AN INVESTIGATION INTO
ALTERNATIVE HUMAN-COMPUTER INTERACTION
IN RELATION TO ERGONOMICS
FOR GESTURE INTERFACE DESIGN

by

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ABSTRACT

Recent, innovative developments in the field of gesture interfaces as input techniques have the potential to provide a basic, lower-cost, point-and-click function for graphic user interfaces (GUIs).

Since these gesture interfaces are not yet widely used, indeed no tilt-based gesture interface is currently on the market, there is neither an international standard for the testing procedure nor a guideline for their ergonomic design and development. Hence, the research area demands more design case studies on a practical basis.

The purpose of the research is to investigate the design factors of gesture interfaces for the point-and-click task in the desktop computer environment. The key function of gesture interfaces is to transfer the specific body movement into the cursor movement on the two-dimensional graphical user interface (2D GUI) on a real-time basis, based in particular on the arm movement.

The initial literature review identified limitations related to the cursor movement behaviour with gesture interfaces. Since the cursor movement is the machine output of the gesture interfaces that need to be designed, a new accuracy measure based on the calculation of the cursor movement distance and an associated model was then proposed in order to validate the continuous cursor movement. Furthermore, a design guideline with detailed design requirements and specifications for the tilt-based gesture interfaces was suggested.

In order to collect the human performance data and the cursor movement distance, a graphical measurement platform was designed and validated with the ordinary mouse. Since there are typically two types of gesture interface, i.e. the sweep-based and the tilt-based, and no commercial tilt-based gesture interface has yet been developed, a commercial sweep-based gesture interface, namely the P5 Glove, was studied and the causes and effects of the discrete cursor movement on the usability was investigated. According to the proposed design guideline, two versions of the tilt-based gesture interface were designed and validated based on an iterative design process. Most of the phenomena and results from the trials undertaken, which are inter-related, were analyzed and discussed.

The research has contributed new knowledge through design improvement of tilt-based gesture interfaces and the improvement of the discrete cursor movement by elimination of the manual error compensation. This research reveals that there is a relation between the cursor movement behaviour and the adjusted R^2 for the prediction of the movement time across models expanded from Fitts' Law. In such a situation, the actual working area and the joint ranges are lengthy and appreciably different from those that had been planned. Further studies are suggested. The research was associated with the University Alliance Scheme technically supported by Freescale Semiconductor Co., U.S.

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Terms and Definitions

Human-Computer Interaction (HCI)

In the ACM SIGCHI Curricula for Human-Computer Interaction (Hewett *et al.*, 2009c), it was argued that there is currently no agreed definition of the range of topics which form the area of human-computer interaction. Thus, the human-computer interaction field needs to be characterized if educational materials are to be derived and developed for it. Therefore, they suggest a working definition that at least permits us to get down to the practical work of deciding what is to be taught.

> *"Human-computer interaction is a discipline concerned with the design, evaluation and implementation of interactive computing systems for human use and with the study of major phenomena surrounding them*" (Hewett *et al.*, 2009c, page 5).

Alternative Human-Computer Interaction

Expanded from the definition of the HCI, this research pays particular attention to the implementation of the ergonomic design guideline and associated design methods for the development of the gesture interfaces. It emphasizes that the design of the gesture interfaces should consider the ergonomics as a whole. It offers the opportunity to explore the relationships between the design factors, the usability, the cursor movement and the associated body movements.

Non-Keyboard Input Device (NKID)

ISO 9241-9 (2000c) points out that Non-Keyboard Input Devices (NKID) are commonly used by operators to perform tasks with interactive office computer systems. Input device design can have a significant impact on efficiency, effectiveness and satisfaction. It provides design guidance based on ergonomic factors for the following input devices: mice, pucks, joysticks, trackballs, tablets and overlays, touch-sensitive screens, styli and light pens.

Feedback and Kinesthetic

According to ISO 9241-9 (2000c) and Oakley *et al.* (2000e), feedback and kinesthetic are defined as follows:

- Feedback: Indicators (such as tactilt, auditory or visual) sensed by a user of an action (such as movement or actuation of an input device);
- Kinesthetic: Meaning the feeling of motion. Refers to sensations originating in muscles, tendons and joints. (Oakley *et al.*, 2000e).

According to ISO 9241-9 (2000c) and Oakley *et al.* (2000e), human-computer-interaction requires the implementation of a combination of one or more of the following feedbacks:

- Display (Visual) feedback: It refers to a change on the display resulting from an input device movement or activation;
- Tactilt feedback: Indication of the results of a user action transmitted through the sense of touch. (Oakley *et al.*, 2000e);
- Force feedback: Mechanical production of information sensed by the human kinesthetic system;
- Kinesthetic feedback: Action perceived by the mechanoreceptors in joints, muscles

and tendons resulting in an awareness of position, movement, weight and resistance of the limbs or other body parts.

Tasks

According to ISO 9241-9 (2000c), interactive office computer operation consists of the following actions:

- Click: Depressing and release of a button or actuation point on an input device;
- Drag: Moving one or more objects on a display by translating it along a path determined by a pointer;
- Freehand input: Input where the input device controls the movement of the cursor without any constraints following the manual input of the user;
- Pointing: Operation with a graphic user interface in which an input device is used to move a small display image (such as a pointer) to a specific location on the display. There are two types of pointing: Direct Pointing: Hitting a target unaided by system feedback, for instance by direct pointing with a finger or stylus; Indirect Pointing: Using system visual feedback to hit a target, for instance, when the system is controlling a screen pointer in response to a mouse movement;
- Selecting: Choosing one or more items on a display;
- Touch strategies: There are two types of touch strategies: First-Contact touch strategy, namely, the actuation of a display area upon touching the display surface; Last-contact touch strategy, namely the actuation of a display area upon withdrawing touches from the display surface;
- Tracing: Following the outline of an image by moving the cursor or input device over the lines or shape of an image;
- Tracking: Moving a pointer or predefined symbol across the surface of a display screen in order to follow a target.

Neutral hand gesture

The international standard ISO 9241-9 (2000c) defined that a neutral hand gesture should fulfil certain criteria. It should:

1. Be completely relaxed without any intentional bending at the joints;
2. Operate without pronation (i.e. medial rotation of the forearm) and without supination (i.e. lateral rotation of the forearm);
3. Operate without radial hand deviation (i.e. bending the hand at the wrist in the direction of the thumb);
4. Operate without ulnar deviation (i.e. bending the hand at the wrist in the direction of the little finger);
5. Operate without extension and flexion.

Context of Use

At the earliest stage of the design development, the context of use must be well-established describes "the end-users, tasks, equipment (i.e. hardware, software and materials) and the physical and social environments in which a product is used" (ISO, 2000c). This definition is incorporated into the ISO 13407 (ISO, 1999e) on human-centred design. Maguire (2001b) emphasized that that understanding the context of use, which involves the scenario, the technical environment, the persona and tasks, has become one of the main stages within the user-centred design process. In this study, to gain novel user experience, the gesture interaction was to perform the point-and-click task at a conventional desktop computer workstation using an alternative pointing device with a small zone of convenient reach (ZOC) (Pheasant, 1997d).

Usability

According to ISO 9241-9 (ISO, 2000c), usability is defined as "the extent to which a product can be used by specified end-users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use". The usability attributes in this study have been narrowed down to some of the most essential factors related to two top-priority independent factors (i.e. to point and to click). This involves objective measures of the human performance, the subjective attributes of the design, discomfort and user experience and the direct observation of the movement of the upper extremity.

Range of motion (ROM)

Each region of the body has different joint motions and a range of motion (ROM). Table 1 shows the range of motion (ROM) of each region in the upper limb (see Table 1).

Table.1 Range of motion of the male (i.e. joint range)(degree)

Joint	5th (%ile)	50th (%ile)	95th (%ile)	S.D.
Shoulder flexion	168	188	208	12
Shoulder extension	38	61	84	14
Shoulder abduction [a]	106	134	162	17
Shoulder adduction	33	48	63	9
Shoulder medial rotation	61	97	133	22
Shoulder lateral rotation	13	34	55	13
Elbow flexion	126	142	159	10
Pronation [b]	37	77	117	24
Supination [c]	77	113	149	22
Wrist flexion	70	90	110	12
Wrist extension	78	99	120	13
Wrist abduction (radial deviation)	12	27	42	9
Wrist adduction (ulnar deviation)	35	47	59	7

a. accessory movements of spine increase this to 180^o.
b. rotation of the forearm about its own axis such that the palm faces downwards.
c. rotation of the forearm about its own axis such that the palm faces upwards.
Source: Pheasant (1997d)

Moreover, the Institute of Occupational Safety & Health (IOSH) in Taiwan provides the anthropometry database of the wrist joint ROM (Chen,2009b), shown in Table 2. The gender differences of the wrist joint are not discussed in this study since the difference is within the 5th percentilt.

Table. 2 Range of motion of the females and males in Taiwan (i.e. joint range)(degree)

Wrist joint	Gender difference	5th (%ile)	50th (%ile)	95th (%ile)	S.D.
Wrist flexion	Male	37.0	63.4	89.8	16.0
	Female	40.6	67.0	93.4	16.0
Wrist extension	Male	26.9	55.2	83.5	17.2
	Female	31.0	57.8	84.6	16.3
Wrist abduction (radial deviation)	Male	13.8	36.1	58.5	13.6
	Female	18.6	43.7	68.9	15.3
Wrist adduction (ulnar deviation)	Male	18.7	39.4	60.0	12.5
	Female	18.8	39.8	60.8	12.8
Pronation [a]	Male	48.0	78.0	60.0	18.2
	Female	54.2	83.5	60.8	17.8
Supination [b]	Male	62.7	103.0	143.3	24.5
	Female	68.4	104.2	140.1	21.8

a. rotation of the forearm about its own axis such that the palm faces downwards.
b. rotation of the forearm about its own axis such that the palm faces upwards.
(Source: Chen, 2009b)

Average range of motions (ROMs) of the upper limb

The following joint motions and associated illustrations are defined by Luttgens and Hamilton (1997c):

(1) Scapula movements (see Figure 1)

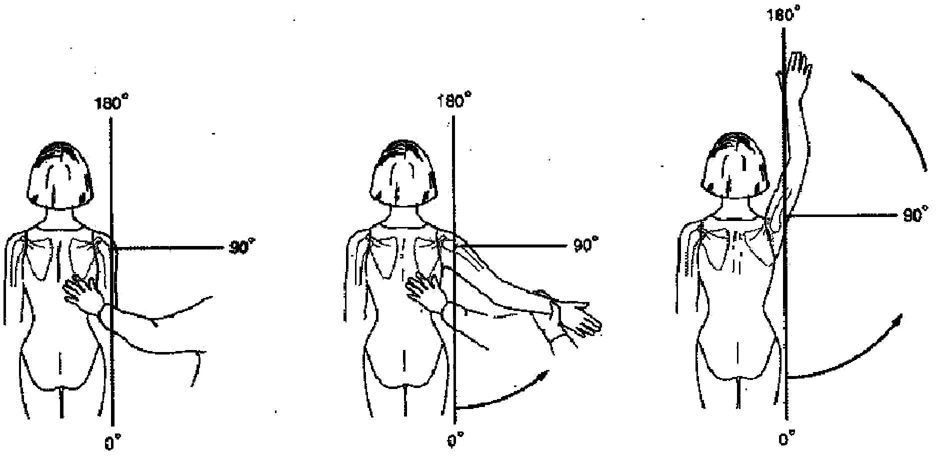

Figure 1. Scapula movements
(Adapted from Luttgens and Hamilton, 1997c)

(2) Medial rotation of the shoulder (see Figure 2)

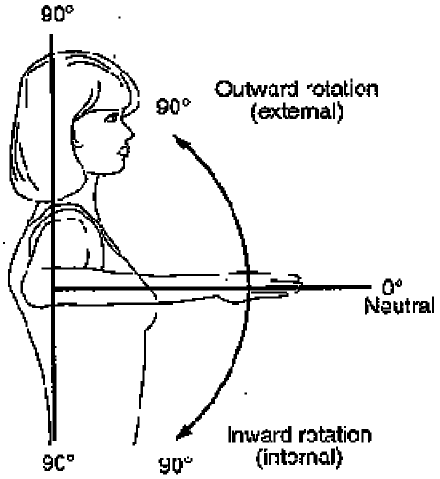

Figure.2 Medial rotation of the shoulder
(Adapted from Luttgens and Hamilton, 1997c)

(3) Lateral rotation of the shoulder (see Figure 3)

