear to be seen, and

CC_5 = Design of virtual environment resembles real environment

In the mapping process, the identified customer's criteria must be translated to functional requirement (FR_s). Thus, the corresponding FR_s to satisfy CC_s should be specified as follow:

FR_1 = Minimize visual symptoms

FR_2 = Design simple layout of VE

FR_3 = Design attractive attributes of VE

FR_4 = Optimize virtual lighting and display

FR_5 = Using CAD software to design virtual object in VE

The design matrix can be formulated as a diagonal matrix (equation 5.1). It indicates that the design is an uncoupled design.

(5.1)

The focus of this study is on minimizing negative effect on user's vision when interacting with VE. Therefore, costumer's criteria that are related with negative effect should be specified. The highest possible relevant CCs with minimum negative effect on vision have been analyzed in Section 5.2. The results showed that the customer or user needs visual comfort when interacting with virtual environment. Thus, CC_1 is most relevant customer's criterion with minimum negative effect on vision and will be further considered in this study. The corresponding functional requirement that can satisfy CC_1 should be FR_1:"Minimize visual symptoms".

5.3.2 Mapping Process between Functional Requirement (FRs) and Design Parameters (DPs)

After defining FR_1, the design parameter (DP) in physical domain to satisfy functional requirement must be specified. However, there are alternative DPs that can fulfil $FR_{1.}$ One of the proposed DP in this study was "Ergonomic design parameter of virtual environment". Thus, the design parameter identified for ergonomic design of virtual environment may minimize visual problem, where the desired visual comfort can be experienced by users.

To achieve ergonomic $DP_{1,}$ FR_1 must be decomposed in more detail by a zigzagging process and according to a hierarchical structure. The corresponding DPs are identified in the same hierarchical structure until the DPs are sufficiently detailed to be implemented. The decomposition of FR_1 produced a second level FR_1 consisting of six functional requirements. They are:

FR_{11} = Soothing virtual colour

FR_{12} = Set an appropriate virtual lighting

FR_{13} = Provide good contrast

FR_{14} = Provide good viewing experience

FR_{15} = Set an appropriate virtual motion

FR_{16} = Select appropriate output devices

All six design activities above must be specified in more detail to develop a good design, where each of the FRs should be satisfied by only one DP. A one-to-one relationship between FRs and DPs is called an uncoupled design. To minimize visual symptoms such as eyestrain, blurred vision, dry and irritated eyes, as well as light sensitivity, virtual colour is set to smooth, virtual lighting is set for an appropriate condition and good contrast between virtual object and background. Good viewing should be defined, as well as motion of virtual object needs to be set appropriately. An output device used to display the virtual environment is selected properly. Therefore, the second level DP_1 that satisfied the second level FR_1 independently can be specified as follows:

DP_{11} = Soothing virtual colour of background

DP_{12} = No glare and dark

DP_{13} = Corresponding contrast level

DP_{14} = Convenient degree of FOV

DP_{15} = Corresponding level of flow rate and speed of virtual object's motion

DP_{16} = Smooth display and compatible resolution

The decomposition of DP to meet FR may not be implemented directly. This is because the corresponding second level DP is not detail enough. Therefore, it is necessary to decompose to a lower level. The following third levels FRs were identified from the decomposition of second level FR and DP. By asking questions of "What" and "How" through the zigzagging process as illustrated in Figure 5.1, FRs at the third level can be defined as:

FR_{111} = Smoothing colour of virtual background

FR_{121} = Set a level of brightness

FR_{131} = Set a level of contrast

FR_{141} = Set a degree of FOV

FR_{151} = Set a speed of flow rate for virtual object

FR_{152} = Set a speed of motion for virtual object

FR_{161} = Use suitable type of display

FR_{162} = Set a level of display resolution

For a good design of the corresponding third level DP to satisfy the third level independence FR, they can be developed as follows:

DP_{111} = Medium slate blue, dark sky blue, fuchsia

DP_{121} = 50% of brightness

DP_{131} = 24.58% of contrast

DP_{141} = 85 degrees of FOV

DP_{151} = Five second per piece of flow rate

DP_{152} = High or low speed of motion

DP_{161} = LCD

DP_{162} = High resolution

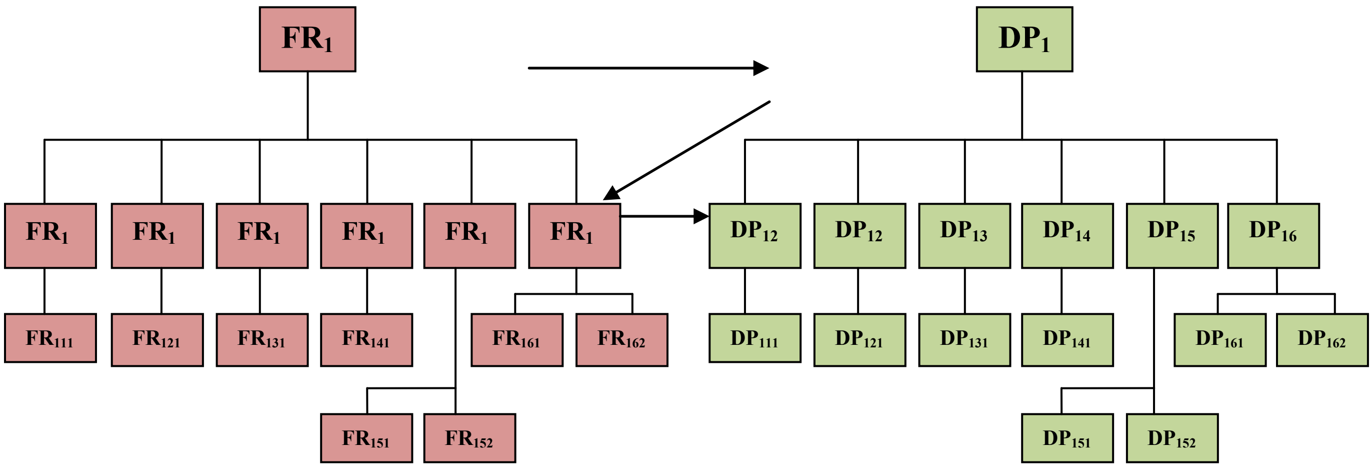


Figure 5.1 Hierarchical structures and decomposition of functional requirements (FRs) and design parameters (DPs)

The design equation describing the relationship between FR and DP at the second level is given by equation (5.2). The equation presents a decoupled design or upper triangular design matrix, where each FR is satisfied by a DP. Even if there are a few of FRs affecting the other FRs, the design is still acceptable.

(5.2)

Hereinafter, the relationship between FR and DP at the third level presented in the design equation (5.3) is equal to the second level, where the design matrix is the upper triangular matrix or decoupled design. This shows that the decomposition in the lower level is consistent with the higher level. Design equation (5.3) explains that FR_{111} (Smoothing colour of virtual background) is affected by DP_{111} (Medium slate blue, dark sky blue, and fuchsia), DP_{121} (50% of brightness), DP_{161} (LCD), and DP_{162} (high resolution). Meanwhile, other FRs (FR_{131}, FR_{141}, FR_{151}, FR_{152}) are independent, where FR_{131} (Set a level of contrast) is only affected by DP_{131} (24.58% of contrast), FR_{141} (Set a degree of FOV) is only affected by DP_{141} (85 degrees of FOV), FR_{151} (Set a speed of flow rate for virtual object) is only affected by DP_{151}(Five second per piece of flow rate), and FR_{152} (Set a speed of motion for virtual object) is only affected by DP_{152} (High speed of motion).

(5.3)

5.4 Conclusion

It can be concluded that the design of a virtual environment is influenced by several attributes such as virtual colour background, virtual lighting, field of view (FOV), flow rate, speed of virtual object, resolution of display, and contrast ratio. These attributes significantly affect the user's vision; particularly eyestrain symptoms, blurred vision, dry and irritated, and light sensitivity symptoms. As for, design parameters developed of a virtual environment based on ergonomics criteria satisfies the independence functional requirement and the customer's voice including medium slate blue, dark sky blue, and fuchsia for smooth virtual colour of background, 50% of brightness for appropriate level of virtual lighting, +24.58% of good contrast between virtual object and background, 85 degrees of field of view for good viewing, high or low speed of flow rate and an appropriate motion of virtual object, liquid crystal display (LCD) and high display resolution for appropriate output devices. The design parameters were validated in the following chapter.

CHAPTER 6 RESULTS OF VALIDATION AND DEVELOPMENT OF A NEW METHODOLOGY

6.1 Introduction

This chapter presents the results of validation test on ergonomics design parameters that have been developed and then proposed a new methodology to design the virtual environment. The aim was to find a method employed in ergonomics design parameters to design virtual environment and to prove their effectiveness. Chapter 6 is divided into four sections including the introduction in the first section. Section 6.2 presents the results of validation test. Section 6.3 presents the development of a new methodology, and finally the conclusion is presented in Section 6.4.

6.2 Validation of Ergonomics Design Parameters

6.2.1 Design of Ergonomics Virtual Environment

Virtual environment, also called ergonomic virtual environment (EVE) is designed based on ergonomics design parameters developed in Chapter 5. EVE describes a virtual robot activity in a manufacturing system, in particular the process of storage loading and unloading (SLU). The background colour is medium slate blue (DP_{111}) which was more soothing than other colours to alleviate symptoms on user's vision. This is supported by using field of view of 85^0 (DP_{141}), setting an appropriate virtual lighting of 50% brightness (DP_{121}), and also 24.58% contrast (DP_{131}). A high resolution display (1280 x 800) (DP_{162}) and an appropriate type of display, in this case was LCD (DP_{161}) increased visual comfort on user's eyes. This was complimented by a combination setting of five second per piece of flow rate (DP_{151}) and low speed motion of material (DP_{152}) in the conveyor as well.

Process variables (PVs) consist of layered manufacturing process that satisfy DPs is shown in Table 6.1.

Table 6.1 Result of mapping process between DPs and PVs

Codes	DPs	PVs
111	Medium Slate Blue	Colour Command Button (Wall: R: 123 G: 104 B: 238)
121	50% of brightness	Light Command Button (ambient light and light brightness)
131	24.58% of contrast	Colour Command Button (virtual object and wall)
141	85 degrees of FOV	Camera Command Button (FOV, Camera and Focus Position)
151	Five second per piece of flow rate	Speed Command Button
152	Low speed of motion	Speed Command Button
161	LCD	Display Configuration Command (Full screen and Monitor Type)
162	High resolution	Display Command Button (1280 x 800)

Figure 6.1 and Figure 6.2 show the design of EVE for virtual robot manufacturing system. EVE was developed using Direct X and Microsoft Visual C# 2010 programme. Autodesk 3DS Max software was used to build the virtual object. It contained a virtual robot, a virtual roller conveyor, and two virtual machines. It also contained two virtual tables used for material storage on the left side and product storage on the right side. The virtual material and product were represented by virtual boxes.

The main virtual buttons were located at the bottom (as desired by 40% of users, whilst 60% of the user preferred the buttons to be located at the top (13.33% of 60% users), left (26.67% of 60% users), and right (20% of 60% users)). The buttons were made of

CONFIGURE virtual button, SAVE virtual button, RESUME virtual button, PLAY virtual button, and EXIT virtual button. The CONFIGURE virtual button contained commands virtual button (PVs) to set the design parameters. Figure 6.2 shows the configuration of the command virtual button of LIGHT, COLOUR, SCENE, SPEED, DISPLAY, CAMERA, and BACK.

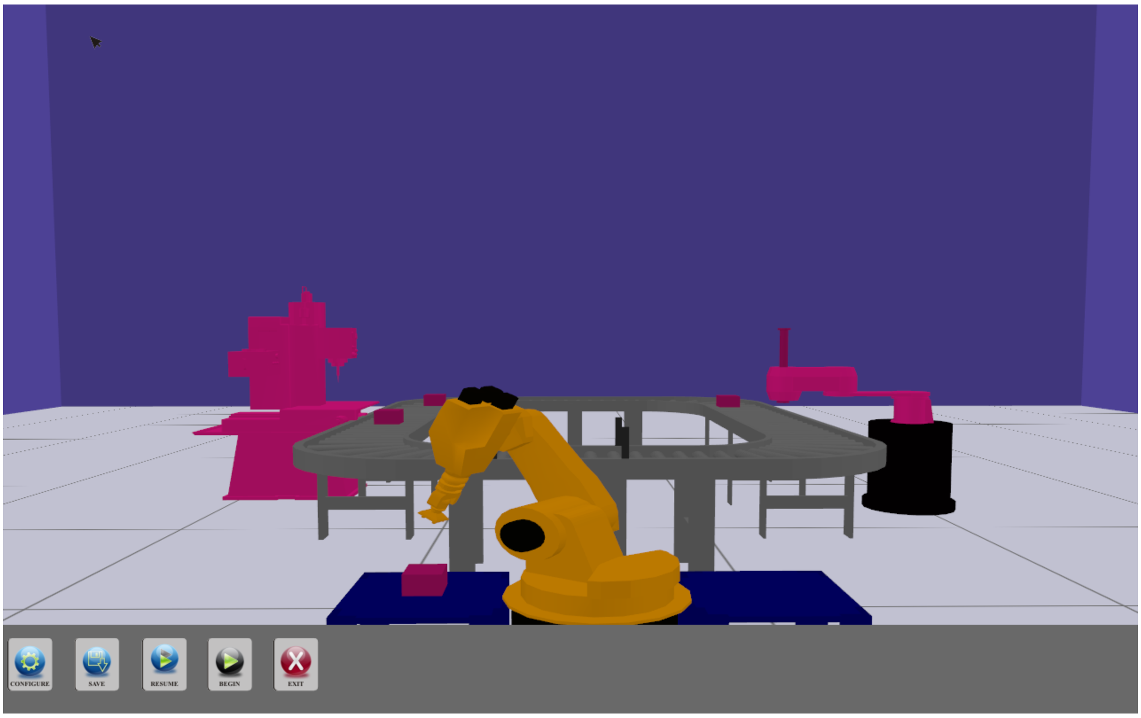


Figure 6.1 A snapshot of EVE design of a virtual robot manufacturing system with main virtual button

LIGHT virtual button allowed the setting of light configuration; ambient light, brightness, and emissive lighting. The COLOUR virtual button was used to set R G B configuration on Robots, Machines, Conveyor, Wall, Material, Tables, and Floor. Meanwhile, line texture configuration was set by clicking SCENE virtual button. SPEED virtual button determined the flow rate and motion speed of virtual object or material. DISPLAY virtual button was used to set the resolution and screen type, while configuration of field of view was set by clicking CAMERA virtual button. BACK virtual button returns the user to the main menu.

Figure 6.2 A snapshot of EVE design of a virtual robot manufacturing system with configuration of virtual command button

The design will be used in the next experiment to verify or demonstrate the effectiveness and conformity of the ergonomics design parameter of virtual environment to customer's criteria. The experiment was conducted in the Ergonomics laboratory. 21 university students with experience interacting with virtual world have participated. Their age ranged from 19 – 22 years old. The same procedure was also used to investigate the ergonomics virtual environment (see Chapter 5).

6.2.2 Results of Validation Test

Table 6.2 and Table 6.3 present the results of validation for hypothesis test. The hypothesis was there are differences or incompatibility between the ergonomic design parameters developed and the customer's criteria of the virtual environment design (H_1). Statistics non-parametric test, chi-square and Mann-Whitney U test at 5% significance level (p <0.05) showed that the ergonomics design parameters satisfied the customer's criteria identified.

Table 6.2 Results of validation test for individual criteria of EVE

No.	**Criteria of the EVE**	**Observation of Customer Voice**				**Non Parametric Test**		**Decision**
		Survey		**Experiment**		**Mann-Whitney U**	**Chi-Square**	
		Prop.	**Median**	**Prop.**	**Median**			
1.	User friendly	.897	4	1.00	4	.688	.175	*Reject*
2.	Easy to use	.886	4	.952	3	.204	.116	*Reject*
3.	Easy to learn	.903	4	1.00	4	.189	.592	*Reject*
4.	Easy to memorize	.886	4	1.00	4	.050	.348	*Reject*
5.	Flexible	.908	4	.905	4	.971	.955	*Reject*
6.	Comfort on vision	.914	4	.905	3	.115	.351	*Reject*
7.	No glare	.849	3	.810	3	.959	.878	*Reject*
8.	Resemble to the real	.849	3	.905	4	.750	.500	*Reject*

$p < 0.05$; 3 = *Important/ Agree* ; 4 = *More important/ more agree*

Results for both statistical non-parametric tests of Mann-Whitney U and chi-square test at p <0.05 showed rejection of the research hypothesis (H_1) significantly. It means null hypothesis (H_0) was accepted, and it concludes that there was no difference or incompatibility criteria of EVE design between ergonomics design parameters and customer's voice. This was indicated by the value of Assymp.sig (2-tailed) for each criteria of EVE higher than p-value (p > 0.05) for both statistical tests. Mann-Whitney U test for the criteria of EVE (Table 6.3) also produced the same result. Table 6.3 also presents the mean rank of criteria for both, experiment and survey.

Table 6.3 Results of validation test for a set of criteria of EVE

Test Statistics	Customer Criteria of the VE	Asymp.Sig (2-tailed)	Decision	Mean Rank	
Mann-Whitney U	1896.000	.857	*Reject*	Survey	103.25
				Experiment	105.71

$p < 0.05$

Table 6.4 presents the results of descriptive analysis on the effect on user's vision. It provided evidence for visual comfort criteria. Five levels of symptoms were divided into two groups i.e. the first group was "no symptoms" that encompassed level 3 (moderate), level 4 (almost no symptoms), and level 5 (no symptoms), and the second group was "got symptoms" that consists of level 1 (get symptoms) and level 2 (little symptoms). For the vision problem, the level of symptoms consist of three levels, namely level 1 which was major problem, and level 2 which was minor problem, and grouped as "problem" and the other group (no problem) was level 3.

The experimental results and binomial test are presented in Table 6.5. The results described the effect of interaction with ergonomic virtual environment designed by using ergonomics design parameters. There were six effects investigated on user's vision when interacting with the ergonomics virtual environment. They are vision problem, visual fatigue, eyestrain, blurred vision, dry and irritated eyes, and light sensitivity symptoms. Statistical binomial test at 5% significance level showed that the user did not experience the symptoms significantly when interacting with the ergonomics virtual environment. Thus, the alternative hypothesis (H_1) was accepted except for vision problem. However, the decision of accepting the null hypothesis for vision problem still meets the objective of the research.

Table 6.4 Results of experiments and descriptive analysis on visual symptoms by using ergonomics design parameters developed on EVE

Visual Symptoms	Level of Symptoms	Observation of User's Voice		Median
		Frequency	Proportion	
Vision Problem	*3. No Problem*	11	.524	3
	2. Minor Problem	10	.476	
	1. Major Problem	0	.000	
Visual Fatigue	*5. No Fatigue*	6	.286	4
	4. Almost not Fatigue	7	.333	
	3. Moderate	3	.143	
		16	***.762***	
	2. Little Fatigue	5	.238	
	1. Fatigue	0	.000	
Eyestrain	*5. No Strained*	3	.143	4
	4. Almost not Strained	8	.381	
	3. Moderate	5	.238	
		16	***.762***	
	2. Little Strained	5	.238	
	1. Strained	0	.000	
Blurred Vision	*5. No Blurred*	8	.381	4
	4. Almost not Blurred	6	.286	
	3. Moderate	6	.286	
		20	***.952***	
	2. Little Blurred	1	.048	
	1. Blurred	0	.000	
Dry and Irritated Eyes	*5. No Dry*	8	.381	4
	4. Almost not Dry	9	.429	
	3. Moderate	2	.095	
		19	***.905***	
	2. Little Dry	2	.095	
	1. Dry	0	.000	
Light Sensitivity	*5. No Glare*	5	.238	4
	4. Almost not Glare	10	.476	
	3. Moderate	4	.190	
		19	***.905***	
	2. Little Glare	2	.095	
	1. Glare	0	.000	

N = 21

Table 6.5 Results of experiments and binomial test on visual symptoms by using ergonomics design parameters developed on EVE

Visual Symptoms	**Category**	**N**	**Observed Proportion**	**Exact Sig. (1-tailed)**	**Decision**
Vision Problem	Problem (H_1) No Problem (H_0)	10 11	.476 .524	.463	*Reject*
Visual Fatigue	No Fatigue (H_1) Fatigue (H_0)	16 5	.760 .240	.017	*Not Reject*
Eyestrain	No Strained (H_1) Strained (H_0)	16 5	.760 .240	.017	*Not Reject*
Blurred Vision	No Blurred (H_1) Blurred (H_0)	20 1	.950 .050	.000	*Not Reject*
Dry and Irritated Eyes	No Dry (H_1) Dry (H_0)	19 2	.900 .100	.000	*Not Reject*
Light Sensitivity	No Glare (H_1) Glare (H_0)	19 2	.900 .100	.000	*Not Reject*

$p < 0.05$; N = 21

6.3 Proposed Methodology to Develop the EDP of the EVE

A methodology proposed was a methodology to develop ergonomic design parameters for the ergonomic virtual environment. It was expanded based on two concepts or principles of ergonomics and axiomatic design. Ergonomic principle is related to the compatibility of the interaction between user and work environment in terms of comfort, safety and health. AD principles describe about the systematic way to design such environment.

6.3.1 Ergonomics Principle

Ergonomics principle in design process is known as "Fitting the Task to the Man" (Granjdean, 1986). This principle focused on the aspect of human limitation as a basis for designing. By considering the limitation, the design developed may alleviate the unwanted negative effect on users.

In designing the virtual environment, customer's criteria were identified. Some of these criteria have been identified in Chapter 4. One of the most important criteria to be considered was visual comfort, which is related to the limitation of user's vision. Some attributes of virtual environment (Chapter 5) affecting the ergonomic criteria (also known as ergonomics attributes) have also been investigated. Figure 6.3 describes the concept of the ergonomics attributes affecting visual comfort on users when interacting with virtual environment.

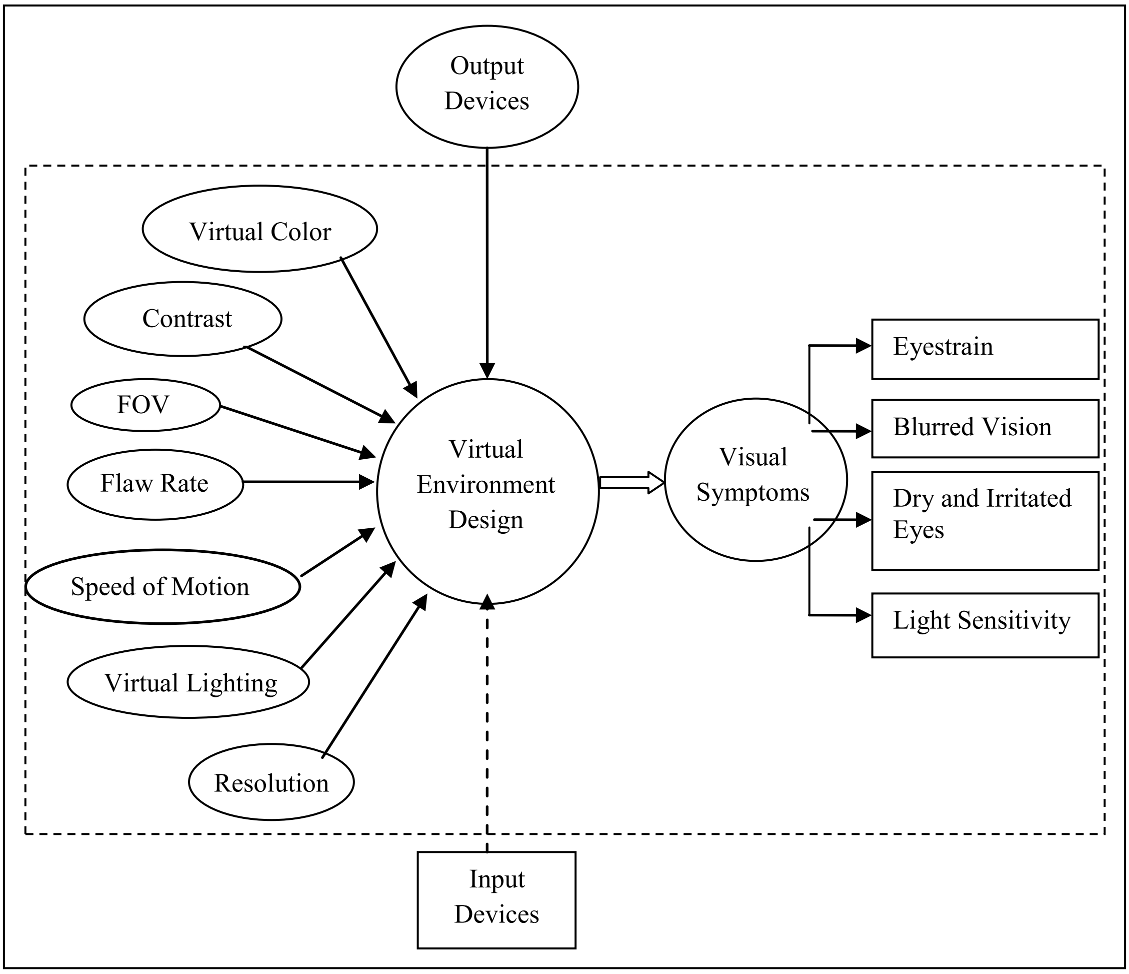


Figure 6.3 Conceptualization of ergonomics specification of virtual environment

The conceptual model (Figure 6.3) explains seven attributes of virtual environment and an output device (type of display) that causes visual symptoms. They are virtual colour, contrast, field of view, flow rate, speed of motion, virtual lighting, and resolution. The type of display was included as an additional attribute.

Anshel (2005) mentioned that typical visual symptoms include eyestrain, headache, blurred vision, dry and irritated eyes, double vision, light sensitivity, colour distortion and slow refocusing. In this study, only four symptoms were experienced by user, which are eyestrain, blurred vision, dry and irritated eyes, and light sensitivity.

To satisfy the ergonomic criteria, these attributes should be able to meet the ergonomic specification defined as "Minimum visual symptoms" as a requirement for ergonomic design parameter (EDP). A simple mathematical formulation can be developed in this study as follows:

Where in this study is:

Min (Visual Symptoms) = Min {Eyestrain (VS_E) *U* Blurred Vision (VS_{BV}) *U* Dry and Irritated Eyes (VS_{DI}) *U* Light Sensitivity (VS_{LS})}

Min $VS_E = Z_1 \text{ U } Z_2 \text{ U } Z_3 \text{ U } Z_4 \text{ U } Z_5 \text{ U } Z_6 \text{ U } Z_7$

Min $VS_{BV} = Z_1 \text{ U } Z_2 \text{ U } Z_3 \text{ U } Z_4 \text{ U } Z_5$

Min $VS_{DI} = Z_2 \text{ U } Z_3 \text{ U } Z_4 \text{ U } Z_5 \text{ U } Z_6 \text{ U } Z_7$

Min $VS_{LS} = Z_6$

Where,

Z_1 : Virtual colour background

Z_2 : Contrast ratio

Z_3 : Field of view

Z_4 : Flow rate

Z_5 : Speed of motion

Z_6 : Virtual lighting

Z_7 : Resolution

6.3.2 The Axiomatic Design Principle

Axiomatic design (AD) principles consist of two important key concepts, which are axiom and domains concepts. Independence axiom and information axiom are two different basic concepts in design process. The domains concept provides a restriction line among four different domains of design activities. This study used the independence axiom only to map the domains of the ergonomic design parameters of virtual environment. Figure 6.4 (a) presents the fundamental concept of domain in axiomatic design principle, while Figure 6.4 (b) is the modified model of AD principle to be applied in ergonomics design principles.