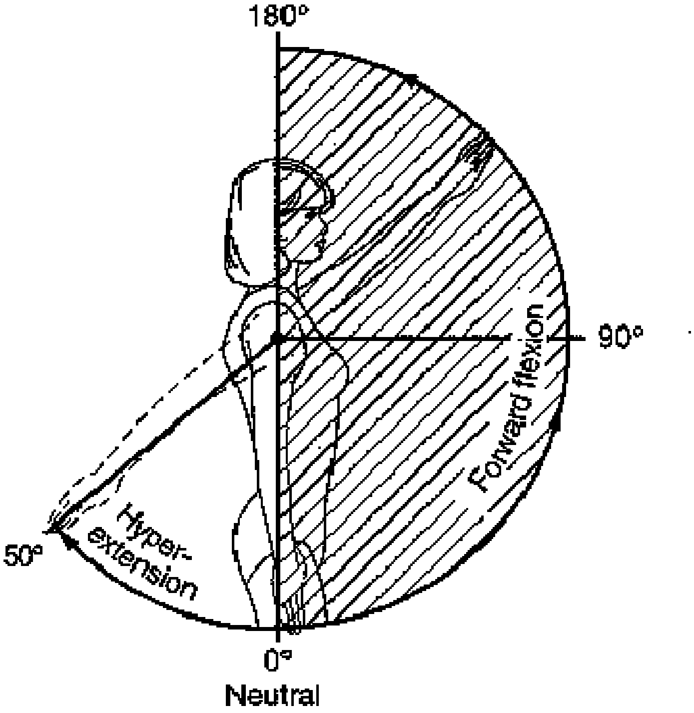

Figure.3 Lateral rotation of the shoulder
(Adapted from Luttgens and Hamilton, 1997c)

(4) Elbow joint motion (see Figure 4)

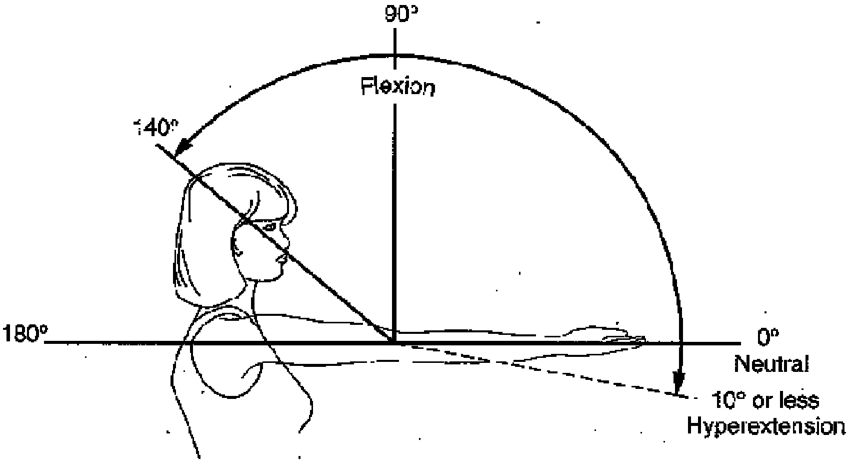

Figure.4 Elbow joint motions
(Adapted from Luttgens and Hamilton, 1997c)

(5) Flexion of the wrist (see Figure 5)

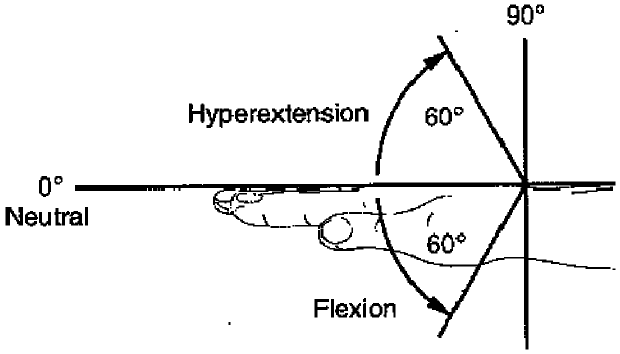

Figure.5. Flexion of the wrist
(Adapted from Luttgens and Hamilton, 1997c)

(6) Radial flexion and ulnar flexion of the wrist (see Figure 6)

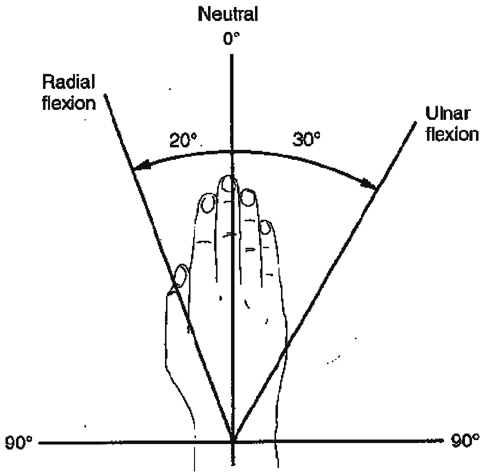

Figure.6 Ulnar flexion of the wrist
(Adapted from Luttgens and Hamilton, 1997c)

Zones of Convenient Reach

According to Pheasant (1997d), the zone of convenient reach, known as ZOR in short, is the concept of a zone or space in which an object may be reached conveniently, that is, without undue exertion. It was also considered as a control to be 'within arm's length'. The zones of convenient reach were also limited to the range of motion of the upper limb. As can be seen in Figure 7, the upper limb measured from the shoulder to the fingertip, sweeps out a series of arcs centred on the joint. It extends sideways to the coronal plane of the body.

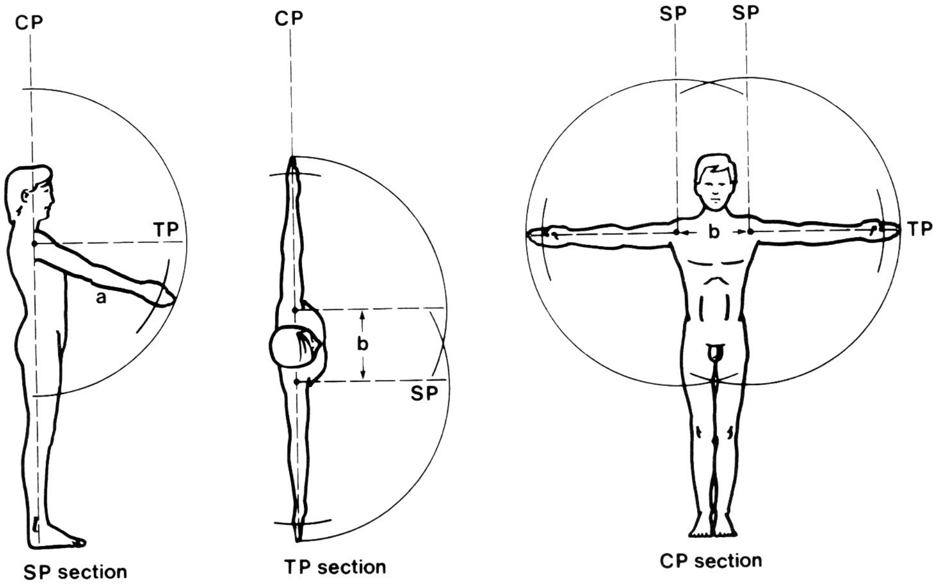

Figure.7 Zones of convenient reach (ZCR)
(Reproduced from: Pheasant, 1997d, pp. 53)

Pheasant (1997d), reported that the ZOR was the basic principle for the design of the workspace and lead to the definition of the normal working area by a comfortable sweeping movement of the upper limb about the shoulder with the elbow flexed to 90^o or a little less.

Working Area

Barbara and Grieve (1989) described that the upper limb consists of the following regions to form the movement: the shoulder and elbow, which help in positioning the hand and the forearm; the wrist and hand, which aim to manipulate the objects (as in this study) and the finger, which is very complex and thus remains as a feature for future study. The shoulder forms the foundation about which the whole of the upper limb can move and which allows the hand to be placed in all directions around the body. The elbow is the hinge joint of the upper limb and lies between the arm and the forearm, which places the hand in the correct position. The shoulder and elbow in functional movements are reaching forwards, pulling back toward the body (from forward reach), reaching across the body, reaching behind the body and lifting the trunk on the arms (as from a seat).

According to Pheasant (1997d), the design of the working area is based on the zones of convenient reach (ZOR). The presentation of the normal working area is shown in Figure 8: The grasping distance takes account of the distance from the shoulder to the hand whilst the working distance is from the elbow to the hand. The values include the 5th percentilt and so apply to men and women of less than average height .

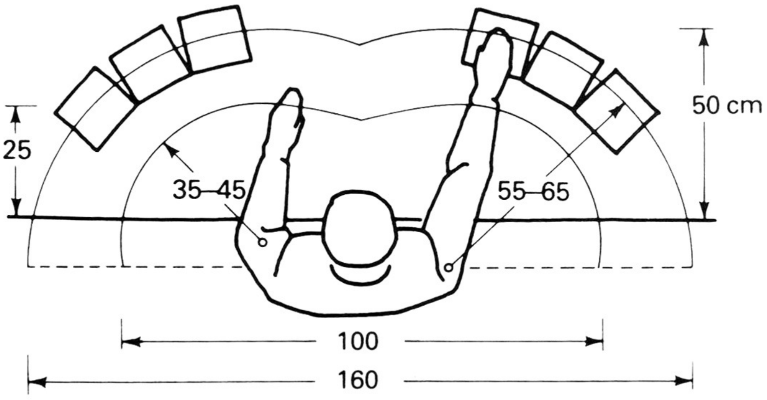

Figure.8 Horizontal arc of grasp, and working area at tabletop height (Reproduced from: Pheasant, 1997d, pp. 51)

As for the conventional desktop computer working environment, it has a CRT screen, a keyboard and a mouse on the table. These items should be located within the normal working area. As can be seen in Figure 9, the block represents the normal working area for a mouse.

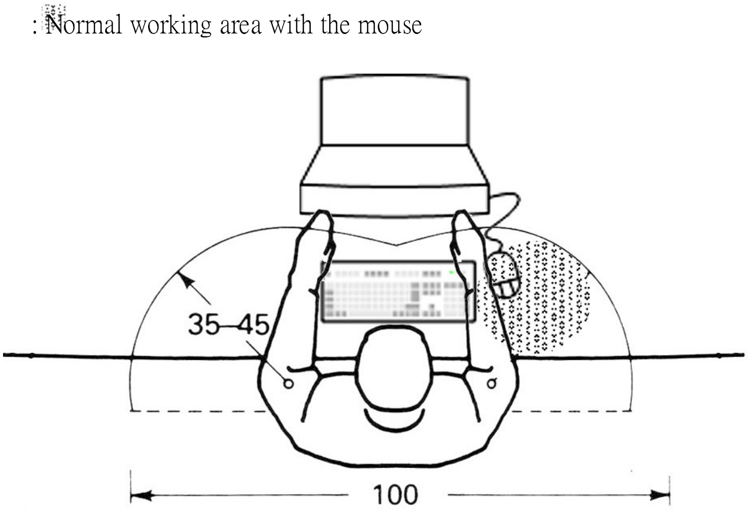

Figure.9 Horizontal arc of grasp, and working area at tabletop height at a typical desktop computer working environment
(Reproduced from: Pheasant, 1997d, pp. 51)

Chapter 1: Introduction

1.1. Background of the research

This research focuses on the design and usability assessment of the gesture interfaces for a point-and-click task within the desktop computer environment. The key function of the gesture interfaces is to transfer the specific body movement into the cursor movement on the two-dimensional graphical user interface (2D GUI) on a real-time basis, based in particular on the arm movement.

Recently, various gesture interfaces have been developed (Hewett *et al.*, 2009c). In terms of the motion-tracking technology, there are generally two types of gesture-interactive system existing in the market, these are computer-vision-based (Hsu *et al.*, 1999c; Alliance Distributor, 2006a) and inertial-sensor-based systems (Cheok *et al.*, 2002a; Suh, H. *et al.*, 2003d). In terms of the advantage, the computer-vision-based system is capable of detecting the sweeping-based motion of the specific body regions and the inertial-sensor-based system is used to detect the tilt-based motion. However, because of a lack of research into user-centred design, the causes and effects of a 'poorly designed' gesture interface on its usability remain unknown.

This study emphasizes the implementation of the ergonomic design guideline (ISO, 2000c) and associated design methods for the design development of the gesture interfaces (MacKenzie *et al.*, 2001a; Zhai *et al.*, 2004f). The design of the gesture interfaces should consider the ergonomics as a whole (Pheasant, 1997d). It offers the opportunity to explore the relationships between the design factors, the usability, the cursor movement and the associated body movements.

This research will create and validate a theory that emphasizes that the ‘poor design of the gesture interface is harmful to the human being’, in turn it proposes an associated design solution for better quality-in-use for the gesture interfaces for the point-and-click task. It will investigate whether the malfunctions of the hardware and software of gesture interfaces can produce the discrete cursor movement which is deemed as being essential for discrete visual feedback and which impacts on the human performance and leads to abnormal body movements. In such as situation the actual working area and the joint ranges are lengthy and away from those that had been planned. It will be confirmed that the abnormal movement will require extra movement that will be outside the neutral posture. Eventually, the malfunction of the system will contribute to the development of discomfort in particular body regions.

Because there are two types of gesture interactive system, an existing sweep-based gesture interface will be investigated. In order to produce a comparative study, two versions of the tilt-based gesture interface will be designed based on an iterative design process with different button actuation manners (i.e. the flex finger sensors and the mechanism buttons). It is hoped that this research can promote the concept of user-centred design for the design and manufacture of gesture interfaces for better quality-in-use with a better user-experience.

Regarding the design methods used in this research, a mixture of methods is employed based on the implementation of objective measurement (i.e. the human performance), subjective assessment (i.e. the design, the discomfort and the user experience) and direct observation of specific body movements. Since the cursor movement is the machine output of the gesture interfaces that need to be designed, a new accuracy measure based on the calculation of the cursor movement distance and an associated model will be proposed in order to validate the continuous cursor movement. Furthermore, in order to collect the human performance data and the cursor movement distance, a graphical measurement platform has also been designed and validated. It is hoped that this platform can simulate the usability studies of various pointing devices in the future.

1.1.1. Definition of the gesture interfaces

In this research, the major function of the gesture interface is to transfer the specific body movement in physical two-dimensional space into the cursor movement on a 2D GUI in the same direction and at the same pace, in particular the arm movement.

The term ‘gesture interface’ appeared earlier in the ACM Special Interest Group on Computer-Human Interaction (SIGCHI) Curricula for Human-Computer Interaction (Hewett *et al.*, 2009c). Professor Tom Hewett (Hewett *et al.*, 2009c) is currently the chair of the SIGCHI in ACM, U.S. and is professor of Psychology and Computer Science at Drexel University where for 30 years he has taught courses on Cognitive Psychology, the Psychology of Human Computer Interaction and Problem Solving and Creativity. He emphasized that the ‘gesture’ was deemed as one of the potential input devices for the technical construction of devices for mediating between humans and machines. He further pointed out that “…utilization of the gesture increases innovation in input techniques and should be considered to combine lower costs, leading to rapid computerization by people previously left out of the computer revolution.” (Hewett *et al.*, 2009c, page 10). These design elements (i.e. the low cost input device for the desktop computer users) become the preliminary product requirements for the design of gesture interfaces in this research.

Moreover, MacKenzie (1995a) emphasized that the gesture interaction is a new paradigm of interaction and the most exciting aspect of such interface design is imagining and experimenting with potential tasks involving gestural input. He is Associate Professor of Computer Science and Engineering at York University. His research is in human-computer interaction with an emphasis on human performance measurement and modelling, interaction devices and techniques, alphanumeric entry and mobile computing. He described the 'gestures' as:

> *"Gestures are actions humans do all the time, and the intent is that intuitive gestures should map into cyberspace without sending users to menus, manuals, or help screens. Simple actions such as writing, scribbling, annotating, pointing, nodding, etc. are gestures that speak volumes for persons engaged in the act of communicating. The many forms of sign language (formal or otherwise), or even subtle aspects of sitting, walking or driving a bicycle contain gestures" (*MacKenzie ,1995a).

MacKenzie (1995a) further argued that 'gestures' were high-level:

> *"They (Gesture) map directly to user intention without forcing the user to learn and remember operational details of commands and options. They chunk together primitive actions into single directives. One application for gestural input is to recognize powerful yet simple commands (viz., strokes) for manipulating text, such as those proofreaders adopt when copy-editing a manuscript" (*MacKenzie ,1995a).

However, MacKenzie *et al.* (2001a) also pointed out that "A key feature of a GUI is a pointing device and point-and-click interaction". In this regard, many existing gesture interfaces provide this basic point-and-click function for the desktop computer environment. For instance, a gesture interface called the ‘P5 Glove’, developed by Alliance Distributor (2006a), made use of computer-vision technology and offered a basic function to emulate the cursor movement on the screen. Furthermore, a 3D mouse was developed by ITRI in Taiwan (Industrial Technology Research Institute, 2007e) based on inertial sensing technology for computer games and that could also be used as an alternative pointing device. In 2008, Logitech (2008d) launched a 3D mouse namely “Logitech MX Air” which allows the user to move it around in 3D space, gesturing the way to screen navigation. Moreover, Lee (2008c) designed the cursor emulation program to allow the user to use the Wii Remote Pointer (2009d) as a remote pointer in physical two-dimensional space. This allows the user to interact with the computer simply by waving the hands in the air similar to the interaction seen in the movie "Minority Report".

1.1.2. Relationship between the body movement and the cursor movement

The design factors of the gesture interfaces could be summarised as in Figure 10:

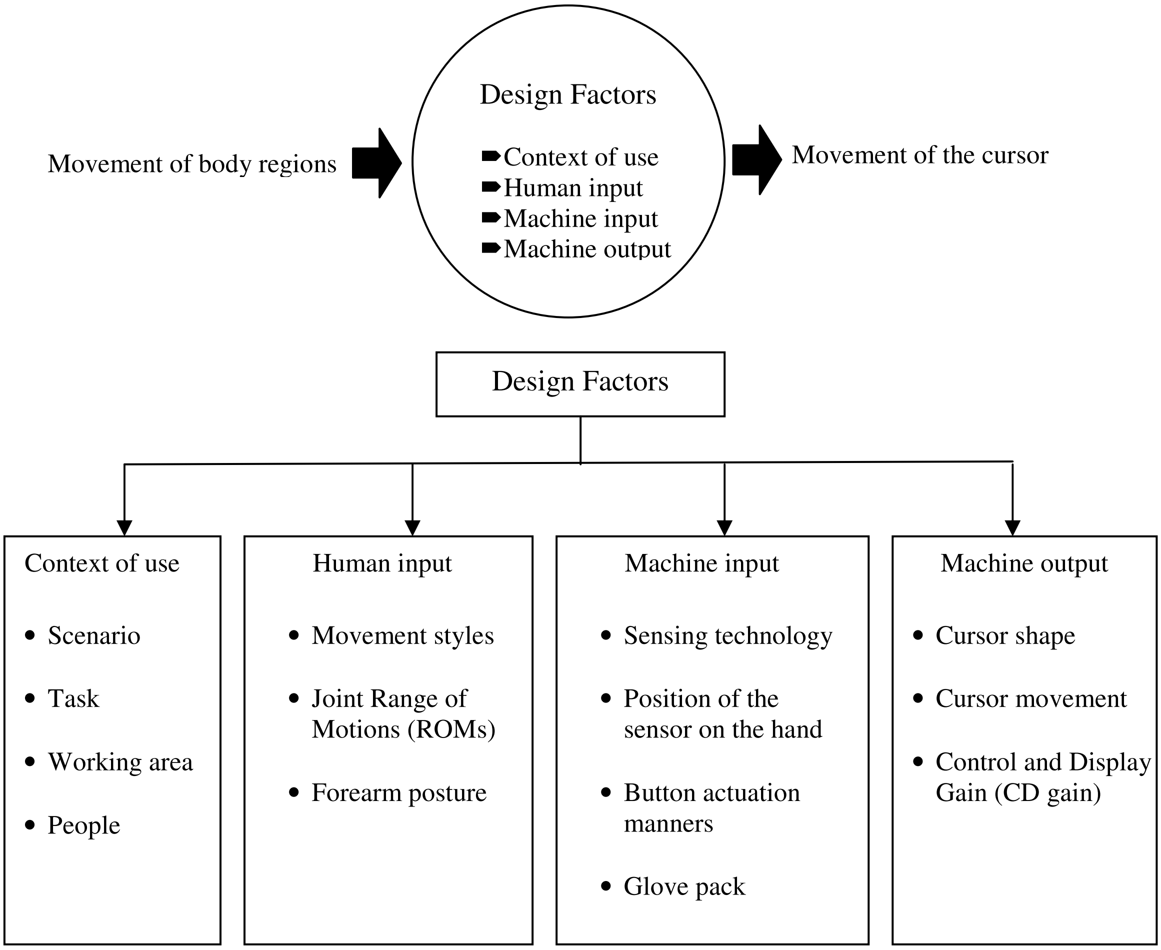

Figure.10 Design factors of the gesture interfaces

In terms of the sensing technology, there are generally two types of gesture interfaces existing in the market: computer-vision-based technology and inertial sensor technology. Both technologies imply different movement styles, associated with different working areas and joint range of motions (ROMs).

As for the computer-vision technology, it can be used to trace the sweep movement of the forearm, which is called a ‘sweep-based gesture interface’ in this research. For instance, suppose a user wants to point to a visual object on the screen, the movement of the fingertip will be traced by a digital camera. Thus, the planned working area is subjected to the optical visual zone (OVZ) of the digital camera, illustrated in Figure 11.

░ : Optical visual zone of the digital camera and planned working area

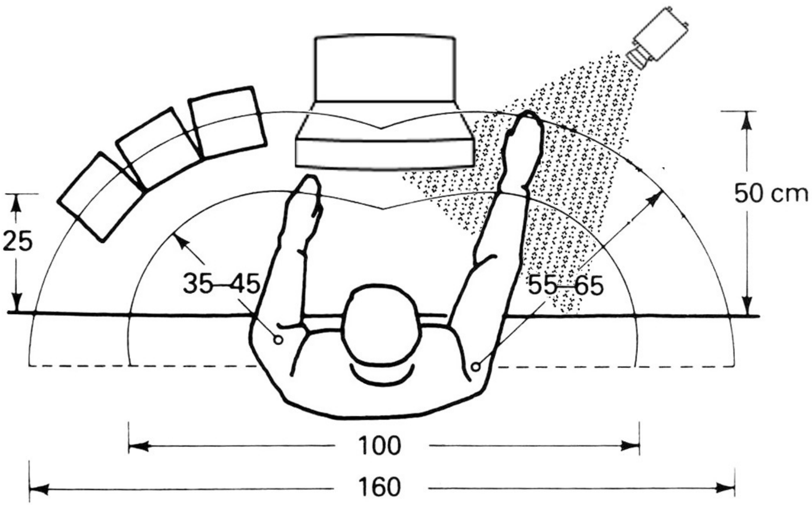

Figure.11 Sweep-based gesture interface and the planed working area
(Reproduced from: Pheasant, 1997d, pp. 51)

where the dimension of the working area was represented in both the horizontal and vertical arcs of grasp as the normal working area for the gesture interfaces using computer vision technology. For instance, the P5 Glove has an optical visual zone (OVZ) ranging from between approximately 30° of the centre of the camera horizontally and vertically.

The inertial sensor technology can be used to trace the tilt movement of the wrist, which is called 'tilt-based gesture interface' in this research. For example, suppose a user wants to point to a visual object on the screen, the movement of the wrist will be traced by the inertial sensor, thus the planned working area is subject to the wrist joint range of motion (ROM), illustrated in Figure 12:

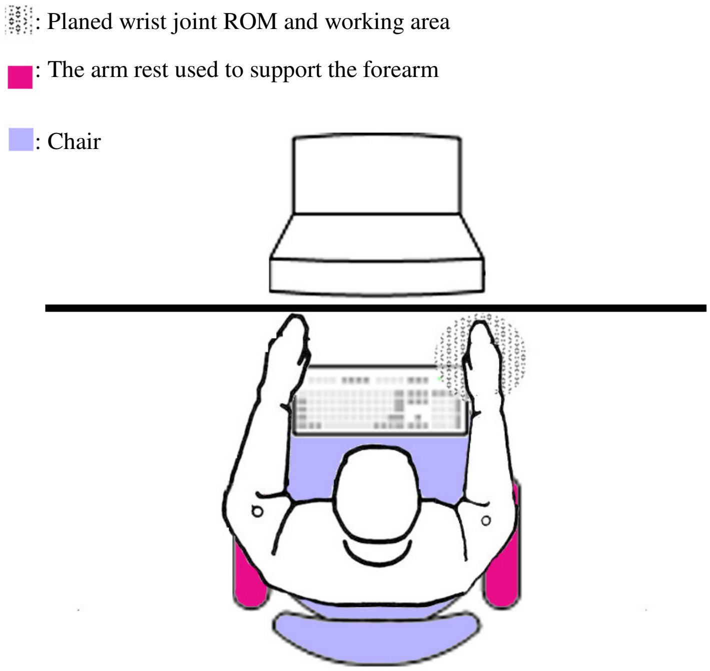

Figure.12 Tilt-based gesture interface and the planed working area
(Reproduced from: Pheasant, 1997d, pp. 51)

Owing to the lack of usage of the gesture interfaces, as yet there is no international standard for the testing procedure and the ergonomic design guideline for the design development of the gesture interfaces. Moreover, there is not yet a tilt-based gesture interface on the market at the present time. Hence, the research area demands more design case studies on a practical basis.