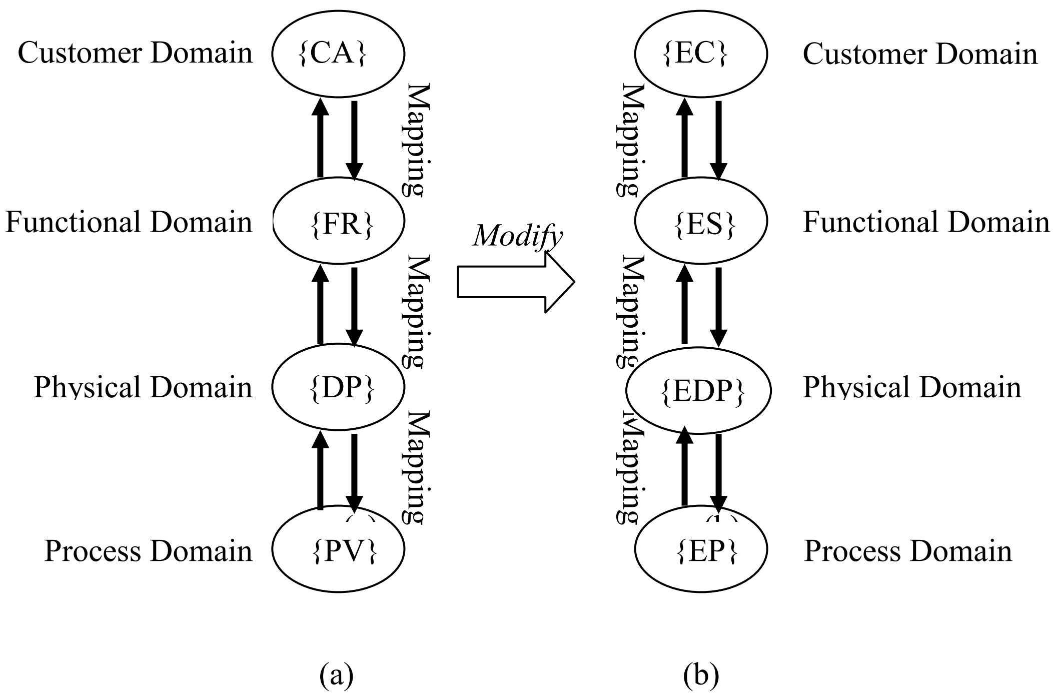


Figure 6.4 Modification of domain concept of AD to ergonomics design

The modified model transformed customer attribute (CA) in AD principle to customer criteria (CC) or ergonomics criteria (EC) in the ergonomics design principle. In addition, functional requirement (FR) or engineering specification was transformed to ergonomic requirements or ergonomic specification (ES), while the design parameter (DP) was converted to ergonomics design parameter (EDP). Finally, process variable used either ergonomics process (EP) or user action (UA).

Customer criteria, also known ergonomic criteria, referred to the characteristics of a product or system designed to meet human need. The use of the ergonomic term in every domain explained that the design of product or system developed should consider human limitation, so that it can satisfy the ergonomics criteria. In this study, virtual environment (VE) was also transformed into ergonomics virtual environment (EVE). EVE design should be based on the ergonomics design parameters that have been developed through the mapping process.

6.3.3 Proposed Methodology

Figure 6.5 illustrates the conceptual model of the proposed methodology to develop ergonomics design parameters of EVE. It began with the identification the customer criteria and ergonomic attributes. Ergonomic requirements or specification were formulated and then the justification of the attributes that satisfied the specification was conducted to obtain ergonomic design parameters.

Customer criteria are the characteristics or attributes of a product or system where the customers are required to interact ergonomically. They represent customer's preference that is usually obtained based on the survey. The preference is a key for the success of a product or system designed. This study found that the most relevant criterion for human vision was visual comfort (ergonomics criteria).

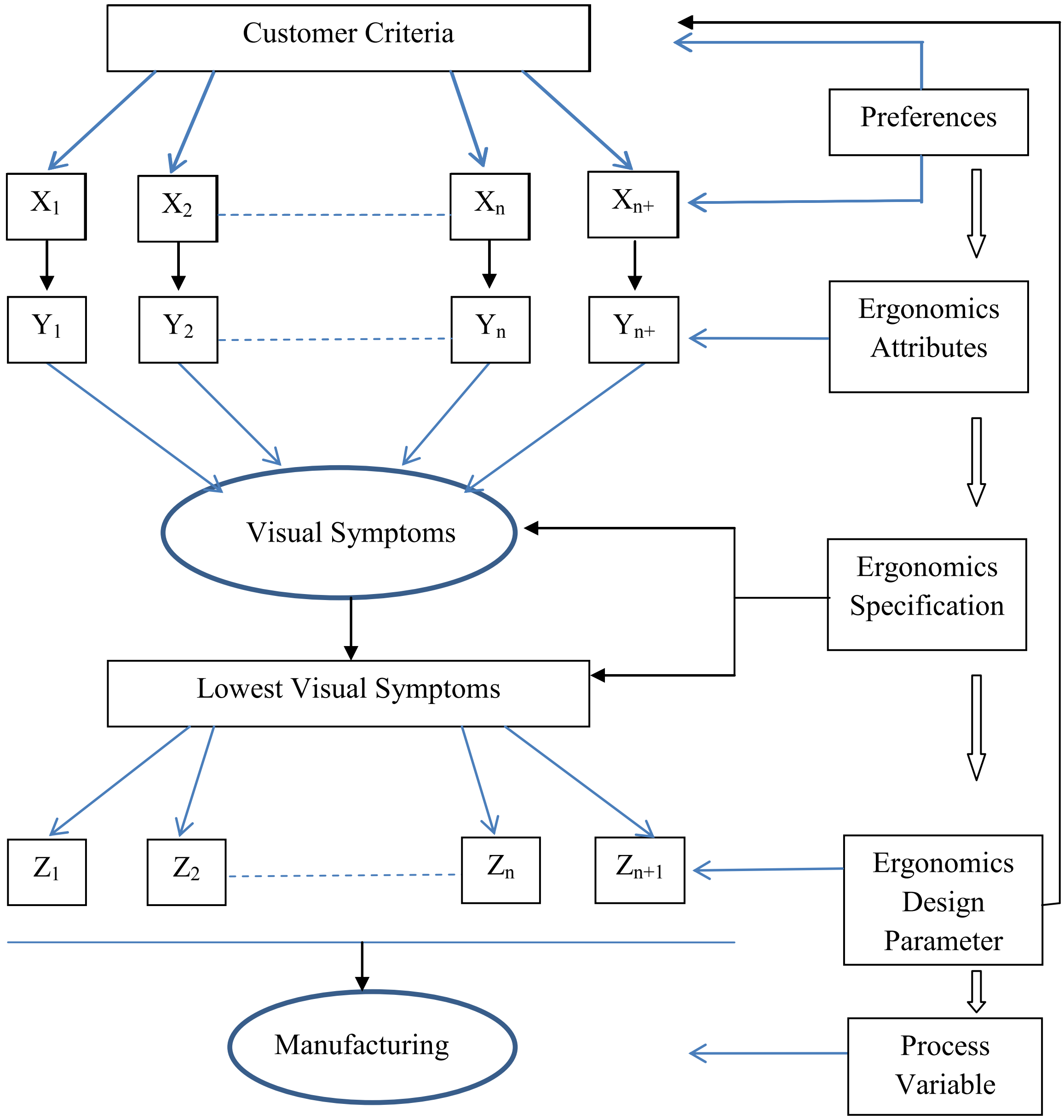


Figure 6.5 Conceptual model of the proposed methodology to develop EDP

The attributes of the product or system should be investigated to identify the appropriate attributes affecting ergonomics criteria. This is done through experimental or preference study, or both. Preference study was conducted to justify the relevant ergonomic attributes and experimental study was performed to test the effect of the attributes on human limitation. Several attributes of virtual environment were identified in this study as discussed in Chapter 5.

The mapping process was also performed in to attain the ergonomics design parameters. Therefore, ergonomic requirement or specification should be formulated previously as functional requirements. This study formulated the ergonomic specification that provided proper effect ergonomically on human vision. It was defined as “lowest visual symptoms”. The attributes of virtual environments that have effect on lowest visual symptom then became the design parameters, which can be referred to as ergonomics design parameters (EDP).

The success of the developed EDP is indicated by the fulfillment of customer’s criteria. The negative effect of the design can also be reduced. Hence, the validation test should be done, and the results of this study have shown it.

6.4 Conclusion

It was found that there was no different in the criteria for ergonomic virtual environment between the developed ergonomic design parameters and the customer’s voice. The number of users who did not experience negative effect of more than 75% implied that the ergonomics design parameters developed using the proposed methodology based on ergonomics principle and axiomatic design principle were able to satisfy the desired visual comfort of users.

CHAPTER 7 DISCUSSION

7.1 Introduction

This chapter discusses the results obtained from the previous chapters. The aim of this chapter is to seek scientific reasons to explain the results. Chapter 7 begins with an introduction in the first section. Section 7.2 discusses the identified customer's criteria for virtual environment. Section 7.3 presents the discussion of ergonomics specification for virtual environment design. Section 7.4 presents the discussion of identified ergonomics design parameter, while Section 7.5 presents the discussion of validation study. Finally, the conclusion is presented in Section 7.6.

7.2 Analysis of Customer's Criteria for Virtual Environment Design

Stanney *et al* (1998) mentioned that for a virtual environment to be effective and well received by the users, it is important to consider the customer's or user's voice on the criteria for designing VE. A survey conducted on 185 university students, which consists of 94 males and 91 females, identified sixteen criteria that are desirable in virtual environment design (Figure 7.1). They are useful, easy to use, simple design, user-friendly, easy to memorize, flexible, easy to learn, fun, wonderful, pleasant, colourful, visual comfort on vision, safe and health, non-glaring, brightness properly, and resemble to the real environment.

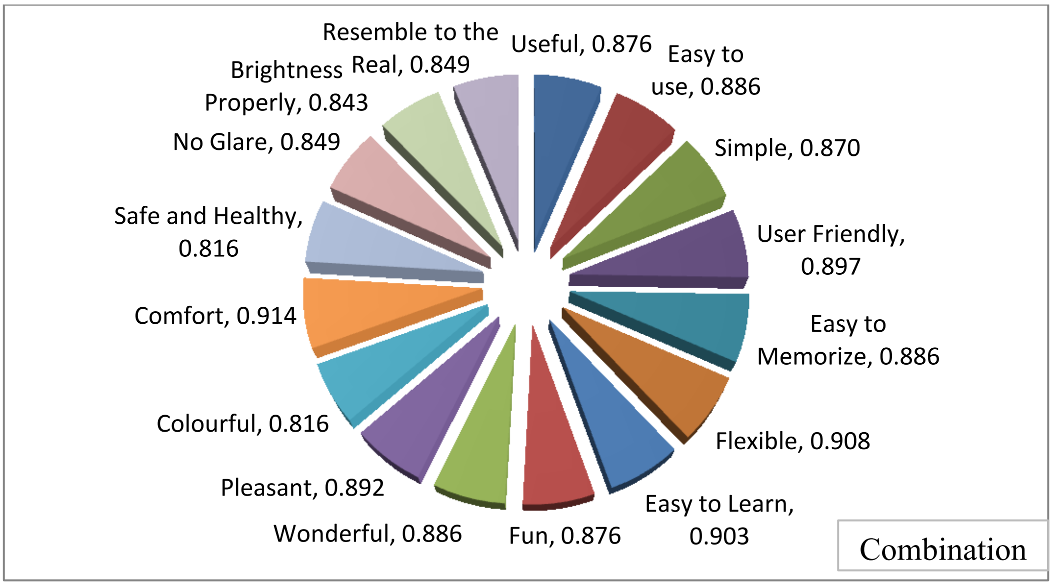


Figure 7.1 Proportion of sixteen customer's criteria of virtual environment

7.2.1 Analysis of Factorial Test on Customer's Criteria of VE Design

The results of factorial analysis test showed that the criteria for virtual environment can be categorized into several groups. This means the criteria are multi-dimensional (It accepts H_1 or reject null hypothesis). Based on rotation of *varimax,* five groups were identified. In particular, group 1 was related to the customer's need of virtual environment design to be useful, easy to use, user-friendly, easy to memorize, easy to learn, and simple and flexible when used.

User-friendly is defined as a system that is easy to learn and easy to use, as well as easy to memorize. Thus, the design must be simple and not complex, and useful as it meets the capacity of visual short term memory of users, so that the user can interact with it more effectively and efficiently. Taha *et al* (2010) investigated and found that the memory span for Malaysian population was in the range of 6 and 11 objects. It was also found that 55.7% of users desired that the number of virtual control button design to be not higher than 9 buttons for simplicity purpose. Another criterion in this group was Flexible. About 88.3 % of the users preferred the VE to be easily modified according to the user's need particularly the attributes of VE.

Group 2 is concerned with the desired visual comfort when interacting with virtual environment. The VE should be comfortable, safe and healthy for user's eyes/vision. Visual comfort is the most important criteria to be considered during the design of a VE. Users desire minimum risk on their vision when interacting with the virtual environment. The design of VE should not cause any visual problems such as eyestrain, blurred vision, dry and irritated eyes, and others on the user's eyes.

Group 3 describes the need for an interesting design for VE. The customer needs a VE that is fun, wonderful, pleasant and colourful.

Non-glaring is an important criterion for virtual environment in group 4. The virtual scene should have the appropriate brightness to avoid visual disorder and discomfort. The last group is group 5, which requires that the virtual environment resembles the real environment.

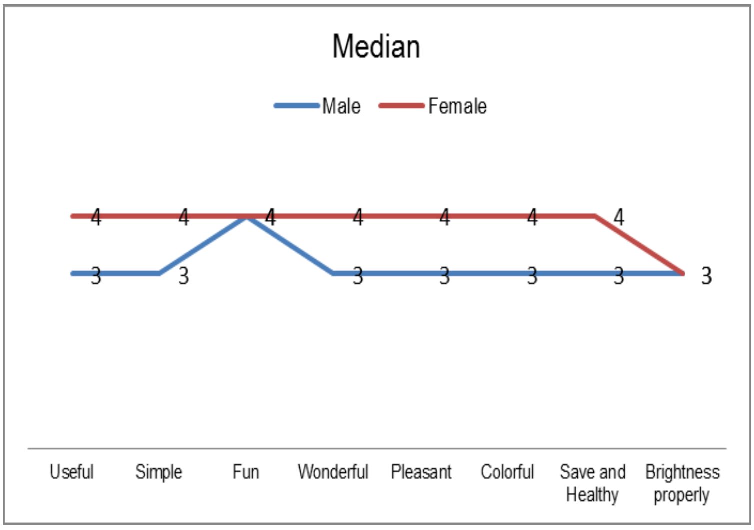
In summary, the criteria can be grouped as follows: Group 1 is user-friendly, Group 2 is visual comfort, and Group 3 is interesting design. Group 4 is clear to see, and Group 5 is resembling the real environment.

7.2.2 Analysis of Chi-square Test of Independence on Customer's Criteria of VE design

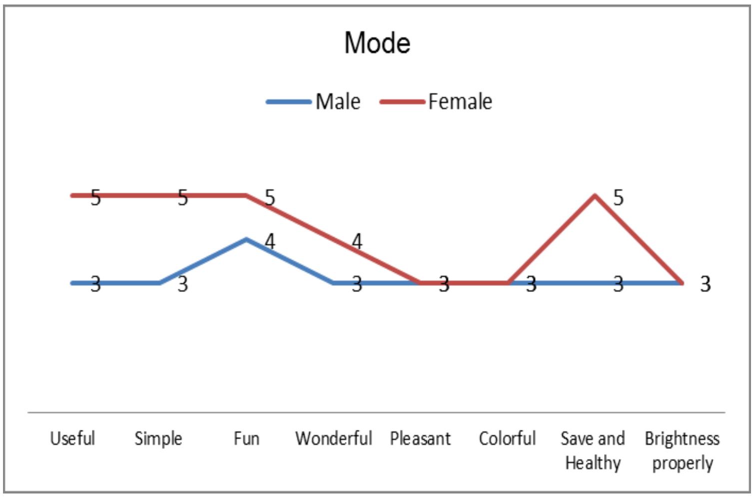
A statistical test was conducted to investigate the difference in response between male and female respondents on the criteria required for a virtual environment. Table 4.8 shows the result of the chi-square test of independence. The results of the test at 5% significance level showed that there was a difference for several criteria. Thus, the hypothesis of research (H_1) was accepted or not rejected at $p < 0.05$ for useful, simple design, fun, wonderful, pleasant, colourful, safe and healthy, and bright properly criteria, and the null hypothesis was rejected. This indicates that male and female groups have different criteria for virtual environment design.