In particular, this research will pay much attention to the design of the tilt-based gesture interface since the plan working area and associated joint angles are narrower than for the sweep-based gesture interfaces, which might contribute to the prevention of fatigue in the specific body regions, thus it might be better for the point-and-click task for the desktop computer users. Besides, there is not yet a commercial, tilt-based, gesture interface launched in the market place currently dominated by the mouse. Thus, there might be a market opportunity for the implementation of the tilt-based gesture interface.

1.1.3. The theoretical basis of Fitts' Law

Ergonomic usability engineering and most recently user-centred design (UCD) and human-computer interaction (HCI), have all shared the same goal of producing multimodal interfaces that can be used efficiently, effectively, safely and with user satisfaction (Hartson, 1998a). At the human-machine interface, the nature of computing has witnessed dramatic transformations from the mouse and keyboard to manipulating 3D virtual objects with an input glove. The technology at our finger tips today has been developed since the 1940s, yet technology must co-exist with humans (MacKenzie, 1995a).

There have been many theories and practices of human-computer interaction developed for studying human performance. One of famous theories is Fitts' Law 1954 (Fitts, 1954). Early in 1954, Fitts (1954) introduced the mathematical relationship between speed, accuracy, amplitude of movement and target size for upper extremity tasks, which can be expressed by a simple liner regression equation shown in Eq. (1):

$$MT = a + b \times ID \qquad (1)$$

$$ID = \log_2(2 \times D / W) \qquad (2)$$

where *ID* is the index of difficulty proposed by Fitts, *D* is distance between targets, *W* is the target width, *MT* is movement time and parameters *a* and *b* are calculated on the basis of simple linear regression. As expected, movement time for hard tasks is longer than for easy tasks. The linear regression prediction for the line in Fig 13 is of the form:

$$ID_e = \log_2(D/\mathrm{W}+1) \qquad (3)$$

In fact, MacKenzie (1995b) augured that Fitts' ID in Eq. (2) was extended in the form of the Shannon formulation (Shannon, 1949) of *ID* shown in Eq. (3). It provides a better fit with observations, is truer to the information theorem upon which Fitts' Law is based and makes a negative ID value impossible (Soukoreff and MacKenzie, 2004d). Moreover, MacKenzie (1995b) recommended the use of an effective target width W_e instead of the nominal target width *W* to measure the actual performance of either devices or tasks:

$$W_e = 4.133 \times S.D. \qquad (4)$$

$$ID_e = \log_2(D/W_e+1) \qquad (5)$$

where *S.D.* is the standard deviation of the endpoint over the target region and ID_e is the effective index of difficulty.

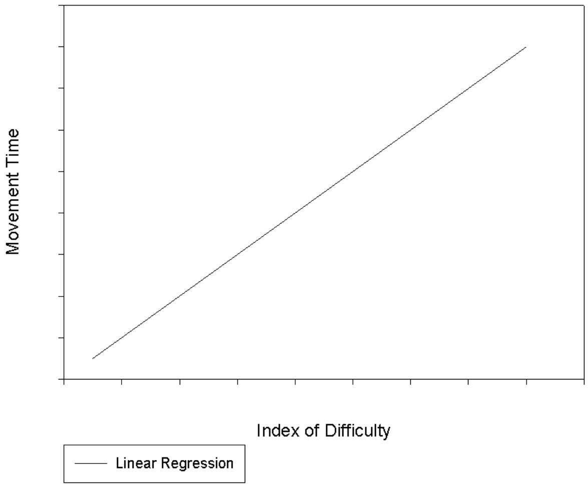

Figure.13 Movement time prediction

Recently, the ID_e model in Eq. (4) and Eq. (5) has been standardized in ISO 9241-9 (ISO, 2000c) as a design and testing guideline and specification for non-keyboard input devices (NKIDs), e.g. mouse, trackball, joystick, indirect touch panel and direct touch screen. In particular, Soukoreff and Mackenzie (2004d) recommended that regression analysis on both MT and ID_e should indicate an adjusted R^2 value, which is ideally over 0.9 when testing on a normal mouse on a one-dimensional Graphic User Interface (1D GUI).

However, the above studies are all based on a one-dimensional graphical user interface (1D GUI). In this study, Fitts' Law is expanded into a two-dimensional description using a polar coordinate system, which is 2D GUI. Furthermore, these studies cannot explain the cursor movement and its relation to the physical body movement, thus it requires the extension of the current Fitts' Law-based studies to the study of complex body-based interaction.

1.2. Motivation

1.2.1. Discomfort development with the ‘poorly designed’ gesture interfaces

It was pointed out (MacKenzie, 1995a) that the ergonomic design must keep pace with advances in technology in the human-computer interface and, hopefully, get ahead. It is this desire to forge ahead that underlies the research undertaken in this study.

The gesture interfaces intend to imply the body movement for a specific task, thus the malfunctions in such an interaction might directly impact on the human being. In 1998, Pheasant (1997d) reported that many design problems are concerned with the intersection of the vertical, horizontal or oblique planes of the range of motions (ROM) of joints and the dimension of the working area. In 2002, Woods *et al.* (2002c) reported the following postural concerns with the desktop computer environment: (1) Neck flexion when looking at the screen, keyboard and documents; (2) Insufficient back support; (3) Static postures; (4) Deviated and extended wrist when using a device - the laboratory study indicated that mouse operation frequently required an extended wrist posture and (5) Poor shoulder posture.

Based on their studies, it can be assumed that there might be a relationship between the movement style and various gesture interfaces, the planned joint ROMs, the planned working area and the type of sensing technology (i.e. computer-vision and/or inertial sensor technology) for the desktop computer environment, as shown in Table 3:

Table.3 The relationship between the movement pattern, the dimensions of the working area and the type of sensing technology

Human input			Machine input
Movement styles	Planed joint ROMs*	Planed working area	Sensor Technology
Sweeping movement	Shoulder	Wide	Computer-vision
	Forearm	↑	↑
	Elbow		
	Wrist		Combination of both
Tilt movement	Wrist	↓	↓
	Elbow	Narrow	Inertial sensor

* The study only focused on the gesture interface based on the movement of the regions in the upper limb.

Here the computer-vision-based technology takes advantage of the implementation of the sweep-based movement, which involves the more regions for the joint than does the tilt-based movement. As for the inertial sensor, it is capable of detecting the tilt angle of the movement associated with the wrist and elbow, where the planned working area is expected to be narrower than that of the computer-vision-based interactive system.

Regarding the impact of the interface design on the discomfort in the specific body regions, it was argued (Paschoarelli *et al.*, 2008g) that the massive use of poorly designed equipment has been strongly related to musculoskeletal problems with handheld devices.

Since the cursor movement is the only outcome of the gesture interfaces, a “poorly designed” gesture interface might reflect that such interfaces generate the “discrete cursor movement“ on the screen, where the actual displacement and the direction of the cursor displayed on the screen is toward an unexpected displacement and the direction that the user intend to.

In human movement science, the discrete cursor movement might be classified as “discrete visual feedback“ which was identified earlier (Elliott, 1990). Recently, Hansen *et al.* (2008h) examined the spatial and temporal limitations of the visual corrective process in the control of upper limb movements and showed that early visual information is required for accurate limb control. As regards the discrete cursor movement, it might impact on the human performance of an aiming task.

However, this research does not intend to implement the movement science methods for the investigation of the effect of discrete visual feedback on human performance for several reasons: Firstly, according to Hansen *et al.* (2008h), the dependent factors for the study of the effect of discrete visual feedback on a manual aiming task involve the peak acceleration, the peak velocity and the estimated time of peak deceleration of the associated body movement, which is very specific and associated with the design methodology for the interface design. Secondly, the discrete visual feedback is the experimental condition in human movement science and is therefore manipulated by the experimenter. In a real-world design case, the discrete cursor movement is not an experimental condition, it is unexpected and is, hopefully, discovered by either the designers or the participants so that it can be prevented. Moreover, the cause and the effects of the discrete cursor movement are still unknown.

Nevertheless, the current researches associated with discrete visual feedback will be reviewed in order to support the theory model that the discrete cursor movement has a similar effect on human performance with the poorly-designed, gesture interactive system.

In this regard, it is possible to draw a systematic relation between the design problems of the gesture interfaces, the discrete cursor movement, the actual working area and joint ROMs, the planned working area and joint ROMs, the discomfort in the particular body regions and the usability of the gesture interfaces, as illustrated in Figure 14:

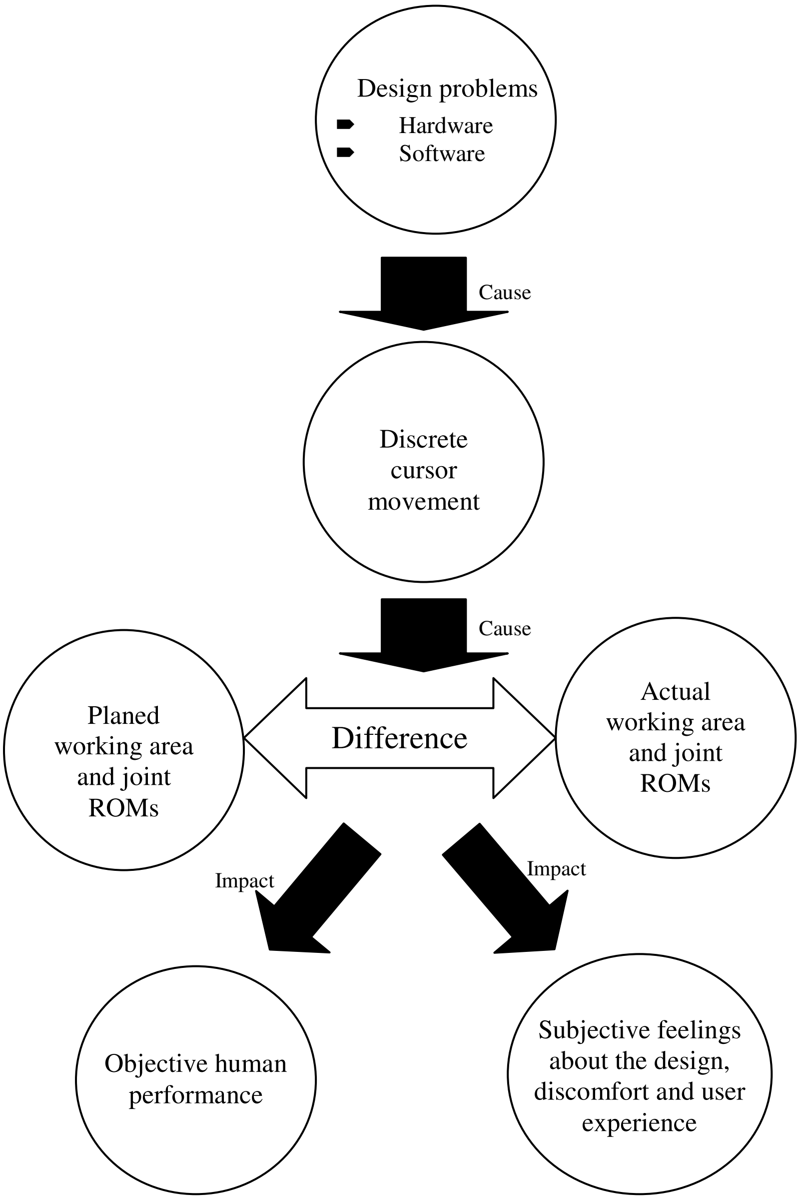

Figure.14 The proposed theory model of the discomfort development with the ‘poorly designed’ gesture interfaces

In order to prove the above theory, these two types of the gesture interface need to be investigated by the implementation of ergonomic "user-centred" design methods. Hornbæk (2006c) reported that the method of measuring usability is an important question for both HCI research and user interface evaluation. Furthermore, Paschoarelli *et al.* (2008g) emphasized that the application of the quantitative (i.e. recording movements) and subjective (i.e. perceptions of discomfort and acceptability) approaches allowed for subsequent redesigns of a handheld device that led to improvements in the product under evaluation. Hence, a user-centred design based on the outcomes from a mixture of usability assessment methods, including the objective measurement of human performance; the subjective assessment of the design, discomfort and user experience (Woods *et al.*, 2003d) and the observation of the body movement, will be employed in order to identify and tackle the critical design factors that cause the discrete cursor movement to ensure better quality-in-use, a better user experience and, in turn, to validate the theoretical model.

1.2.2. Effects of gender difference and mouse experience on the human performance with gesture interfaces

Since the ordinary mouse and the sweep-based gesture interface differ in terms of the working area, the movement styles (i.e. the sweeping and the tilt) and associated joint Range of Motions (ROMs). Therefore, it is assumed that the motor skill gained from using the ordinary mouse for many years might not benefit human performance with the sweep-based gesture interface. Furthermore, both the ordinary mouse and the tilt-based gesture interface utilize the wrist movement for the control of the cursor movement, the motor skill gained from using the mouse might possibly be beneficial to human performance with the tilt-based gesture interface. Long experience of using a mouse might be beneficial for this specific type of gesture interface. Furthermore, since females and males differ in their physical attributes, thus human performance with both types of the gesture interface might also differ. Both issues need to be investigated in this research.

1.2.3. Beyond Fitts' Law for the study of complex gesture interaction

First of all, the adoption of the ISO9241-9 (2000c) standard is considered for the ergonomic design of non-keyboard input devices (NKIDs), thus the gesture interfaces for the point-and-click task will be deemed as NKIDs.

Recently, Soukoreff and MacKenzie (2004d) reviewed 24 published Fitts' Law models of the mouse and 9 studies that used the ISO 9241-9 standard (ISO, 2000c). They made seven recommendations to HCI researchers wishing to construct Fitts' Law models for either movement time prediction, or for the comparison of conditions in an experiment with NKIDs. Among these, their recommendations are considered for the human performance measurement study with gesture interfaces in this research.

(1) Use the Shannon formulation of *ID* in Eq. (3) because it provides a better fit with observations, is truer to the information theorem on which Fitts' Law is based and because, with this formulation, a negative ID value is not possible;

(2) Measure the scatter of movement end-point positions as error rates or end-point position data in Eq. (4);

(3) Perform the adjustment for accuracy to transform the index of difficulty values into *effective index of difficulty* values. Without the adjustment for accuracy, researchers may experience problems modelling movement data with low *ID* values;

(4) Use linear regression of movement time and the effective index of difficulty ID_e in Eq. (3) to measure the goodness of fit (to decide whether Fitts' Law indeed applies).

Furthermore, Soukoreff and MacKenzie (2004d) also reported that many of these papers are investigations of devices other than the mouse and of conditions other than 'normal' mouse pointing — but they all build and publish a Fitts' Law model for the mouse. Thus, the ordinary mouse will be used for experiments, as it is the 'baseline' for comparison with current studies.

Based on their reviewed literature, no study has considered the cursor movement as the accuracy measure. This might be because the cursor movement is commonly generated by the Operating System (OS) with conventional NKIDs, such as the mouse and the joystick, thus it is continuing and stable and it is not necessary to measure it. However, the cursor movement generated by the cursor emulation program with the gesture interfaces differs from the cursor movement generated by the OS itself. Thus, the measurement of the cursor movement is required if it is to be proved that the outcome of the gesture interface is as continuing and stable as that of the mouse.

In 2001, MacKenzie *et al.* (2001a) proposed various new accuracy measures, namely movement behaviours, which help to explain neutral human body motion in a two-dimensional environment with the NKIDs. Extending from their theory, it is possible to develop a new accuracy measure based on the calculation of the cursor movement distance between targets on the screen, which reflects the length of the cursor movement travelling between the targets. Moreover, by integration of the new accuracy measure with Fitts' Law, a new prediction model can be proposed which offers an alternative explanation of the relationship between the cursor movement behaviour and the type of NKID: For instance, the cursor movement is unpredictable for those NKIDs that produce discrete cursor movement.

1.3. Aim and Objectives

The purpose of the research is to investigate the design factors of gesture interfaces for the point-and-click task in the desktop computer environment. The areas of study will involve the proposal of a new accuracy measure and an associated model based on the calculation of the cursor movement distance D_e on the two-dimensional graphical user interface (2D GUI), the development of a graphical measurement platform, the investigation of an existing sweep-based gesture interface, namely the P5 Glove, and the design development of two versions of the working model based on the use of inertial sensor technology (i.e. tilt-based gesture interfaces) and the associated ergonomic design guidelines and design methods. In this research, the P5 Glove and the two developed working models will be investigated in order to validate that there is a relationship between the design factors, the cursor movement and the body movement and the usability of the gesture interfaces.

The objectives of the research are

- To identify the design factors of the gesture interfaces for the desktop computer environment in order to produce a design guideline and associated design methods for the design development of the tilt-based gesture interfaces, based on reviewing the relevant literature. The subject area concerns both the ergonomic factors and Fitts' Law as related to the Non-keyboard Input Devices (NKIDs), computer-vision technology and inertial sensor technology;
- To develop a new accuracy measure for the cursor movement distance based on the extension of Fitts' Law and the movement behaviours and for the study of the causes and effects of the discrete cursor movement on the usability of the gesture interfaces;

- To design and validate a graphical measurement platform for gathering objective data for both the new accuracy measure and conventional human performance measures with the ordinary mouse;
- To investigate the limits and the design problems of various gesture interfaces which might lead to discrete cursor movement and the development of discomfort in particular body regions resulting from the use of various pointing devices, i.e. an ordinary mouse, existing sweep-based gesture interfaces, e.g. the “P5 Glove”, and the tilt-based gesture interfaces;
- To validate the proposed new accuracy measure and the associated model that could help to validate the continuous cursor movement on the two-dimensional graphical user interface (2D GUI) with various pointing devices;
- To investigate the effect of gender difference and the mouse experience (i.e. the number of years spent in using the mouse) on the human performance with the following pointing devices: the ordinary mouse, the P5 Glove and two versions of the tilt-based gesture interface;
- To investigate the relationship between the design factor, the cursor movement and the body movement in the context of both types of gesture interface, i.e. the P5 Glove and the two versions of the tilt-based gesture interface;
- To summarise the findings and original contributions to the research areas, highlight the problems that occurred during the study and identify the further research required.

1.4. Methodology

1.4.1. Documentary research

A general literature search related to the subject areas has been undertaken and summarized into two parts: Firstly, the background information on the design factors of the gesture interfaces for desktop computer users is reviewed in Chapter 2.1. Secondly, the background information regarding the design methods, related to Fitts' Law and the movement behaviour and discrete visual feedback, the subjective questionnaire survey and the observation techniques used to investigate the joint ROMs is reviewed in Chapter 2.2 to 2.6. Both chapters will help to develop the ergonomic design guideline and associated design methods used in the primary experiments described in the following section.

1.4.2. Framework development

Based on the international standard ISO 9241-9 (ISO, 2000c) and Fitts' Law studies, a new accuracy measure based on the calculation of the cursor movement distance travelling between targets and the associated model will be proposed for the study of the effect of the discrete cursor movement on the usability of the gesture interfaces. A new graphical measurement platform, namely "Fitts' Law Generator (FLG)", will be developed in order to gather real-time data for both the human performance measures of the *speed* (i.e. the sub-movement time) and of the *accuracy* (i.e. *error rate*, target re-entry (*TRE*) and the new accuracy measure of the cursor movement distance).

Based upon the graphical measurement platform "Fitts' Law Generator (FLG)", this research will consist of four primary experiments: (1) an ordinary mouse will be investigated; (2) a sweep-based gesture interface, the "P5 Glove", will be investigated; (3) and (4) two versions of the tilt-based gesture interface will be designed, investigated and validated. In Figure 15, a framework is given to illustrate the research structure and the relationship between the chapters.

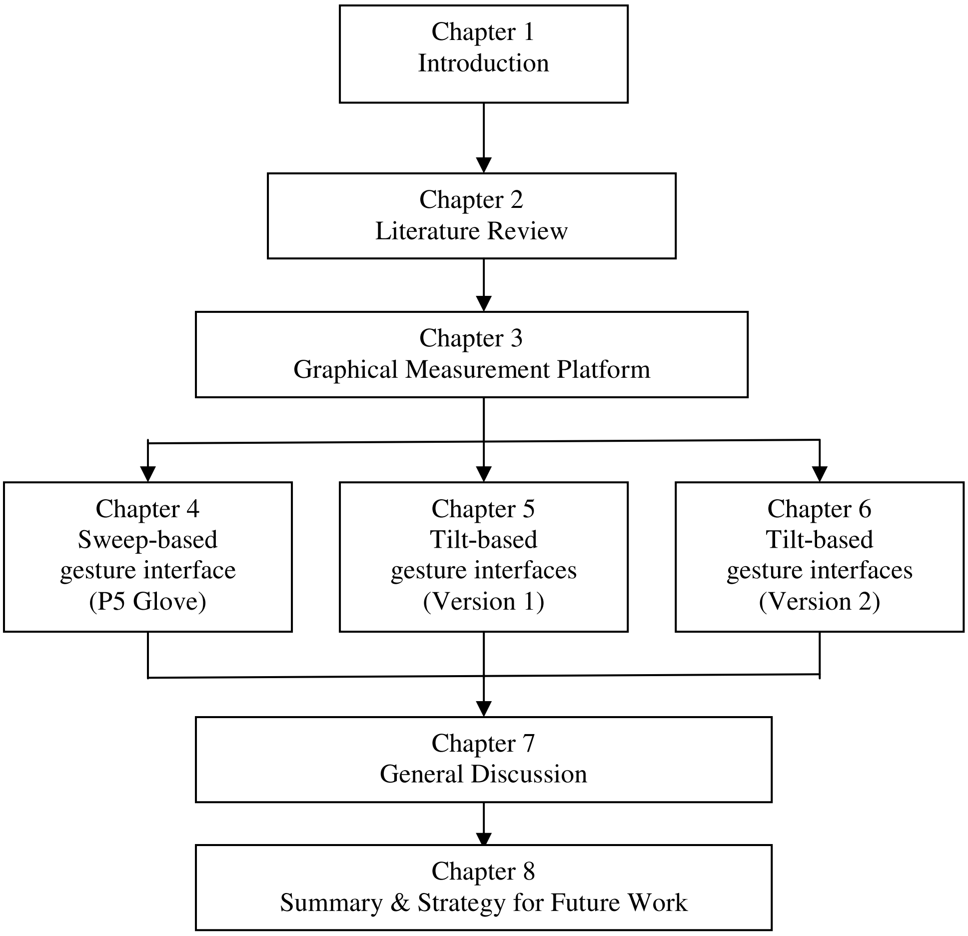

Figure.15 The framework of the research

Following the introductory Chapter 1, Chapter 2 gives a brief review of the ergonomic design factors of the tilt-based gesture interfaces for the desktop computer environment. This chapter will also provide the design guideline for the design development of the tilt-based gesture interfaces in the following chapters. Furthermore, in Chapter 2, the design methodology is introduced based on the review of the background information of the ergonomic design methods, related to the objective measurement of human performance, the direct observation of the specific arm movement and associated analysis protocols and the subjective assessment of the design, discomfort in particular body regions and the user experience. This chapter will develop a new accuracy measure based on the calculation of the cursor movement distance travelling between targets and the associated new performance model that will be proposed based on the extension of Fitts' Law.

In Chapter 3, the review of the background information relating to various graphical measurement platforms is given. This chapter will develop a new two-dimensional (2D) graphical measurement platform "Fitts' Law Generator (FLG)" for gathering real-time data about human performance and the new accuracy measure of the cursor movement distance. In order to validate this graphical measurement platform, a repeat-measurement experiment will be undertaken based upon the new graphical measurement platform and involving thirty-six participants using an ordinary mouse. This study will investigate the hypothesis that if the cursor movement is continuous on the 2D GUI, the new model will be more predictable than the existing models (i.e. ID and ID_e) for the prediction of the movement time MT. The inter-reliability of the subjective questionnaire will also be examined.

Followed by Chapter 4, a repeat-measurement experiment will be undertaken based upon the new graphical measurement platform with ten participants for the study of human performance and fitness-of-models with the ordinary mouse and an existing sweep-based gesture interface, namely the "P5 Glove". During the experiment, direct observation using a digital video recorder (DV) will also be employed based on the proposed experimental procedure and analysis protocol. This study will identify the limits of the sweep-based gesture interface and will investigate the relation between the design problems of the sweep-based gesture interface, the discrete cursor movement, the abnormal movement pattern where the actual working area and actual joint ROMs are mismatched to the planned working area and planned joint ROMs and the development of discomfort in the particular body region.