Figure 7.2 explains this dissimilarity where female's median responses are more agree or more important (grade 4) while male's median responses are agree or important (grade 3) for those eight criteria. This illustrates that females think usable, simple design, fun, wonderful, pleasant, colorful, safe and healthy, and brightness properly criteria should be also considered in designing a virtual environment. This is also supported by mode score where most females' responses are strongly important (grade 5) and more important (grade 4). However, most males assumed that these criteria should not moderately important than other criteria to be considered in the virtual environment design. Also the mode scores showed similar status with median that is at grade 3 (agree/important). This describes the different level of need between them in making use of a virtual environment.

This situation will make it difficult or inefficient to design a virtual environment that will satisfy the all users who have different criteria. Because of the design of virtual environment will be used by part of users, male or female only. Therefore, this process is too complex to design. Suh (2007) recommended that this complexity should be reduced by applying appropriate design process.



(a) Median score



(b) Mode score

Figure 7.2 a) Median score (b) Mode score of customer's criteria of virtual environment for male and female groups

It is important to consider only the criteria of virtual environment that will satisfy both groups (male and female). Thus, it can increase user's satisfaction when using virtual environment. On the other hand, the designer or programmer can develop a virtual environment efficiently and effectively that meet the user's requirements.

In this study, it can be referred to the null hypothesis at $p > 0.05$, where there are no difference between male and female responses for easy to use, user friendly, easy to memorize, flexible, easy to learn criteria in the first group, visual comfort criteria in group 2, non-glaring criteria in group 4, and resemble the real environment criteria in group 5. The criteria in group 3 are ignored in the next activities of this study, because these criterions showed the significant difference between male and female response.

Male's median responses and female's median responses are similar to partial criteria, such as user friendly, easy to memorize, easy to learn, and comfort. Hence, the grade for these criterions is more important (see Figure 7.3). This situation allows four other criteria, which are important may also be considered in designing a virtual environment for use. Similarity criterions need to be considered, which are able to bring out comfort, efficiency and effectiveness on use of virtual environment for overall users, as well as manufactures and designers.

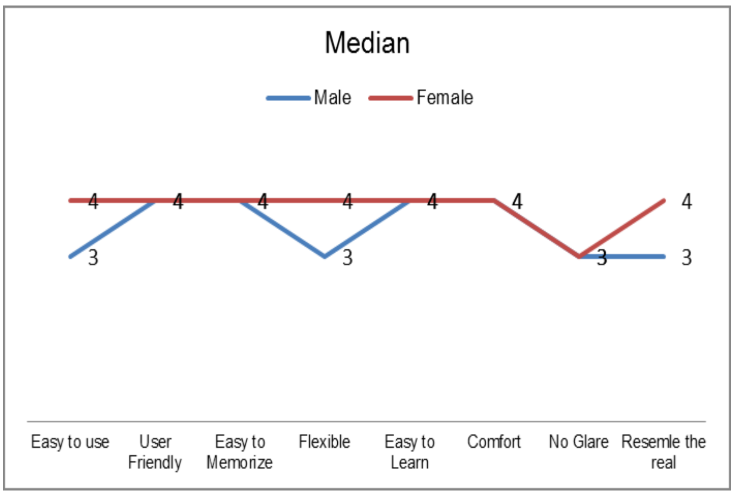


Figure 7.3 Median score for eight criteria between male and female groups

Figure 7.4 described the proportion of combination data (male and female groups) for the selected criteria of VE. More than 85 % of users required these criteria to design the any virtual environment.

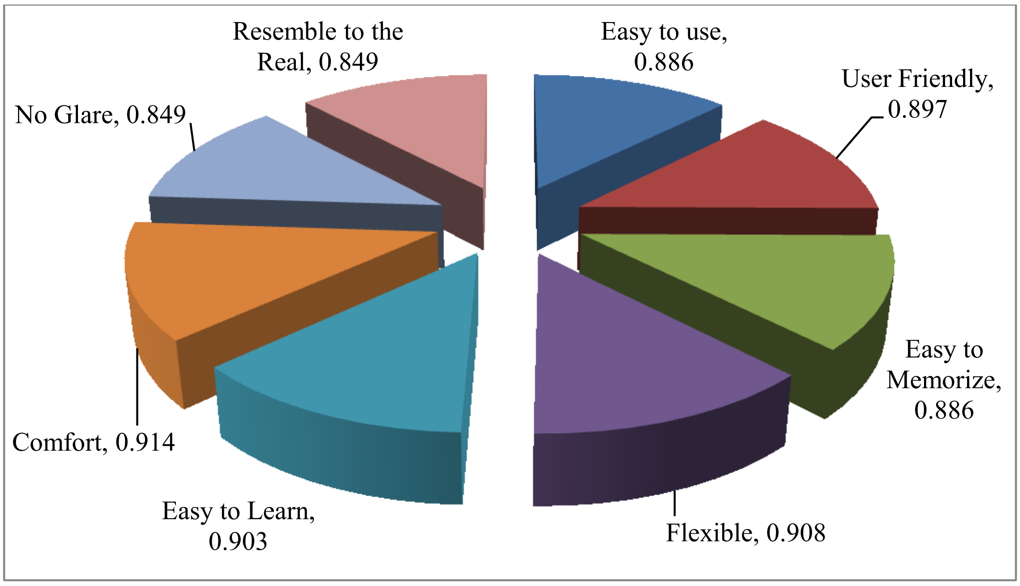


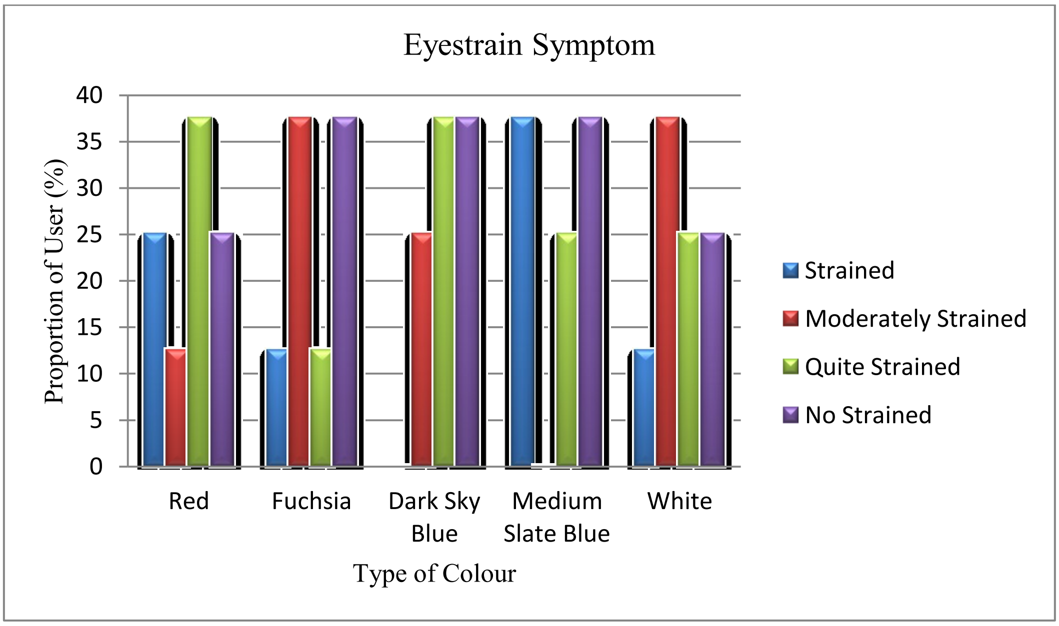
Figure 7.4 Proportion of customer's criteria of virtual environment for male and female groups

7.3 Analysis of Ergonomic Attributes of Virtual Environment Design

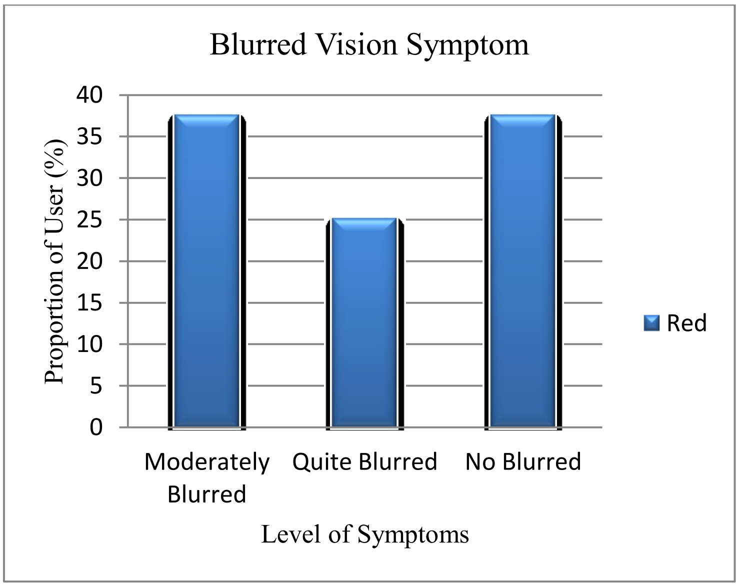
One of the parameters of cyber sickness is visual symptoms (Barret, 2004). In his handbook, Anshel (2005) mentioned that visual symptoms can vary but these mostly include eyestrain, headache, blurred vision, dry and irritated eyes, double vision, colour distortion and light sensitivity. The symptom often occurs when the viewing demand of the task exceeds the visual abilities of the user. The viewing task is influenced by the design of the virtual environment viewed or interacted with. This research has identified some attributes or variables of VE that may cause the occurrence of visual symptoms.

7.3.1 Analysis of Colour Types for Virtual Background Design

Statistical binomial test on five types of virtual background colour (Table 5.1) showed that colour type inflicts the users with eyestrain and blurred vision symptoms. Figure 7.5 (a) and (b) exhibit the levels of eyestrain and blurred vision symptoms experienced by users when interacting with VE. Only red colour significantly resulted in blurred vision. This might be caused by red colour that discomforts the eyes when a virtual object is in motion. The colour is also quite glaring in such way that it would be difficult for the eyes to focus on a virtual object. Other types of colours also generally caused eyestrain symptoms. Ergonomics recommendation on background colours stipulates the use of a design that is able to reduce or minimize the incidence of visual symptoms. The targets in the design of the background colour are no strain and no blur level. Thus, red, fuchsia, dark sky blue, medium slate blue and white colours must be changed to a smoother and softer colour that can alleviate the occurrence of visual symptoms.



(a)

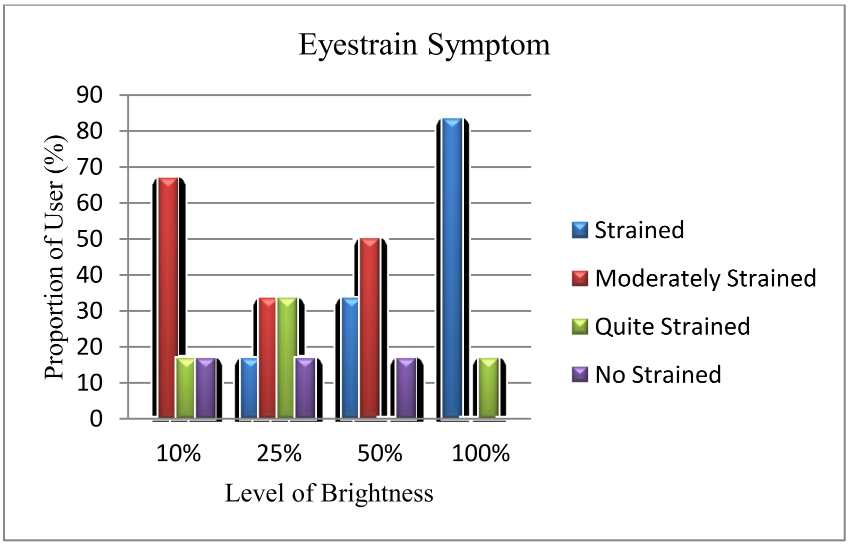


(b)

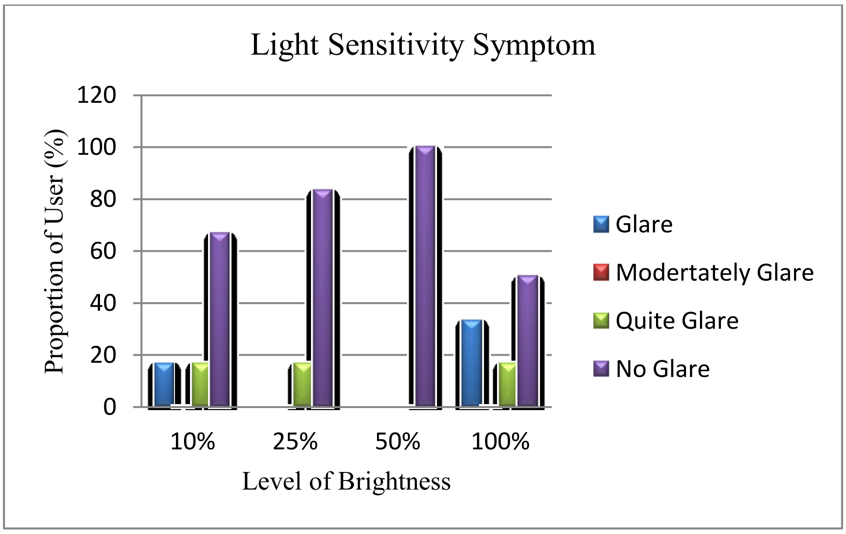
Figure 7.5 (a) Level of eyestrain symptom (b) Level of blurred vision symptom

7.3.2 Analysis of Virtual Lighting Level

The results of statistical binomial test in Table 5.2 demonstrated the effect of brightness level of virtual light on the occurrence of visual symptoms. The level of brightness affects the eyes when tracking virtual objects in the VE. A darker level (10%) or higher level (100%) can induce eyestrain and dry and irritated eyes symptoms, as well as light sensitivity symptom. This is because the eyes are forced to focus, which caused strain to the eyes, as well as dryness and irritation, and decreases the sensitivity to light. Figure 7.6 (a), (b) and (c) describe the level of symptoms occurring in human visual system. No negative effect (no strained, no dry, no glare) is the best condition of virtual lighting to be considered as one of the attributes in designing a VE.