Chapter 5 and Chapter 6 are iterative design case studies for the design development of two versions of the tilt-based gesture interface (i.e. the working models V1 and V2). In Chapter 5, the working model (V1) will be designed based on the proposed design guideline given in Chapter 2. Then, the working model (V1) will be evaluated based on the proposed experimental procedure with 100 participants. In Chapter 6, the same experimental procedure will be undertaken with the working model (V2) with forty-three participants randomly invited from the same sample population.

In Chapter 7, many results from these experiments, which are related to each other, are analyzed and discussed. Finally, Chapter 8, the concluding chapter, gives a summary of the research findings. The problems that occurred during the study will be highlighted and the remarks and suggestions for further research outlined.

1.5. Related Work

In the industry field, IBM, Logitech and Microsoft, are the leaders in the design and manufacture of non-keyboard input devices (NKIDs). However, under the conditions of their conservative and confidential principles, it is extremely difficult to get the information that is related to research work in this field. Therefore, much of the background information has been found in the research field, in particular, from the recent studies by two pioneers, Shumin Zhai [1] and Ian Scott MacKenzie [2].

In 1995, Zhai (1995d) theoretically and practically investigated the relation between human performance and various design dimensions for six degrees-of-freedom (6-DOF) interfaces. [3] Since the gesture interfaces involve three-dimensional movement in physical space, the author had been inspired to undertake his current studies, which have included an investigation into the effects of shape and size and the finger participation on human performance with 6-DOF interfaces (Zhai, 1996c) and distinguishing two types of 6-DOF interface, i.e. a free-moving, position-control device and a desk-top, rate-controlled, hand controller (Zhar, 1998c). Furthermore, MacKenzie (1991a) expanded the theoretical basis of Fitts' Law into several modifications for the improvement of the model's predictive power in general and to extend its applicability to movement tasks with various types of non-keyboard input devices (NKIDs). Since the gesture interfaces aimed to allow the user to use it as an NKID for point-and-click tasks, this research paid much attention to his recent studies on human performance measurement and modelling, in particular of the movement behaviour theory (MacKenzie *et al.*, 2001a).

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1. Shumin Zhai is a Research Staff Member at the IBM Almaden Research Center. He is on the editorial boards of Human-Computer Interaction, ACM Transactions on Computer-Human Interaction and other journals.
2. I.S. MacKenzie is an Associate Professor of Computer Science and Engineering at York University, Canada.
3. Six degree-of-freedom (6-DOF) involves the direction of the movement in three-dimensional (3D) space (i.e. *X*, *Y* and *Z)* and three movement activities (i.e. roll, pitch, yaw). 6-DOF devices are typically used with a 3D visual environment.

Nevertheless, this research is distinguished by what appear to be novel features: Firstly, it has paid much more attention to the investigation of the design factors from a more user-centred perspective (i.e. ergonomic), such as the working area, associated movement styles (i.e. the sweeping and tilt) and joint ROMs, etc. Thus, the direct observation technique is employed in this research, which helps to identify the movement pattern with various gesture interfaces. Secondly, in order to identify the gesture interfaces producing a discrete cursor movement, this research proposes the use of the new accuracy measure of the cursor movement distance D_e instead of the ordinary target distance D based on both Fitts' original formulation (Fitts, 1954), the Shannon formulation (Shannon, 1949) and the international standard ISO 9241-9 (ISO, 2000c). In terms of the similarity, the experimental procedures are based on the international standard ISO 9241-9 (ISO, 2000c).

In addition, thanks to the Wii console, there is a similarity between this research and other current studies, especially considering the possibility that gesture interaction could contribute to the discomfort development in particular body regions. For instance, many reports about the injuries to Wii players have been discussed in www.wiihaveaproblem.com. In 2007, the first case of 'Wii knee', which is a dislocated patella caused by a fall whilst simulating a serve in Wii Tennis, was reported (Galego, 2007d). It was also suggested (Pasch, 2008f) that adapting games to monitor exertion levels and movement patterns could promote more healthy body movements[4].

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4. In Oct 2006, my proposal to cooperate with Wii developers was rejected. The following letter was sent by the Ailive.net, which is one of leaders in Artificial Intelligence for entertainment: "Dear Ken….Your suggestion with respect to research cooperation with AiLive is a good idea. But we are still a small company and as such we are currently not able to do that. We wish you all the best with your research and please keep us posted of your progress.". The proposal was also rejected by the headquarters of Nintendo Co., Japan. Under the conditions of their conservative and confidential principles, it is quite difficult to access information which is related to the research work in this field.

Chapter 2: Literature Review

2.1. Design Guideline of Tilt-based Gesture Interfaces

2.1.1. Design concept

According to ISO 9241-9 (ISO, 2000c), the usability and context of use need to be defined at the earliest stage of the design concept.

(1) Usability

In this study, usability of the gesture interfaces involves objective measures of human performance (i.e. sub-movement time, error rate, target-re-entry rate and cursor movement distance), subjective assessment (i.e. design, discomfort, user experience and open-ended comment) and the joint ROMs.

(2) Context of use

The context of use is defined in ISO 9241-9 (ISO, 2000c) as consisting of "the end-users, tasks, equipment (i.e. hardware, software and materials) and the physical and social environments in which a product is used". This definition is incorporated into ISO 13407 (ISO, 1999e) on human-centred design. Maguire (2001b) emphasized that the understanding of the context of use becomes one of the main stages within the user-centred design process. In this study, the context of use of the tilt-based gesture interfaces is well defined in the following sections in terms of the scenario, tasks, working area and the people.

(3) Scenario

Based on the design concept, a scenario was proposed, illustrated in Figure 16: the tangible pointing device allows the end-user to control the two-dimensional cursor movement independently “off-desk” by using the hand gesture. Thus, the lower back and the forearm can be fully supported by the chair.

Figure.16 Scenario: end-user using the tangible pointing device (right picture) allows a more relaxed and neutral posture than using the ordinary mouse (left picture)

(4) Task

In order to fulfil the scenario, the gesture interfaces must allow the end-user to use the forearm and the wrist to control the direction and acceleration of the cursor movement on the screen for a point-and-click task and secondly to maintain a neutral posture of the upper limb.

(5) Working area

As can be seen in Figure 17, the end-user places his/her forearm fully on the armrest of the chair in order to reduce fatigue. Regarding the neutral posture of the body during the operation of a desktop computer, a broad guide (ISO, 1998b) and Woods *et al.* (2002c) suggests adjusting the chair and display to find the most comfortable position for the work. The forearms should be approximately horizontal and the eyes at the same height as the top of the video display unit.

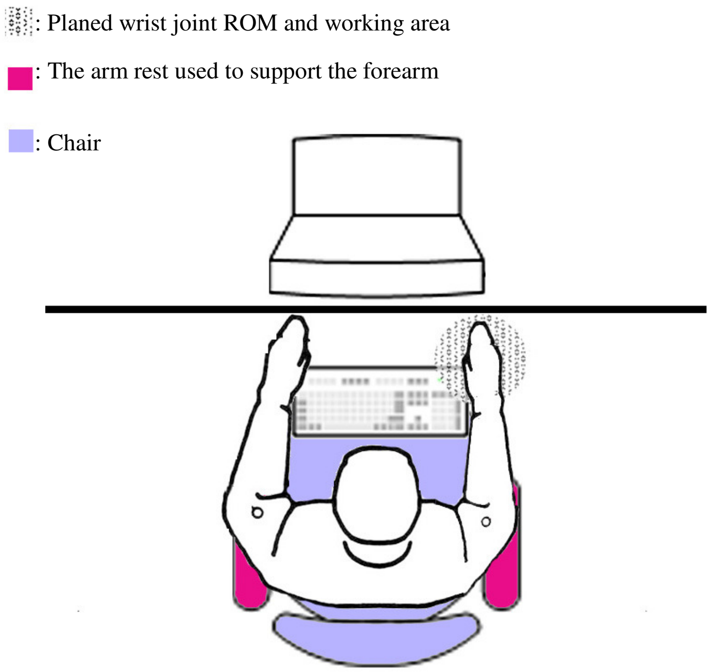

Figure. 17 Tilt-based gesture interface and the planed working area
(Reproduced from: Pheasant, 1997d, pp. 51)

(6) People

Taylor and Hinson (1988b) investigated individual differences in the ability to use a mouse to point to words in a piece of displayed text. They found that the performance of a user depended on the nature of the task, the inherent characteristics of the input device, the implementation of the device and its driving software, the users' previous experiences of the task and device and other individual user characteristics. Moreover, earlier in 1999, Hsu *et al*. (1999c) investigated the effects of gender difference and age on human performance using a remote pointer with a group of forty-eight participants. As a result, they found significant gender- and age-related effects on the movement durations. To sum up, this research will investigate the effect of gender and motor skills on human performance when using a mouse and gesture devices.

(7) Forearm posture

It was suggested (Werner *et al*, 1997e) that the wrist and forearm should be maintained in a neutral position during vocational and avocational activities so as to minimize pressure within the carpal tunnel and in turn reduce the risk of developing carpal-tunnel syndrome. Therefore, the usability of the gesture interfaces could be influenced by two types of forearm posture: the 'palm-down' and the 'hand-shank' postures, shown in Figure 18.

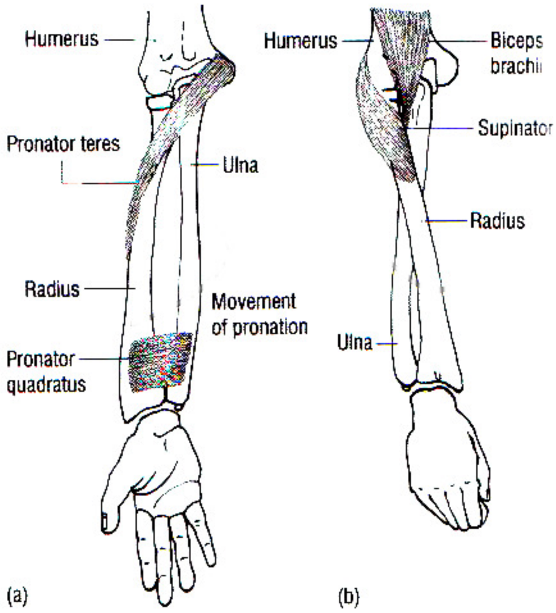

Figure.18 Muscles and movements of (a) "handshake" posture, (b) "palm-down" posture
(Modified from Tyldesley and Grieve, 1989, page 100)

Since most of the mouse users have years of the experience in using the 'palm-down' posture, in order to study the effect of the mouse experience on human performance with the gesture interfaces, the 'palm-down' forearm posture is used throughout this research. In the future, studies will be conducted to explore the difference in the performance between both the forearm postures and with various gesture interfaces.

(8) Sensor position on the hand

In 2005, Farella *et al.* (2005) designed a gesture interface system based on body-mounted accelerometers for navigation in virtual spaces. In their work, they implemented qualitative and quantitative assessments with ten participants aged from 23 to 30, based on a 3D game application as a test-bed to evaluate the effectiveness of the interface. During the test, they asked participants to wear one of the sensing units on their wrist or on the back of their hand, depending on their personal preference, as shown in Figure 19. However, the study did not compare the difference in the effectiveness between the two sensor positions. Furthermore, their study did not employ Fitts' Law or allow for the fact that the effect of the user preference on the selection of the sensor position might bias the study.

Figure.19 Wearable setup used in human-based tests: The one at the right hand side is on the hand, and the left hand side is on the wrist.
(Source: Farella *et al.*, 2005).

Three years later, Oakley *et al.* (2008e) developed a wearable pointing system using an inertial sensor pack. In their work, they invited twelve participants (i.e. six females and six males, average age 29 years) in order to compare performance when the pack is held in the hand, mounted on the back of the hand and finally on the wrist, as shown in Figure 20. The results showed a significant, but numerically small, advantage in using the hand over using the upper arm only. They further suggested that for wearable tasks where pointing is relatively infrequent, a wrist-based sensor pack may well be sufficient to enable effective and usable interaction. Moreover, they also emphasised that many aspects require further exploration. For example, the movements in their study were delineated by a button held in the participants' non-dominant hand. They also highlight that a hands-free solution should be developed to solve the button participant problem with gesture interfaces.

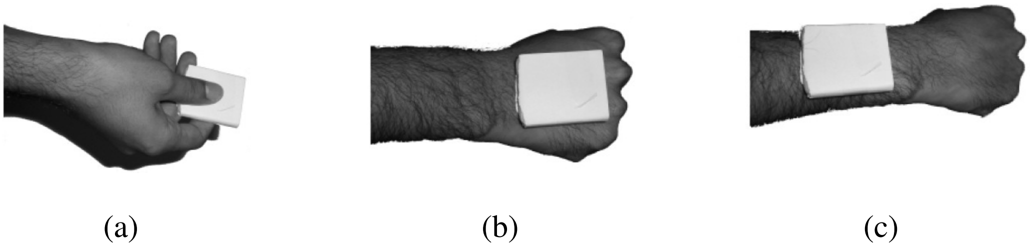
(a) (b) (c)

Figure.20 Three sensor positions used in the Oakley *et al.* (2008e) study, where the white rectangle indicates Held (a), Hand-back (b) and Wrist (c). Sensor mounting materials are not shown. (Source: Oakley *et al.*, 2008e)

Thus, in order to allow the user to use the tilt-based gesture interfaces by fully utilizing the tilt movement of the wrist, the sensor position of the Zstar sensor pack will be mounted on the hand, similar to the position shown in Figure xxx (b). In the future, a study will be conducted to explore the differences in the performance between these sensor positions.

2.1.2. System design

Generally speaking, there are three problems with the inertial sensor system, the drift noise (Suh, 2003d; Cheok *et al.*, 2002a), nonlinear effects caused by gravity (Suh, 2003d) and peak noise, as revealed in this research:

(1) Drift noise

Suh (2003d) reported that the bias drift problem could cause accumulated errors and the accuracy can deteriorate as time increases due to integration. A similar problem was reported by Cheok *et al.* (2002a), who designed a wearable, tilt-based pen for navigation in a 3D visual world. They reported that ideally the final displacement should be zero, as the device returns to the original position. As can be seen in Figures 21, the random bias drifts can cause a large error in the position determination.

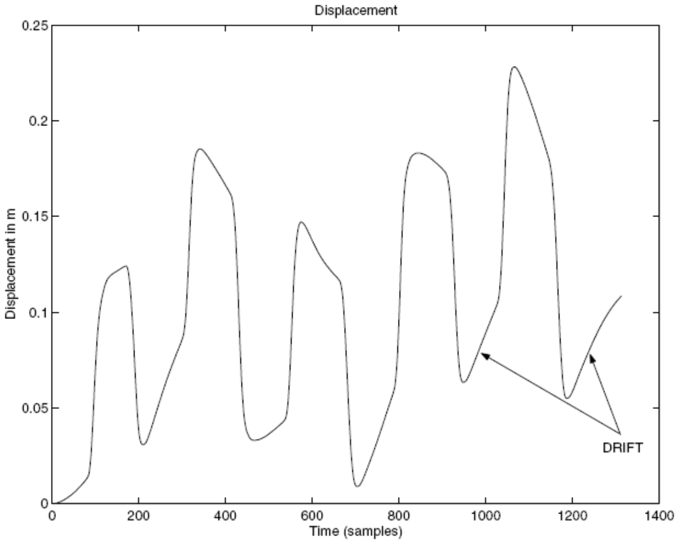

Figure.21 The displacement test: To-and-fro displacements were carried along the x-axis of the accelerometer over the slider for five times and the data was recorded. Note that, ideally, the final displacement should be zero, as the device returns to the original position (Source: Cheok et al., 2002a).

In order to cope with the bias drift problem, noise and the nonlinear gravity problem, a noise filter needs to be used in either the software development or the hardware. Since this research does not propose to modify the hardware system, a software-based noise filter is considered for development in order to couple it with the drift problem.

(2) Nonlinear effects caused by gravity

The other problem is that single or double integration of an acceleration signal suffers from not only noise but also nonlinear effects caused by gravity. Such signal integration may often lead to divergence far from a true value (Suh, 2003d).

(3) Peak noise

Finally, this study assumed that there is another problem which might also lead to error displacement. As can be seen in Figure 22, the inertial sensor system designed by Cheok *et al*. (2002a) produced the peak noise during the to-and-fro displacements carried along the axis of the inertial sensor. Furthermore, a similar result can be seen in Suh's design (2003d), shown in Figure 23.

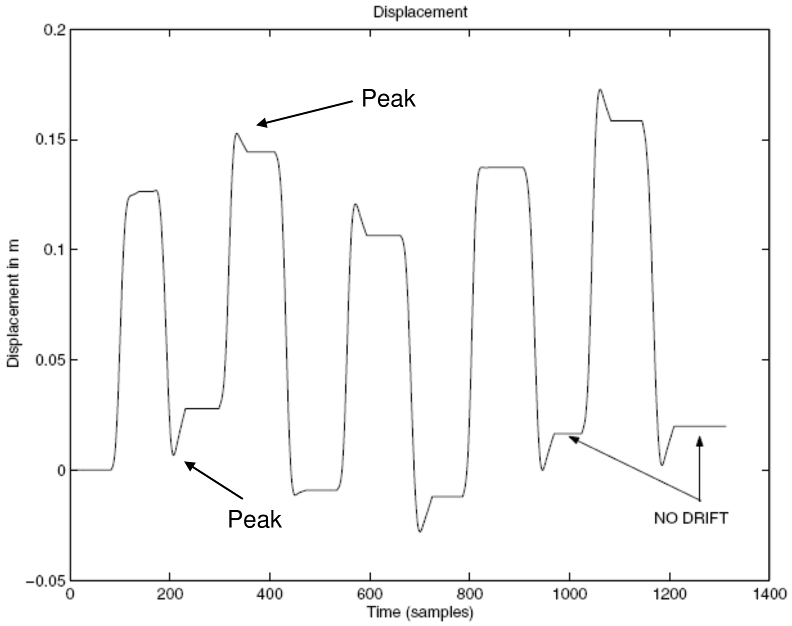

Figure 22. Displacement calculated from filtered acceleration with the gesture pad designed by Cheok *et al.* (2002a): the peak noise occurred during the to-and-fro displacements carried along the axis of the inertial sensor.

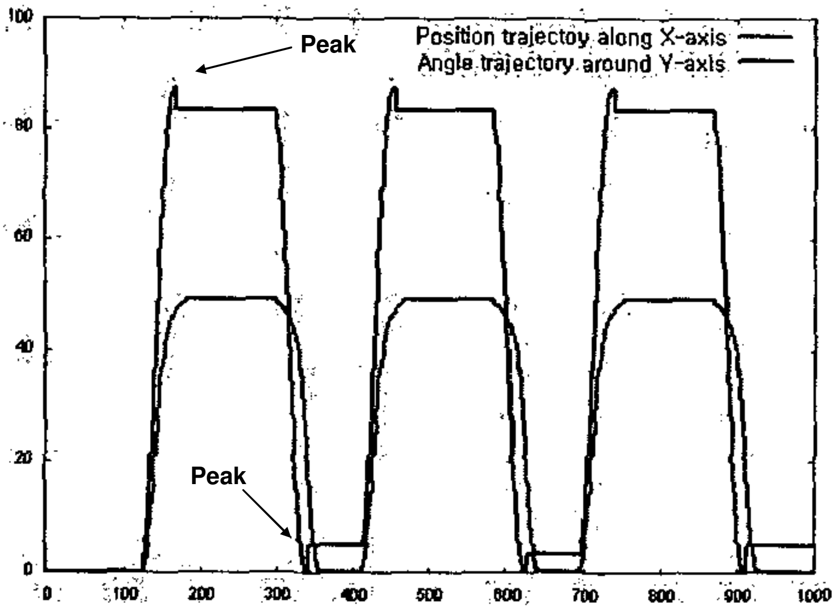

Figure.23 Displacement calculated from filtered acceleration with a low-cost 6-DOF spatial tracker system based on Suh's design (2003d): the peak noise occurred during the to-and-fro displacements carried along the axis of the inertial sensor.

Both studies did not mention the effect of the peak noise on the displacement and did not propose a method of error compensation to deal with this noise. As a result, Chapter 6 reports that, without elimination of the peak noise with the Zstar, an error in the displacement determination occurs and that this results in discreet cursor movement on the screen.

In order to deal with these errors and at the same time produce the cursor movement according to the hand movement state, a sensing system is proposed which consists of hardware and software, as shown in Figure 24.

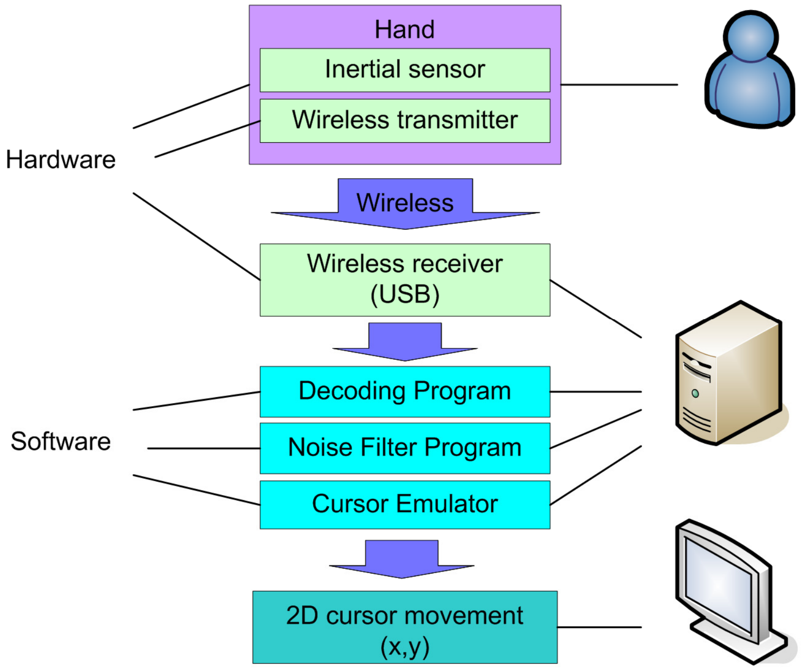

Figure.24 The system architecture of the working model[5]

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[5] The proposed system has been published (Wu *et al.*, 2008i), as following:

Wu, F. G., Chen, C. C. and Chen, T. K. (2008i) A user-centred design case study of a novel gesture-based pointing device. CREATE 2008 on Embedding People-centred Design in the Process of Innovation, London, U.K., Ergonomics Society HCI Group & British computer Society.

The modification will be made, subject to the type of the hardware employed for the gesture interactive system.

2.1.3. Hardware

It was highlighted by Nugent and Augusto, (2006e) that the trend of HCI has been driven by the development of state-of-art sensor technology having advantages in terms of size and power consumption. Thus, the following criteria will be considered as the system requirement:

- Low-cost,
- Embedded system,
- Energy-saving,
- On-line technical support.

In this study, an inertial sensor evaluation board known as “Zstar”, manufactured by the Freescale Semiconductor Co., U.S., was selected. It consists of two boards with a 2.4GHz wireless transmitter and a wireless receiver, as illustrated in Figure 25. For more detailed information about the Zstar please refer to the official data sheet (Wireless Sensing Triple Axis Reference Design: Designer Reference Manual. ZSTARRM, Rev. 3, 01/2007) (Lajšner and Kozub, 2007f).

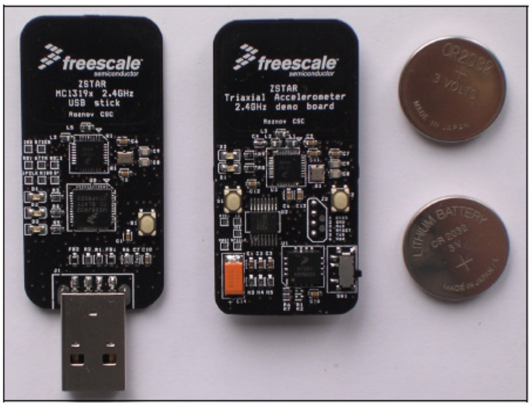


Figure.25 The Zstar demo photos (CR2032 batteries for comparison):
The transmitter is the one at left hand side, another one is the receiver
(Source: Lajšner and Kozub, 2007f)

The system blocks are illustrated in Figure 26 and 27:

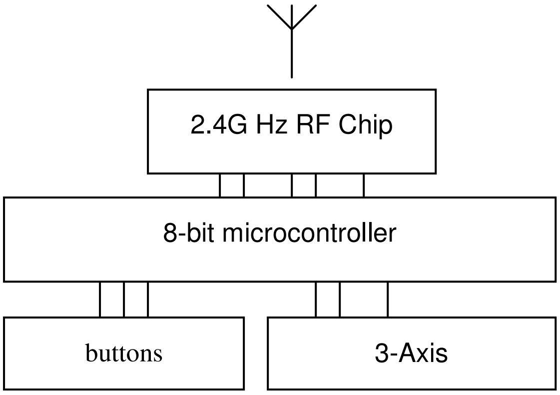


Figure.26 System block of the transmitter of the Zstar
(Modified from Lajšner and Kozub, 2007f)

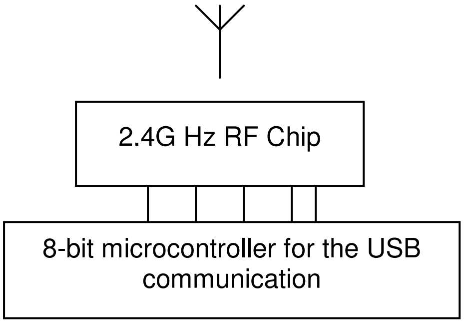


Figure.27 System block of the receiver of the Zstar
(Modified from Lajšner and Kozub, 2007f)

Furthermore, the ISO 9241-9 (ISO, 2000c) also recommended the ergonomic requirements for the following design factors:

(1) Sensor technology

In order to operate with a graphic user interface in which an input device is used to move a small display image (such as a cursor/pointer) to a specific location on the display, the position of the device itself needs to be given to the computer by the sensor technology embedded in the input device.