(a)



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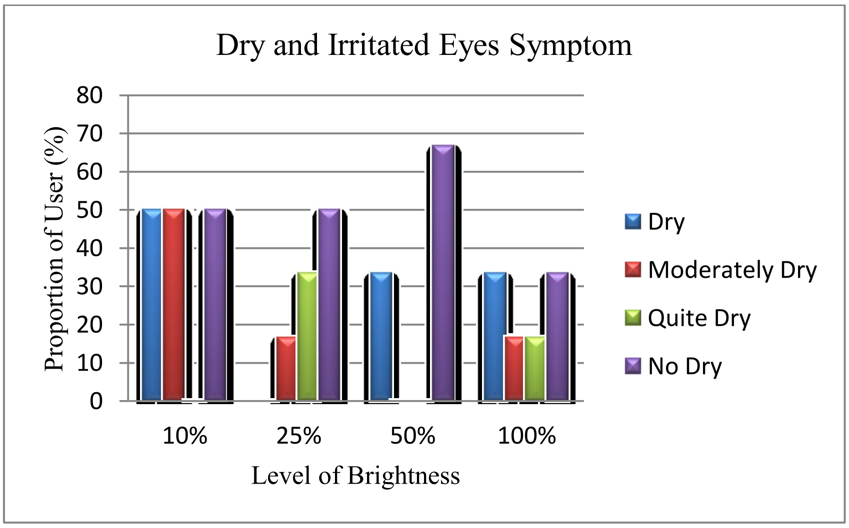


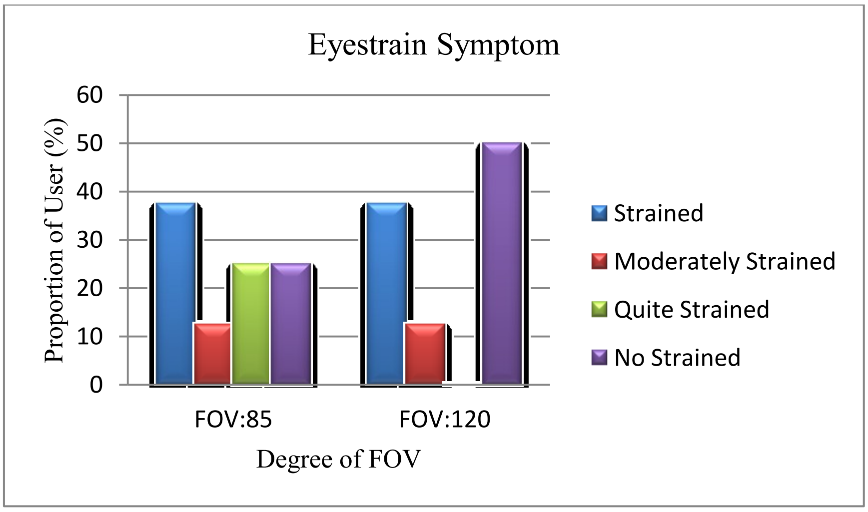
(c)

Figure 7.6 (a) Level of eyestrain symptom (b) Level of light sensitivity symptom (c) Level of dry and irritated eyes symptom

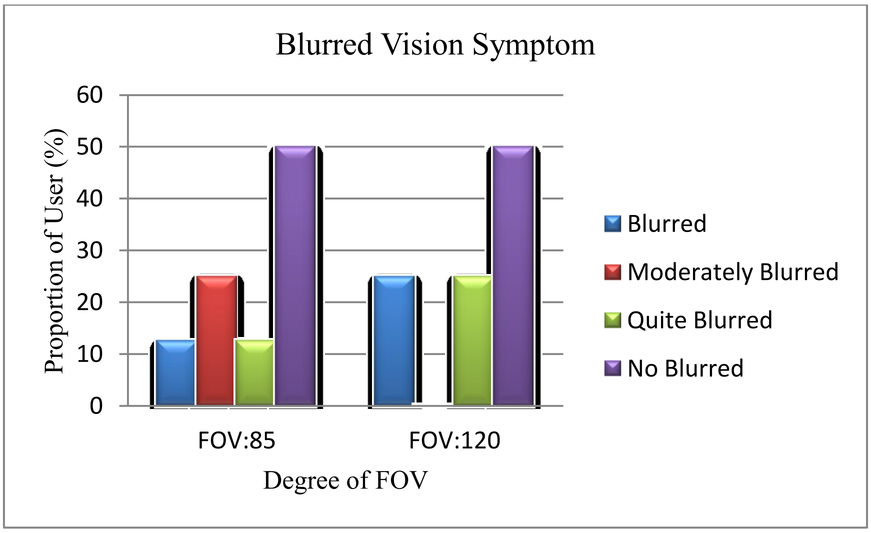
7.3.3 Analysis of Field of View (FOV)

Table 5.3 shows the result of statistical binomial test of the effect of field of view (FOV) on users. It shows that the degree of visual field can develop visual disorder especially eyestrain, blurred vision and dry and irritated eyes. Therefore, the degree of FOV has to be taken into account when designing a VE. It can be seen that 120^{o} of FOV caused 50% of the users to suffer eyestrain symptoms as compared to 85^{o} of FOV.

On the other hand, dry and irritated eyes symptoms were experienced by 63% of the users when using 120^{o} of FOV, which is higher than when they were using 85^{o} of FOV. Thus, a wider FOV or narrower FOV will cause users to suffer one of the visual symptoms. It is because both conditions require the eyes to focus. Thus, it is essential to determine the FOV required reducing these symptoms. Figure 7.7 (a), (b) and (c) describe the levels of symptoms occurring for eyestrain, blurred vision, and dry and irritated eyes symptoms, respectively. For the eyestrain symptoms, 120^{o} FOV was better than 85^{o} as about 50 % users did experience the incidence. On the contrary, 120^{o} FOV was not acceptable compared to 85^{o} for dry and irritated eyes symptom. This is because 50% of the users did not experience any eye symptoms when using 85^{o} FOV.



(a)



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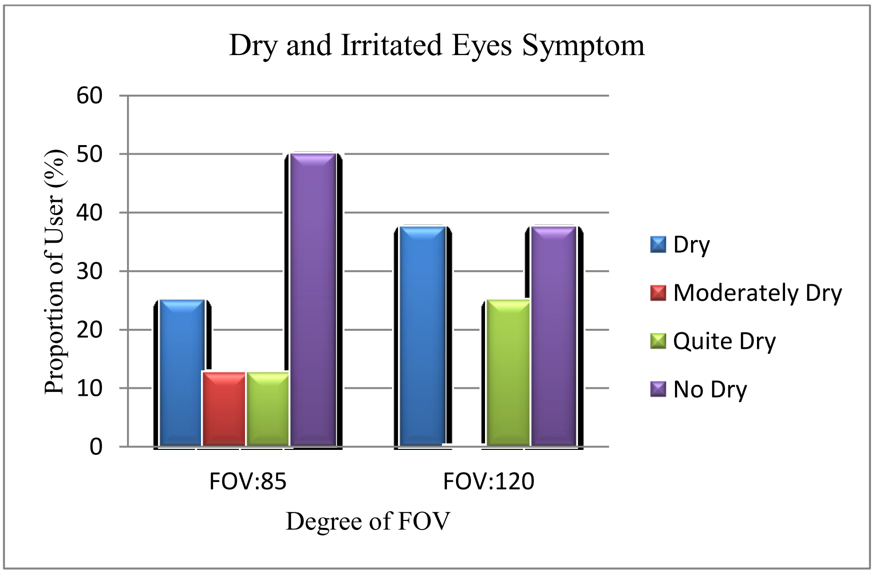
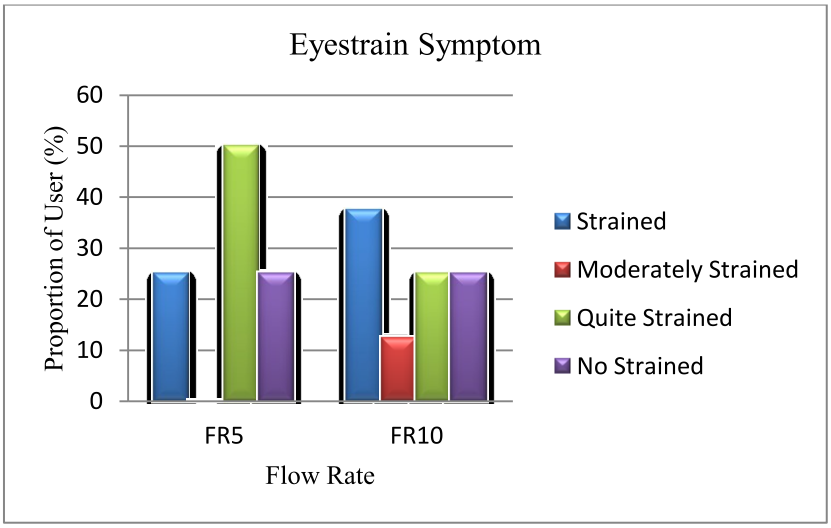


(c)

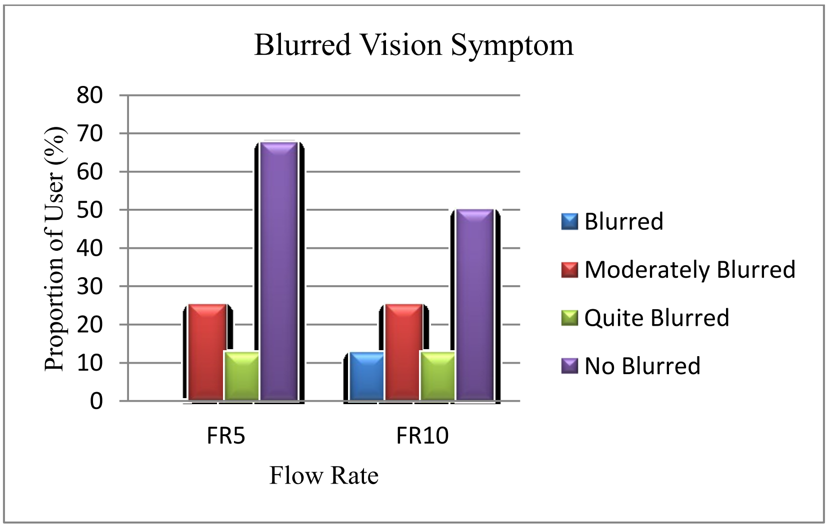
Figure 7.7 (a) Level of eyestrain symptom (b) Level of blurred vision symptom (c) Level of dry and irritated eyes symptom

7.3.4 Analysis of Flow Rate (FR) of Virtual Objects

Flow rate (FR) is the rate at which subsequent flow of the virtual object can be generated per unit time. The result of statistical binomial test in Table 5.4 has found that the flow rate of virtual object affects on the incidence of eyestrain, blurred vision, and dry and irritated eyes symptoms. This is because it affects the ability of the eyes to see virtual objects as it is being generated, hence the eyes experienced strain, blur and also dryness or irritation during that period. Figure 7.8 (a), (b), and (c) depict the level of the symptoms experienced by users. The effect can be minimized by designing the appropriate flow rate of the virtual object generated. A flow rate at 5 seconds per piece was better than the flow rate of 10 seconds per piece to avoid blurred vision symptoms. This is because more than 69% of users did not suffer this condition at this flow rate.



(a)



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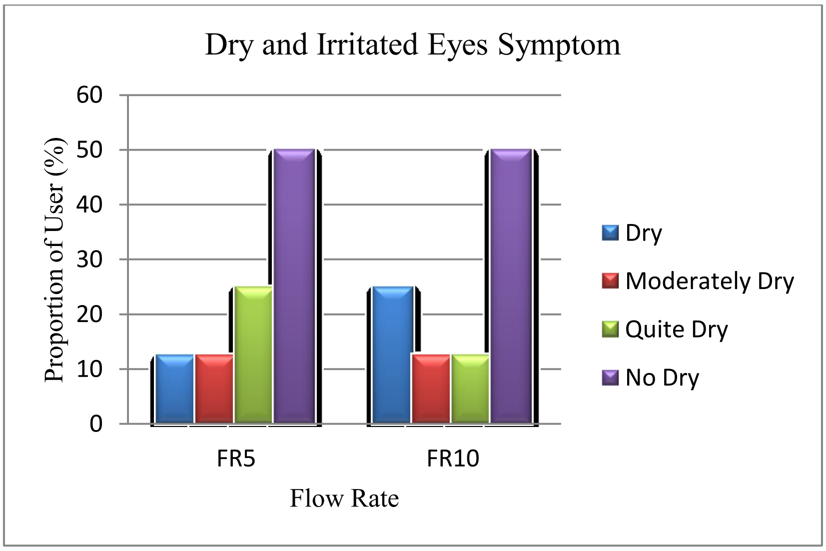


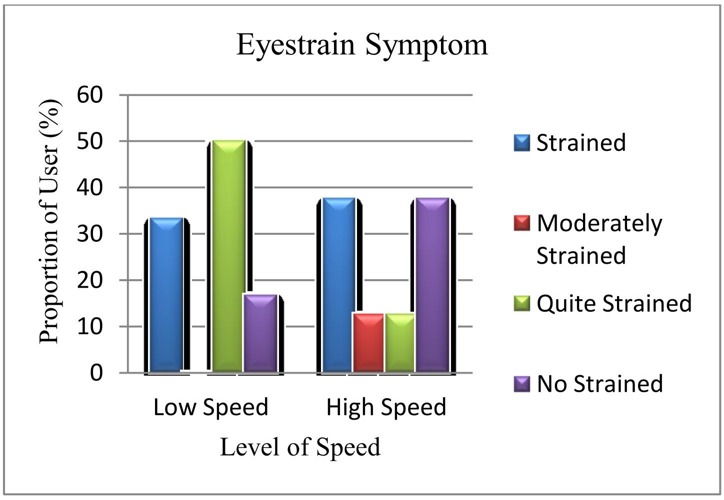
(c)

Figure 7.8 (a) Level of eyestrain symptom (b) Level of blurred vision symptom (c) Level of dry and irritated eyes symptom

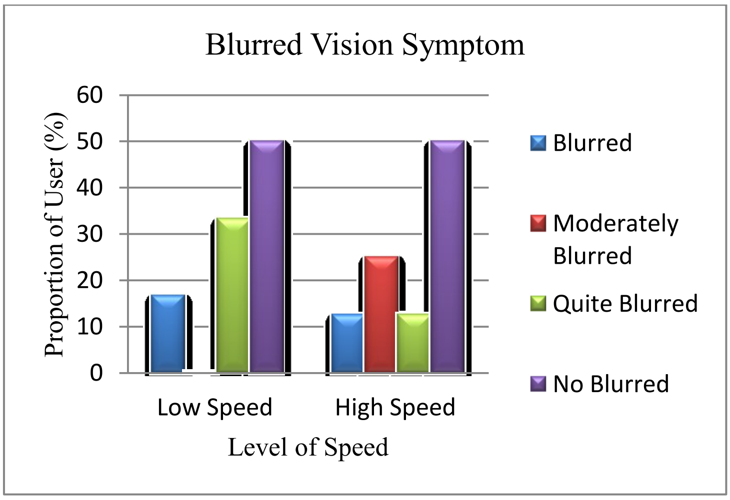
7.3.5 Analysis of Speed of Virtual Object's Motion

Different speeds of virtual object's motion in VE were investigated. Statistical binomial test (Table 5.5) showed that users suffered from eyestrain, blurred vision, and dry and irritated eyes when interacting with virtual objects at low and high motion speed.

This is because the eyes are trying to focus on the moving virtual object, which requires good coordination with the hand when performing a task. Figure 7.9 (a), (b) and (c) show the level of symptoms experienced by the users. It can be seen that the speed of virtual object's motion needs to be considered as an attribute in designing a VE. A higher speed of the virtual object's motion is better than a lower speed. This is because at higher speed, there is no effect on users whether for eyestrain symptom or dry and irritated eyes symptom compared with lower speed.



(a)



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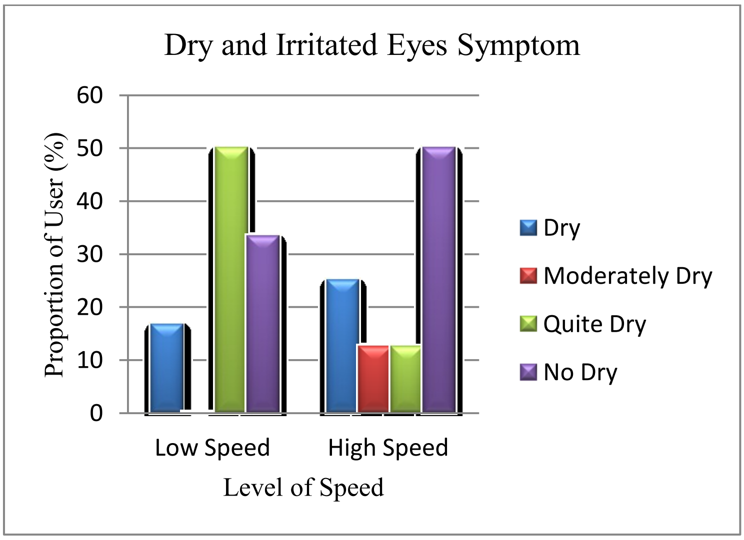
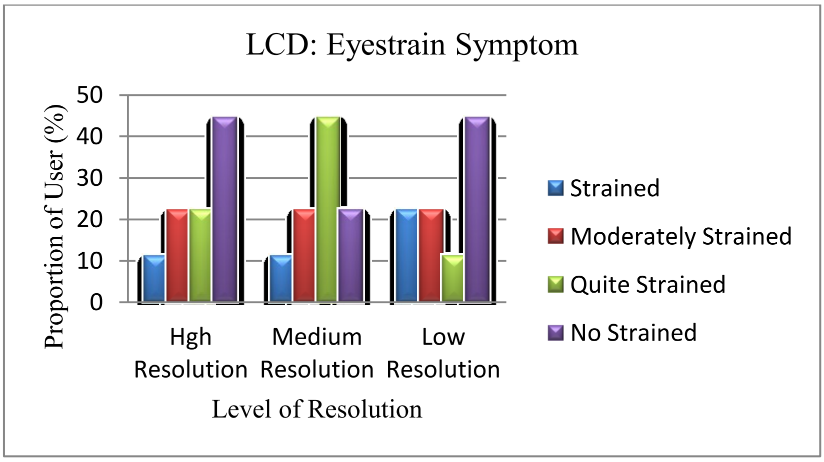


(c)

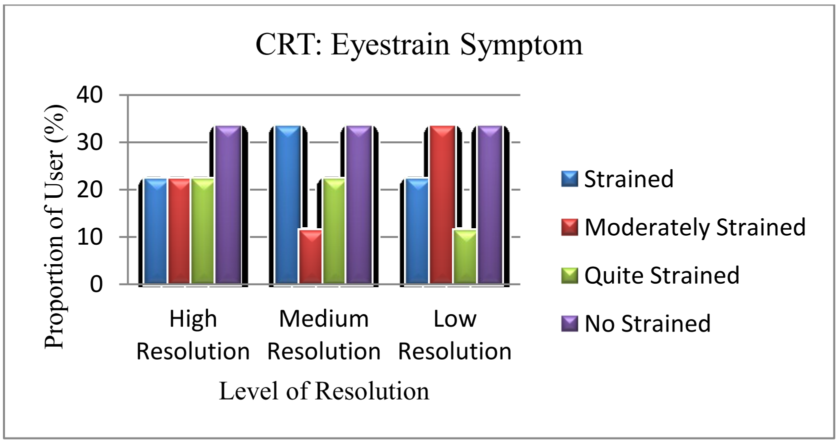
Figure 7.9 (a) Level of eyestrain symptom (b) Level of blurred vision symptom (c) Level of dry and irritated eyes symptom

7.3.6 Analysis of Screen Resolution

Many researches have been conducted and concluded that working with LCD screen is much more comfortable compared to working with CRT screens (Alstrom *et al*, 1992; Saito *et al*, 1993; Shieh & Lin, 2000). This is contributed to the luminance contrast and limited viewing angle of LCD screens (Snyder, 1988). Additionally, TFT-LCD screen seems to be the preferred technology by users for identifying letters on VDTs (Shieh & Lin, 2000). In the current research, statistical binomial test (Table 5.6) has found that eyestrain and dry and irritated symptoms were experienced by users at three different resolutions (high, medium and low resolutions), whilst dry and irritated eyes incidence were experienced by users with the CRT screens at medium and low level of resolution only. This indicates that the resolution of display needs to be considered as one of the attributes in designing a VE.



(a)



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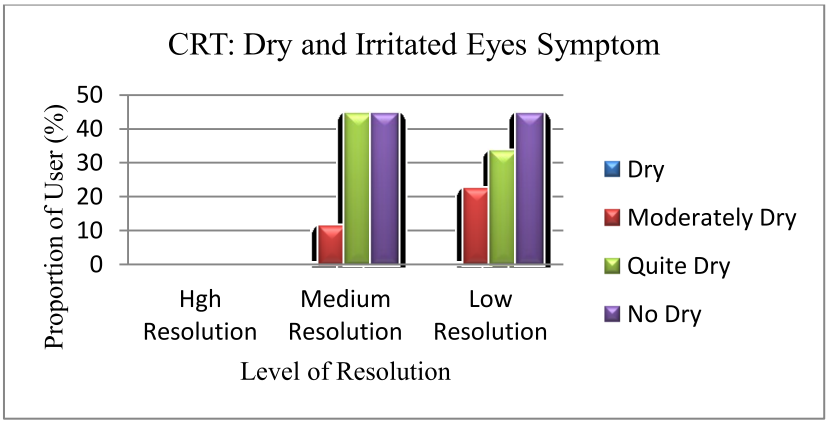


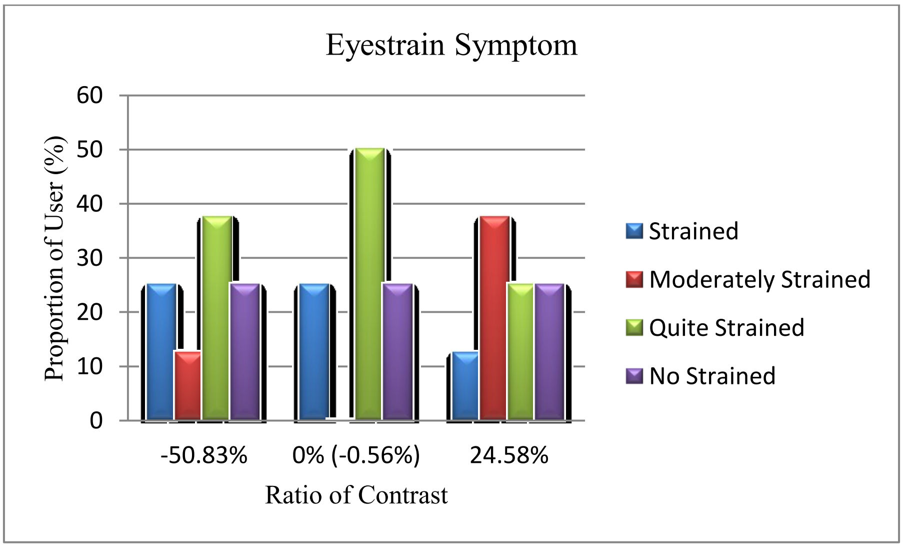
(c)

Figure 7.10 (a) Level of eyestrain symptom on LCD (b) Level of eyestrain symptom on CRT (c) Level of dry and irritated eyes symptom on CRT

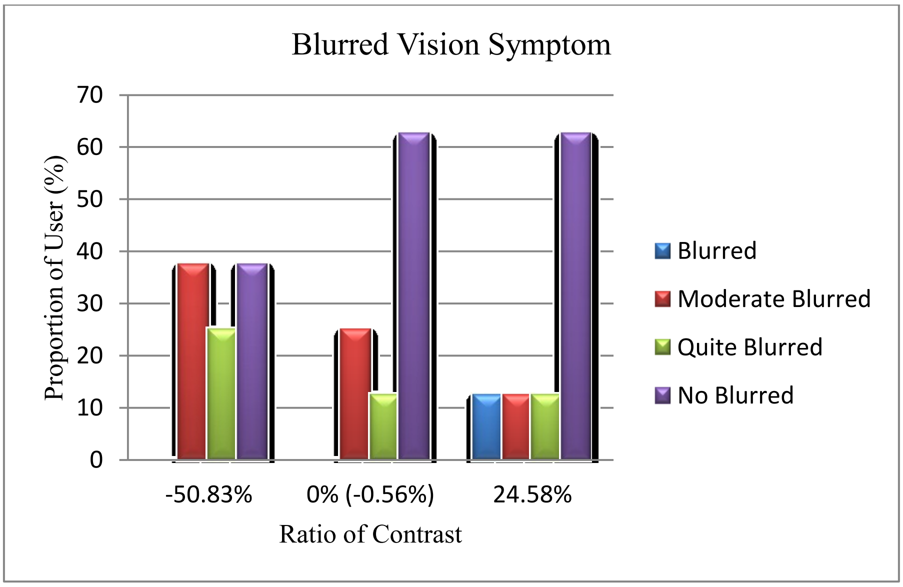
Figure 7.10 (a), (b) and (c) show the level of eyes symptoms for different resolution. To avoid eyestrain symptoms, high and low resolutions were preferred for LCD screen because more than 40 % of the users did not experience any strain. However for CRT screen, all resolution levels can be used because there was no incidence of eyestrain symptoms or dry and irritated eyes symptoms.

7.3.7 Analysis of Contrast Ratio between Target and Background

Figure 7.11 (a), (b) and (c) describe the level of incidence experienced by users for different contrast ratios. The result of statistical binomial test in Table 5.7 showed that eyestrain was experienced by most users (75%) for all condition of contrast. Meanwhile, blurred vision was experienced by 63% of the users at -50.83% contrast ratios, and dry and irritated eyes was experienced by 50% of the users at 0% (-0.56%) contrast ratios. This was due to the contrast condition affecting the ability of the eyes to distinguish the target from the background. Thus, contrast ratio should be considered as one of the attributes or variables in designing virtual environment.



(a)



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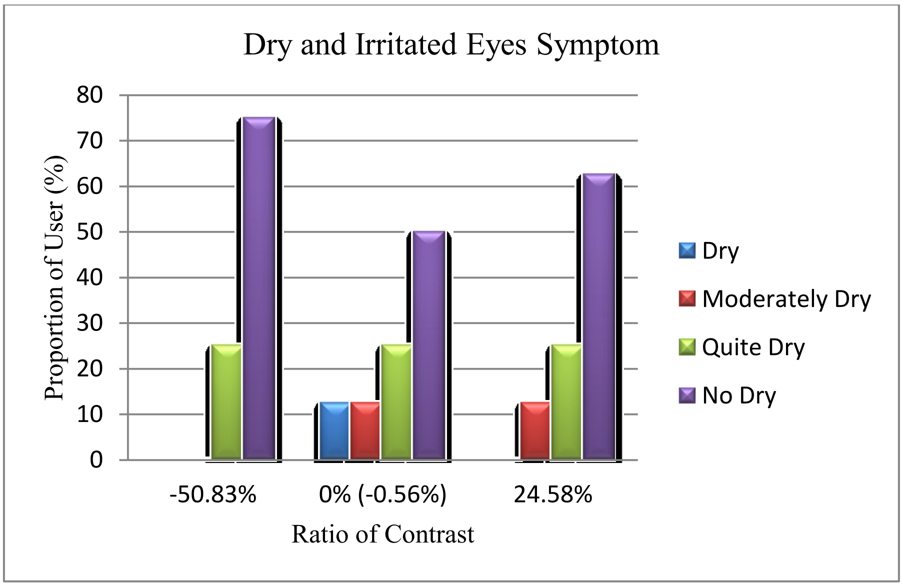

(c)

Figure 7.11 (a) Level of eyestrain symptom (b) Level of blurred vision symptom (c) Level of dry and irritated eyes symptom

7.4 Analysis of Ergonomics Design Parameters of Virtual Environment Design

7.4.1 Analysis of Independence of the Design

To maintain the independence axiom, the design matrix must be either diagonal/uncoupled or triangular/decoupled (Suh, 1990; 2001). The design equation (7.1) describing the relationship between FR and DP at the second level is given by:

(7.1)

The equation presents a decoupled design or upper triangular design matrix, where each FR is satisfied by a DP. Even if there are a few FRs affecting other FRs, the design is still acceptable. However, such design activities are rather difficult to complete due to the difficulty of designing smooth virtual colour of the background (DP_{11}) previously to meet FR_{11} before selecting the smooth display and compatible resolution (DP_{16}), and the setting for non-glaring and dark (DP_{12}) virtual lighting. This equation exhibits the existence of complexity in the design. Thus, a proper sequence of design activities should be developed such that a smooth display and compatible resolution (DP_{16}) and non-glaring and dark virtual lighting (DP_{12}) should be first specified so that the complexity can be eliminated. The design equation (7.2) shows uncoupled design or diagonal design matrix at the second level, where it is independent to each other. This is an ideal design that should be achieved.

(7.2)

The relationship between FR and DP at the third level presented in the design equation (7.3) is equal to the second level, where the design matrix is a diagonal design matrix or uncoupled design. This shows the decomposition in the lower level that is consistent with the higher level. The design equation (7.3) explains that the design activities begin firstly using liquid crystal display (DP_{161}) to meet FR_{161} and followed by setting high or low resolution (DP_{162}), and setting 25% - 50% of brightness (DP_{121}) in virtual lighting independently. Then, the other independence DPs (DP_{111}, DP_{131}, DP_{141}, DP_{151}, DP_{152}) are the next design activities that should be conducted to satisfy other independence FRs, which are FR_{111}, FR_{131}, FR_{141}, FR_{151}, and FR_{152}.

(7.3)

The diagonal design matrix presented in equations (7.2) and (7.3) for the second and third level showed that the sequence of design activity begins by specifying the corresponding DP_{161} of determining the LCD to meet the independent functional requirement FR_{161}. This is followed by DP_{162} and DP_{121} which are to set high or low resolution of display and also the level of brightness. These design activities are carried out without affecting the others. It also facilitates a designer to work with the next design activities effectively and efficiently. Thus, the sequence of the design activities should be FR_{161}-FR_{162}-FR_{121}-FR_{111}-FR_{131}-FR_{141}-FR_{151}-FR_{152}.

7.4.2 Analysis of Ergonomics Design Parameters

According to International Ergonomics Association (2003), ergonomics (or human factors) is related to designing methods to optimize human well-being and overall system performance. In view of this, system elements (in this context is virtual environment) must be designed to address the needs, abilities, and limitations of users. However, one of the fundamental problems is the multiple functional system-human compatibility requirements that must be satisfied at the same time (Karwowski, 2005). Suh (2007) proposed using axiomatic design theory to map human capabilities and limitations to system (technology-environment) requirements and affordances.

The results of axiomatic design approach and ergonomic principles in this study showed that the design parameters identified have satisfied the independence functional requirement (see design equation (7.3)). It was found that medium slate blue, dark sky blue and fuchsia produce no visual symptoms compared to other colours. It was also found that 25% - 50% range level of brightness of virtual lighting caused only one visual problem, with some users did not experiencing any visual symptoms at all. The findings above indicated that the colour of virtual background should be softer and level of brightness should not produce glaring effect to suit the ability and limitation of user's vision.

A level of contrast of 24.58% between virtual object and background caused no symptoms on user's vision. It also causes less visual symptoms. An 85 or 120 degrees field of view has similar effect on vision. This was because both FOVs did not produce any visual symptoms on more than 50 % of the users. Thus, the setting of contrast and field of view is crucial in reducing visual problems. A five second per piece flow rate and high or low speed motion of virtual object set simultaneously can resulted in the reduction of visual disorders perceived by the users. Finally, the use of liquid crystal display (LCD) with high or low resolution is the best choice because there was no problem with vision encountered by more than 40% of the users. This is consistent with the result of Saito *et al*. (1993) and Menozzi *et al*. (1999).

7.5 Analysis of Validation Test on Ergonomic Design Parameters

The results of Mann-Whitney U test and chi-square test at 5% significance level are shown in Table 6.2. The results showed that there was no difference in the user's criteria of ergonomics virtual environment design between ergonomic design parameters identified and user's or customer's response based on the survey. This indicates that ergonomic design parameters developed to design EVE was valid and satisfies the criteria that customers looked for in a virtual environment. This was also indicated by the median level of agreement of the customer for overall criteria that are important or agree (3), and more important or more agree (4) as the criteria used for designing ergonomically virtual environment.

Figure 7.12 shows a comparison of the user's or customer's voice of the criteria for virtual environment from survey and experiment. It showed that more user or customer agree to virtual environment being designed using ergonomics design parameters of user-friendly, easy to use, easy to learn, easy to memorize, flexible, comfort on vision, non-glaring, and resemble the real environment.

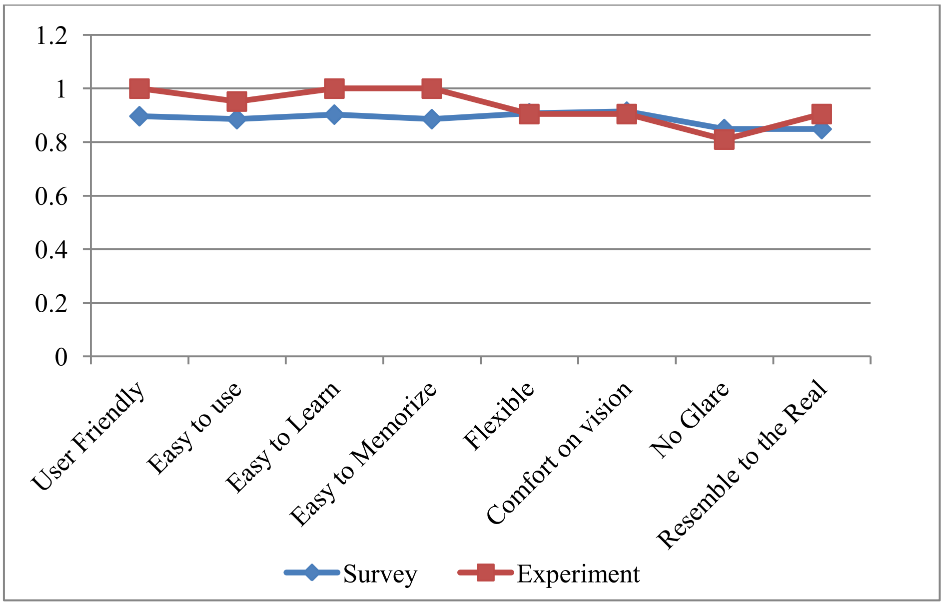

Figure 7.12 User's voice on the criteria of EVE between survey and experiment

This was also supported by the result of Mann-Whitney U test on a box plot graph in Figure 7.13. It showed that median grade for experiment and survey were close. Table 6.3 presents a median rank of criteria is 105.71 for experiment and 103.25 for survey.

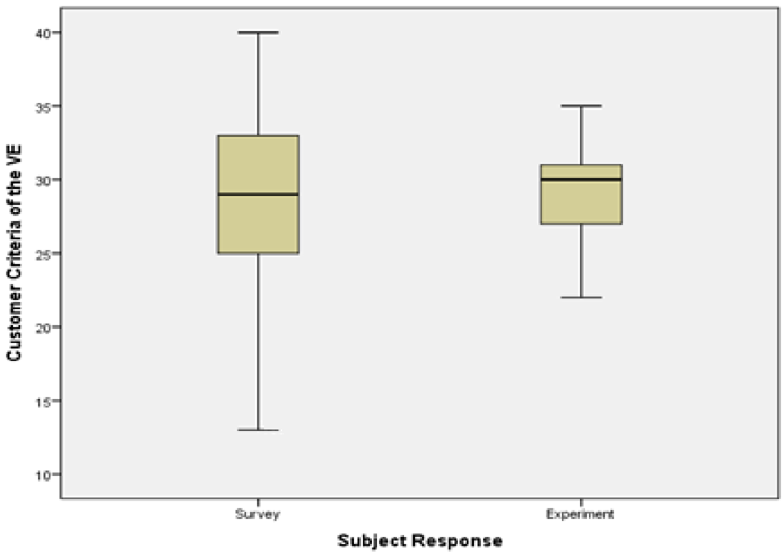

Figure 7.13 A median grade of user's response on the criteria of EVE between survey and experiment based on a set of criteria

The special case in this study is related to the visual comfort experienced by user when interacting with ergonomic virtual environment. It supports the evidence that the developed ergonomics design parameters was able to alleviate the negative effect on user's vision. The results of binomial test showed that there was no significant problem or symptom perceived by users. Most of the users (> 50%) indicated that they did not experience significant visual disorder, where the median is almost not getting disorder (4) or no problem (3). This was due to ergonomic design parameters developed which includes medium slate blue as colour of background, 50% of brightness of virtual lighting, 24.58% of contrast between virtual object and background, 85 degree of field of view, appropriate combination between five second per piece of virtual material flow rate, and low speed of virtual product's motion, use of high resolution of screen and LCD provides visual comfort effect on user's vision.

7.6 Conclusion

The analysis indicates that the identified ergonomic design parameters for the design of virtual environment using the proposed methodology give the best description to satisfy eight customer's criteria, which are easy to use, user-friendly, easy to memorize, flexible, easy to learn, visual comfort, non-glaring, and resemble the reality. These design parameters can even alleviate the negative effects on the user's vision, where the user did not experience the symptoms significantly.

CHAPTER 8 CONCLUSION AND FUTURE WORK

This chapter concludes the thesis, and contains three sections. Section 8.1 presents the conclusion of the research, while Section 8.2 presents the major contribution, and some recommendations are presented in Section 8.3.

8.1 Conclusion

The conclusion from this study can be made as follows:

1. A survey was conducted by considering sixteen criteria for designing a virtual environment. However, only 8 criteria were found to be applicable for male and female correspondents. The criteria are easy to use, user-friendly, easy to memorize, flexible, easy to learn, comfort on vision, no glare and resemble the real. And the design of virtual environment was influenced by several attributes such as virtual background colour, virtual lighting, field of view (FOV), flow rate, speed of virtual object, display resolution, and contrast ratio. These attributes significantly affect user's vision, particularly with eyestrain symptoms, blurred vision, dry and irritated eyes, and light sensitivity symptoms.
2. The design parameters of virtual environment developed based on ergonomic criteria satisfied the independence functional requirement and the customer's voice, which includes medium slate blue, dark sky blue, or fuchsia for smooth virtual background colour, 50% of brightness for appropriate level of virtual lighting, +24.58% of good contrast between virtual object and background, 85 degrees of field of view (FOV) for good viewing, high or low speed of flow rate, appropriate motion of virtual object, liquid crystal display (LCD), and high resolution of display for appropriate output devices. While, the validation test resulted in there was no difference in the criteria of ergonomic virtual environment

between the identified ergonomics design parameters and the customer's voice based on the survey. The number of users who did not experience negative effect was more than 75%. This leads to the conclusion that the ergonomics design parameters developed were valid.

3. The proposed methodology was an appropriate methodology to develop ergonomic design parameters in a field of the ergonomic virtual environment design.

8.2 Major Contribution

This study has resulted in three major contributions. They are:

1. Ergonomics design parameters in designing ergonomic virtual environment.
2. A new methodology to develop ergonomics design parameters in a field of ergonomics virtual environment design.
3. Guideline to apply this methodology to design ergonomics virtual product.

8.3 Recommendation for Future Study

This study focuses on the development of ergonomics design parameters for designing ergonomics virtual environment. This EDP can be used as a guide for designer to design various kind of virtual environment. Moreover, the proposed methodology can be used for the case study in visual ergonomics design, especially for virtual environment. However, this methodology can be also applied to a wider field of ergonomic design that involves the effects of musculoskeletal system.

Thus, it is necessary to further the research in the future and apply this methodology in the field of ergonomics design for developing others ergonomics design parameters. It can be used as a guide or standard of the virtual product or system design.

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APPENDIX A : Questionnaire to Identify Costumer's Criteria for Virtual Environment

QUESTIONS ON THE DEVELOPMENT OF VIRTUAL ENVIRONMENT

SOALAN BERKENAAN PEMBANGUNAN PERSEKITARAN MAYA

The questions are a part of my PhD research on "Virtual Environment Design" conducted by the Department of Engineering Design and Manufacture, Faculty of Engineering, University of Malaya

Soalan-soalan ini adalah merupakan sebahagian daripada kajian Doktor Falsafah saya mengenai "Rekabentuk Persekitaran Maya" yang dijalankan oleh Jabatan Kejuruteraan Rekabentuk dan Pembuatan, Fakulti Kejuruteraan, Universiti Malaya.

The questions are developed to acquire your feedback on the characteristics needed for designing virtual environment.

Soalan-soalan ini direkabentuk untuk mendapatkan maklumbalas dari anda mengenai beberapa kriteria yang diperlukan untuk merekabentuk persekitaran maya.

Your answers are confidential and no questions are "deceptive". Please answer each question honestly.

Jawapan yang anda berikan akan dirahsiakan dan tiada soalan berbentuk "muslihat". Sila jawab setiap soalan dengan jujur.

Thanks for your cooperation.

Kerjasama anda disudahi dengan ucapan terima kasih.

Section A: Personal Background

A1 Name/*Nama* :…………………….…………………….(Optional)

A2 Gender/*Jantina* : ☐ Male ☐ Female

A3 Age/*Umur* : ………………years/tahun

A4 Ethnics/*Bangsa* : Malay ☐ China ☐ India ☐ Others ☐

A5 Weight/*Berat Badan* : ………..kg Height/*Tinggi Badan* : ……………cm

A6 Status : ☐ Married *(Berkahwin)*

☐ Single *(Bujang)*

A7 Highest qualification/*Pelajaran tertinggi*: SRP/SPM/Sijil Kemahiran/Ijazah Tinggi

A8 Have you interacted with the virtual world? *Adakah anda pernah berinteraksi dengan dunia maya?*

a. Yes b. No c. N/A

A9 How many years do you have experience in interacting with virtual world? *Berapa tahun anda mempunyai pengalaman berinteraksi dengan dunia maya?*

a. < 1 year b. 2 – 4 years c. > 5 years

A10 What kind of virtual world have you used to interact? (More than one answer can be chosen) *Apakah jenis dunia maya yang telah anda gunakan untuk berinteraksi?(Boleh pilih lebih dari pada satu)*

a. Virtual sport (football, tennis, etc) game
b. Virtual boxing game
c. Virtual fighting game
d. Virtual driving
e. Virtual airplane
f. Virtual train
g. Virtual robot
h. Virtual manufacturing
i. Others (please specified) : ____

A11 Where do you get the experience in interacting with virtual world? *Dimana anda memperoleh pengalaman berinteraksi dengan dunia maya?*

a. Computer set c. Television set e. Others (please specified) :
b. Cinema/Theater d. Simulator ______________________

Section B: Virtual Environment Characteristic/*Kriteria Persekitaran Maya*

VIRTUAL ENVIRONMENT

PERSEKITARAN MAYA

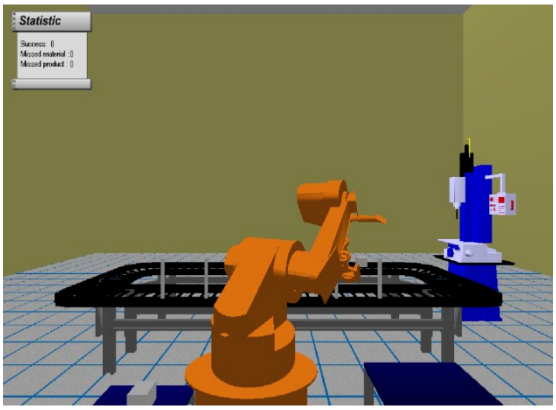
Virtual environment is an environment other than the one in which the participant is actually present. A computer generated model is more useful, where a participant can interact intuitively in real time with the environment or the object within, and to some extent has a feeling of actually 'being there', or a feeling of presence.

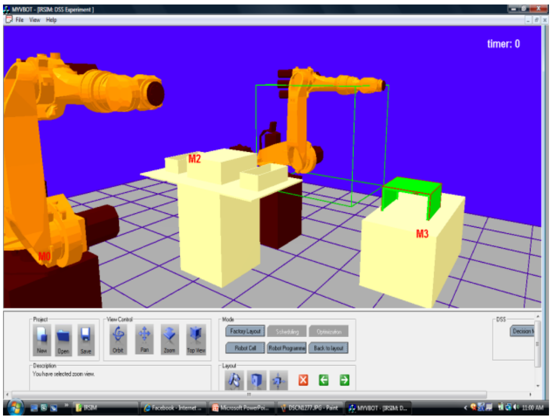
Persekitaran maya (Virtual Environment) adalah sebuah model persekitaran maya yang dihasilkan komputer di mana peserta dapat berinteraksi secara intuitif dengan persekitaran atau objek di dalamnya, dan sampai had tertentu mempunyai perasaan untuk benar-benar 'berada di sana', atau perasaan kehadiran.

Case Study/*Kajian Kes*:

VIRTUAL ROBOT MANUFACTURING SYSTEM (3D)

SISTEM PEMBUATAN ROBOT MAYA(3D)





The table below presents some statements related to the criteria required for a virtual environment design.

Jadual dibawah menunjukkan beberapa pernyataan tentang kriteria yang diperlukan untuk merekabentuk persekitaran maya.

Which criteria do you think are needed to design the virtual environment? *Kriteria manakah yang anda fikirkan perlu untuk mereka bentuk persekitaran maya?.*

The criteria of response:

1 =	Strongly Disagree		Strongly Not Important
2 =	Somewhat Disagree		Less Important
3 =	Agree	OR	Moderate
4 =	More Agree		Important
5 =	Strongly Agree		Strongly Important

Kindly, tick (√) at the appropriate circle that satisfies your response by referring the criteria of response above.

Pilih salah satu jawapan dengan menanda (√) pada lingkaran yang sesuai dengan respons anda.

Statements		**Responses**				
		1	**2**	**3**	**4**	**5**
1.	It must be useful	○	○	○	○	○
2.	It must be easy to use	○	○	○	○	○
3.	It must be simple to use	○	○	○	○	○
4.	It must be user-friendly	○	○	○	○	○
5.	It must be easily remembered on how to use it	○	○	○	○	○
6.	It must be flexible	○	○	○	○	○
7.	It must easy to learned quickly	○	○	○	○	○
8.	It must be fun to use	○	○	○	○	○
9.	It must be wonderful	○	○	○	○	○
10.	It must be pleasant to use	○	○	○	○	○
11.	It must be colourful	○	○	○	○	○
12.	It must be comfortable to use	○	○	○	○	○
13.	It must be safe and healthy to use	○	○	○	○	○
14.	It must not be glare	○	○	○	○	○
15.	The brightness must be properly	○	○	○	○	○
16.	It must be close to the real environment	○	○	○	○	○

Please answer the questions by circling the number that satisfies your response or your choice.

Sila jawab pertanyaan dibawah dengan memilih salah satu respons yang sesuai dengan pilihan anda.

17. How should the layout of virtual control button (command or menu) be arranged? *Bagaimanakah seharusnya butang pengendali maya didalam persekitaran maya disusun atur?.*

    a. At the top only

    b. At the bottom only

    c. At the top and bottom

    d. On the right side only

    e. On the left side only

    f. On the right and left side

    g. At the top and the right side

    h. At the top and the left side

    i. On the right side and at the bottom

    j. On the left side and at the bottom

    k. In the center

18. Which display do you prefer to show the virtual environment? *Paparan manakah yang anda lebih suka untuk menampilkan persekitaran maya?*

    ☐ CRT display monitor

    ☐ LCD monitor

    ☐ Widescreen display using projector

    ☐ Head mounted display (HMD)

19. What is your reason? *Apakah alasan anda dengan pilihan tersebut?*

    a. The display is more comfortable to see/*Paparan lebih selesa untuk dilihat*

Strongly Disagree	*Somewhat Disagree*	*Agree*	*More Agree*	*Strongly Agree*

b. The display has no flicker/*Paparan tidak ada kerlipan*

Strongly Disagree	*Somewhat Disagree*	*Agree*	*More Agree*	*Strongly Agree*

c. The display is smoother to view / *Paparan lebih halus untuk di pandang*

Strongly Disagree	*Somewhat Disagree*	*Agree*	*More Agree*	*Strongly Agree*

d. Others? (Please specify if any)

……………………………......................................………………………...

APPENDIX B : Questionnaire for Identification of Visual Symptoms

Please choose the most accurate answer that reflects the description of your condition in interacting with virtual robot.

Pilih jawapan yang paling sesuai yang menggambarkan keadaan anda ketika berinteraksi dengan robot maya.

1. Do you have any problems in interacting with virtual robot/environment?
   Apakah anda mempunyai masalah ketika berintraksi dengan persekitaran /robot maya?
   (3). No problem *(Tidak ada masalah)*
   (2). Minor problem *(Masalah kecil)*
   (1). Major problem *(Masalah besar)*

2. What do you experience or feel on visual fatigue when interacting with virtual robot/environment?
   Apa yang anda rasakan berkaitan dengan "visual fatigue" (keletihan visual) ketika berinteraksi dengan persekitaran/robot maya?
   (5). My eyes are not tired *(Kedua mata saya tidak letih)*
   (4). My eyes are hardly tired *(Kedua mata saya hampir tidak letih)*
   (3). I cannot say if my eyes are tired or not *(Saya tidak dapat mengatakan apakah kedua mata saya letih atau tidak)*
   (2). My eyes are little tired *(Kedua mata saya sedikit letih)*
   (1). My eyes are tired *(Kedua mata saya letih)*

3. What kind of symptoms/problems that you experienced during or after interacting with virtual robot/environment? (permitted to choose more than one).
   Apakah jenis gejala/masalah yang anda rasakan ketika berinteraksi dengan persekitaran/robot maya? (dibenarkan untuk memilih lebih daripada satu).

   a. Eyestrain
   (Ketegangan mata)
   b. Headaches
   (Sakit kepala)
   c. Blurred Near Vision
   (Penglihatan jarak dekat yang kabur)
   d. Blurred Distant Vision
   (Penglihatan jarak jauh yang kabur)
   e. Dry and Irritated Eyes
   (Mata kering dan menjengkelkan)
   f. Double Vision
   (Penglihatan berganda)
   g. Colour Distortion
   (Kecacatan warna)
   h. Light Sensitivity
   (Kepekaan/sensitivity terhadap cahaya)

Please chose the number that describes the symptoms that you experienced.

Sila pilih nombor yang menerangkan gejala/masalah yang anda hadapi.

4. Which level of eyestrain (asthenopia) that you experienced?
   Ketegangan mata (asthenopia) seperti mana yang anda rasakan?

   1.........................2.................. ....3.........................4............................5
   Strained Quite strained Moderate Quite not strained No strained
   Tegang Sedikit tegang Sederhana Hampir tidak tegang Tidak tegang

5. Which level of headaches that you experienced?
   Sakit kepala seperti mana yang anda berasa?

   1.........................2.................. ....3.........................4............................5
   Very painful Painful Moderate Little pain No pain
   Sangat sakit Sakit Sederhana Sakit sedikit Tidak sakit

6. Which level of blurred (near or distant) vision that you experienced?
   Penglihatan kabur (dekat atau jauh) seperti mana yang anda rasakan?

   1.........................2.......................3........................4...........................5
   Blurred Quite blurred Moderate Quite not blurred No blurred
   Kabur Sedikit kabur Sederhana Hampir tidak kabur Tidak kabur

7. Which level of dry and irritated eyes vision that you experienced?
   Mata kering dan menjengkelkan seperti mana yang anda rasakan?

   1........................2........................3.......................4............................5
   Dry Quite dry Moderate Quite not dry No dry
   Kering Sedikit kering Sederhana Hampir tidak kering Tidak kering

8. Which level of double vision (diplopia) that you experienced?
   Penglihatan berganda (diplopia) seperti mana yang anda rasakan?

   1....... ....2........................3.......................4.......................5
   Uncomfortable Quite uncomfortable Moderate Quite comfortable Comfortable
   Tidak selesa Agak tidak selesa Sederhana Hampir selesa Selesa

9. Which level of colour distortion that you experienced?
   Kecacatan warna seperti mana yang anda rasakan?

   1.........................2......................3........................4............................5
   Uncomfortable Quite uncomfortable Moderate Quite comfortable Comfortable
   Tidak selesa Agak tidak selesa Sederhana Hampir selesa Selesa

10. Which level of light sensitivity that you experienced?
Kepekaan/sensitiviti cahaya seperti mana yang anda rasakan?

1	2	3	4	5
Glare	Quite glare	Moderate	Quite not glare	No glare
Silau	*Agak silau*	*Sederhana*	*Hampir tidak silau*	*Tidak silau*

APPENDIX C : Questionnaire for Validation Test

Kindly, tick (√) at the appropriate circle that satisfies your response related with design of virtual robot (environment) manufacturing system (VRMS) by referring to the criteria of response below.
Pilih salah satu jawapan dengan menanda (√) pada bulatan yang sesuai dengan respons anda tentang Sistem Pembuatan Robot Maya (SMRM) dengan berpandukan pada kriteria bagi respons dibawah.

The criteria of response *(Kriteria respon):*
1 = Strongly Disagree *(Sangat Tidak Setuju)*
2 = Somewhat Disagree *(Agak Tidak Setuju)*
3 = Agree *(Setuju)*
4 = More Agree *(Lebih Setuju)*
5 = Strongly Agree *(Sangat Setuju)*

Pernyataan *(Statements)*	Responses					
Sangat Tidak Setuju (Strongly Disagree)	**1**	**2**	**3**	**4**	**5**	**Sangat Setuju (Strongly Agree)**
1. It is easy to use *Ia mudah digunaka*	○	○	○	○	○	
2. It is user friendly *Ia mesra pengguna*	○	○	○	○	○	
3. It can be easily remembered on how to use it *Ia sangat mudah diingati bagaimana hendak menggunakan*						
4. It is flexible *Ia fleksibel*	○	○	○	○	○	
5. It is easy to be learned quickly *Ia amat mudah untuk dipelajari*	○	○	○	○	○	
6. It is visually comfortable *Ia mempunyai visual yang menyelesakan*	○	○	○	○	○	
7 It is non-glaring *Ia tidak menyilaukan*	○	○	○	○	○	
8. It resembles the real *Ia menyerupai bentuk asal*	○	○	○	○	○	

APPENDIX D : List of Publications

1. Zahari Taha, **Hartomo Soewardi**, and Siti Zawiah MD. (2013). Axiomatic Design Approach : The Customer Criteria Analysis for Virtual Environment Design. Design Studies**.** ***(Submitted-ISI-Q1)***
2. Zahari Taha, **Hartomo Soewardi**, and Siti Zawiah MD. (2012). Axiomatic design principles in analysing the ergonomics design parameter of a virtual environment. International Journal of Industrial Ergonomic. ***(Submitted-ISI-Q2)***
3. Zahari Taha, **Hartomo Soewardi**, and Siti Zawiah Md Dawal**.** (2012). Color Preference of the Malays Population in the Design of a Virtual Environment. IEEE Xplore; Digital Library 978-1-4673-2565-3/12.
4. Zahari Taha, **Hartomo Soewardi**, Siti Zawiah MD, Aznijar Ahmad-Yazid**.** (2012). Ergonomics Design Criteria of a Virtual Environment. InTech Book : Virtual Environment / Book 1",ISBN 979-953-307-618-7.Croatia
5. **Hartomo,** M. Ibnu Mastur, Ahmad Syukri, and Yopika Mutia Sandra. (2011). Usability Analysis on the Quality of Keypad Design in Mobile Phones. *Proceeding:* APSIM2011. 14 – 15 December 2011. Kuala Lumpur. Malaysia
6. Zahari Taha, **Hartomo,** Siti Zawiah Md Dawal and Yap Hwa Jen. (2010).A Conceptual Prediction Model of the Individual Susceptibility Level on Cybersickness. *Proceeding:* The 11th Asia Pacific Industrial Engineering & Management Systems Conference (APIEMS2010). Melaka. Malaysia
7. Zahari Taha, **Hartomo,** Yap Hwa Jen, and Raja Arifin R. G. (2010).Capacity of Visual Short Term Memory of the Malays Population in the Design of Virtual Environment. IEEE Xplore; Digital Library , E-ISBN: 978-1-4244-9026-4/10.
8. Zahari Taha , **Hartomo**, Yap Hwa Jen, Raja Arifin Raja Ghazilla4 and Norhafizan Ahmad. (2009). The Ergonomics Virtual Reality Station Design (ErgoVR).

Proceeding: The 10th Asia Pacific Industrial Engineering & Management Systems Conference (APIEMS 2009), Kitakyushu, Japan

9. **Hartomo**, Zahari Taha, and Emy Dwi Hastutiningsih. (2009). Analysis of Ergonomics Workstation Layout Design Using Analytical Hierarchy Process. *Proceeding*: The 10th Asia Pacific Industrial Engineering & Management Systems Conference (APIEMS 2009), Kitakyushu, Japan
10. Zahari Taha, **Hartomo**, Yap Hwa Jen, Raja Arifin Raja Gadzila and Alex Poh Tech Chai, (2009). The Effect of Body Weight and Height on Incidence of Cyber sickness Among Immersive Environment Malaysian Users. *Proceeding*: The 17th International Ergonomics Association Congress (IEA 2009). Beijing. China
11. **Hartomo**, Zahari Taha, and Fauzia Ratih Damayanti, (2008), Analysis Of Manual Work By Using The Strain Index Approach. *Proceeding*: The 9th Asia Pasific Industrial Engineering & Management Systems Conference and The 11th Asia Pacific Regional Meeting Of International Foundation For Production Research (APIEMS 2008). Bali. Indonesia