(2) Button actuation

Click task is based on depressing and release of a button or actuation point on an input device and button is a mechanical object integrated into an input device, which responds to force when depressed, and provides input to the computer in terms of hardware. Furthermore, the human performance of the button actuation can be measured by the pointing time PT, which is the time to move a pointing device from a start position to a target position excluding stimulus presentation time and button actuation time.

Because the aim of this research is to investigate the causes of the discrete cursor movement with gesture interfaces, this research directly adopt the commercial buttons activations from market places in order to minimize the bias that influenced by the button actuation on the human performance with gesture interfaces. In fact, the button design is a specific research area that needs to look at in the future, which the design factor can be broken down into more details, such as button shape, button force, button displacement, etc, which the ergonomic requirement is proposed by ISO 9241-9 (ISO, 2000c).

(3) Sensor location

The motion sensing point should be located under the fingers rather than under the palm of the hand, which makes it not applicable for gesture interface design.

(4) Shape and size

Finger, hand-held or grasped input devices should be designed to accommodate the hand size of the intended user population.

(5) Weight

The weight, and hence inertia, of the input device should not degrade the accuracy of the device during use under a defined normal range of actions including translation, rotation, and button actuation.

2.1.4. Software

The software in this research is not only to produce the relative cursor movement on the screen based on the reorganization of the movement states of the hand when using the inertial sensor, but also to deal with the noises generated by the inertial sensor system.

In order to deal with these errors, and at the same time produce the cursor movement according to the hand movement state, three functional units need to be developed, these are: (1) a decoding unit, (2) the noise filter unit and (3) the cursor emulation unit. The following sections describe the requirements and the specifications for these functional units (i.e. for more details please see C# codes in Appendix A).

(1) Decoding Unit

A decoding program should fulfil the following requirement (Lajšner and Kozub, 2007f):

1. The data must be captured without the loss of any bytes or putting any byte into a wrong offset;
2. The software must be very stable and have a high degree of reliability over a period of time;
3. The estimated data after decoding must be meaningful in terms of the calibrated *g force* (m/s^2);
4. The program must be stable, i.e. number of outlets must not exceed 99% of the confidence level[6] and the S.D. must be the same as the value specified by the data sheet of the Zstar;

---

[6] Because an 8-bit microprocessor is used in the Zstar, 1% of the error is expected, according to the technical support team from the Freescale Co., U.S.

(2) Noise Filter Unit

According to the technical note provided by Freescale Semiconductor Co (Seifert and Camacho, 2007i), the noise filter unit is based on the following steps to calculate the positioning algorithms using the ‘Zstar’ inertial sensor board according to the software design considerations:

1. The signal is not noise free so it must be digitally filtered. The filter used in this algorithm is a moving average; the value to be processed is the result of averaging a certain number of samples. Even with the previous filtering, some data can be erroneous due to the mechanical noise; so another filter must be implemented. Depending on the number of samples filtered, a window of real acceleration can be selected (typically ± 2 sample steps for an average of 16 samples).
2. A no-movement state is critical to obtain the correct data. A calibration routine is needed at the beginning of the application. This calibration value must be as accurate as possible. The real value of the acceleration is the sample minus the calibration value; it can be either positive or negative. This must never be ignored when declaring variables (signed).
3. A faster sampling frequency implies more accurate results due the fact that error is reduced; yet more memory, timing and hardware considerations are needed.
4. It is essential that the time between samples is always the same. Errors can be generated if this condition does not obtain.
5. A linear approximation between samples (interpolation) is recommended for more accurate results.

As for the decoding unit and the noise filter unit, the Zstar has a very low sampling rate (i.e. 30HZ), thus the noise could not be filtered by using a simple moving average[7]. Thus, an outlet filter is proposed to remove the noise. An *outlet* is defined as 'a value outside the *95% confidence level* (*mean* ± 2 *S.D*)' and that of the total number of samples can be defined as the *error rate (%)*. Based on the variance test, the *average error rate* for both the x and the y is less than 1%[8]. Furthermore, the average *S.D.* for the x is 0.013, for the y is 0.023 and for the z is 0.007. Based on the Freescale Semiconductors' application note (Clifford, 2006b), the *S.D.* for the *g force* of the x is 0.017, for y is 0.018 and for the z is 0.02. Therefore, the *S.D.* produced by the noise filter unit is better than the default values. The data is also clarified by the technical team from Freescale, who stated that the filter noise unit was acceptable "…variances from attachment are reasonable and looks good comparing my experiences…" (i.e. for more details please see the letter and associated tables in Appendix B).

(3) Cursor Emulation Unit: This is described in the following sections in some detail.

---

[7] This is because the moving average can further reduce the sampling rate to less than 15HZ and the value is lower than the graphical measurement platform FLG: the sampling rate for the measurement of the cursor movement is 17Hz.

[8] However, the error rate for the z-axis is not stable, i.e. average error rate is 8.12%. Therefore, this research did not utilize the z-axis data.

2.1.5. Cursor Emulation Unit

As illustrated in Figure 28, the gesture interface aims to produce the relative cursor movement on the screen based on the reorganization of the movement states of the hand:

- Direction: According to the movement state of the hand, how can the tilt movement direction of the forearm and the wrist in terms of relative *g forces* (+/−) in the air be transferred into the relative cursor movement direction on the screen in terms of the *x* and y *relative coordinates* (+/−)?
- Displacement: According to the movement state of the hand, how can the tilt movement acceleration of the forearm and the wrist in terms of relative *g force per sec* in the air be transferred into the relative cursor movement acceleration on the screen in terms of the displacement (*pixel*) per cycle time?
- Stop: How can the cursor be stopped when the hand is not moving in the neutral posture?

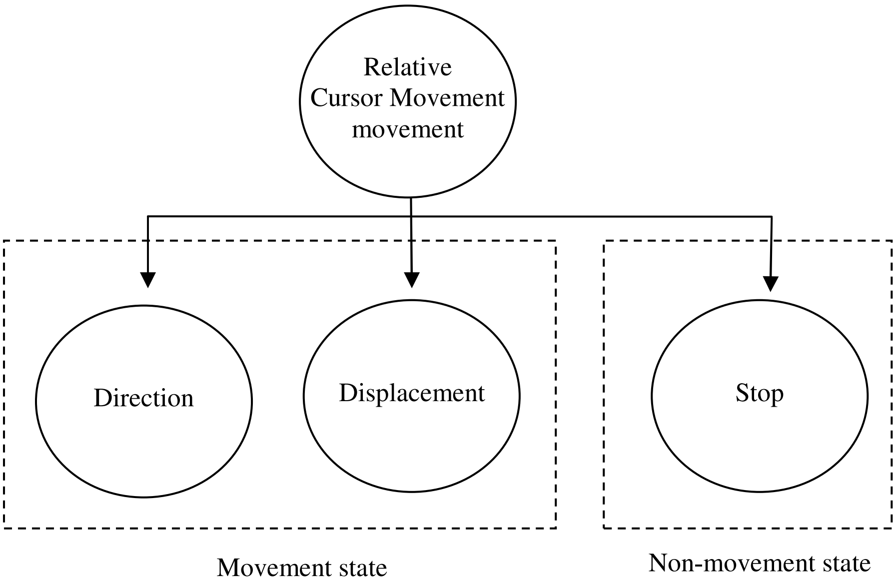


Figure.28 The relative cursor movement

(1) Direction

The tilt-based gesture interface aims to transfer these relative joint ROMs in terms of relative *g forces* (+/–) in the air into the relative cursor movement direction on the screen in terms of the *relative x* and y *coordinates* (+/–), as shown in Table 4, Figures 29 to 32.

Table.4 The relation between the cursor movement direction and the joint motion

Cursor movement direction	Joint Motion
↑	Extension
↓	Flexion
←	Pronation
→	Supination

Since the inertial sensor technology can detect the directional acceleration of each pair of coordinates for a movement, the design solution for the determination of the cursor movement direction is to compare the difference between the *previous g force* and the *current g force* for each pair of coordinates for the movement.

Direction = Current g force – Previous g force .... Formula (1)

For instance, if the *Direction* > *0,* it means that the physical movement should be either flexion or supination or a combination of both movements, which means that the cursor movement, is going in a positive direction relative to the coordinates on the screen (x: +, y: +). By contrast, if the *Direction* < *0,* it represents that the physical movement should be either extension or pronation or a combination of both movements, which means that the cursor movement is going in a negative direction relative to the coordinates on the screen (x: –, y: –).

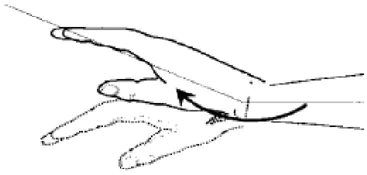


Figure.29 Extension of the wrist, used to control the cursor movement direction to relative coordinate y: + (🡩 90 °)
Source: ISO 9241-9 (ISO, 2000c)

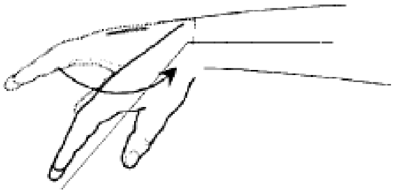


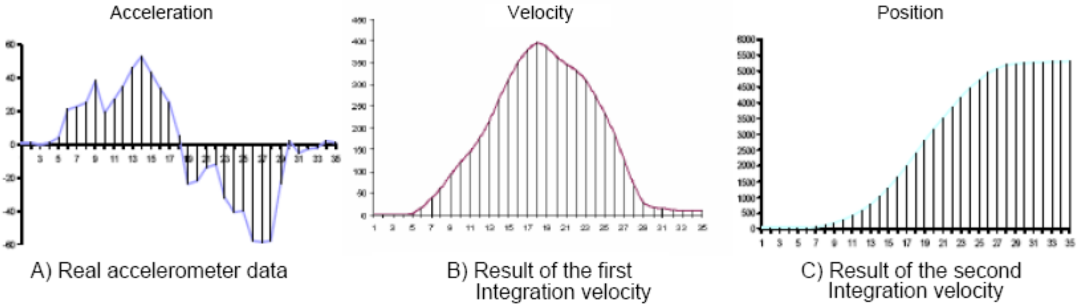
Figure.30 Flexion of the wrist, used to control the cursor movement direction to relative coordinate y: – (🡫 225 °)
Picture Source: ISO 9241-9 (ISO. 2000c)

Figure.31 Pronation of the forearm, used to control the cursor movement direction to relative coordinate x: – (🡨 180 °)
Source: ISO 9241-9 (ISO. 2000c)

Figure.32 Supination of the forearm, used to control the cursor movement direction to relative coordinate x: – (🡪 0 °)
Source: ISO 9241-9 (ISO. 2000c)

(2) Displacement

In order to calculate the displacement, a double integration needs to be employed (Seifert and Camacho, 2007i): The first integration is to get a proportional approximation of the velocity based on the acceleration given by the inertial sensor, shown in Figure xxx (b). In order to obtain the position, the integration must be performed again. The second integration gives a proportional approximation of the instantaneous position, as shown in Figure 33[9].


Acceleration

Velocity

Position

A) Real accelerometer data

B) Result of the first Integration velocity

C) Result of the second Integration velocity

Figure.33 Double integration
(Source: Seifert and Camacho, 2007i):

Similar to the double-integration, the cursor movement displacement can be produced based on the following formula:

Displacement = (Current velocity – Previous velocity)^2 ………… *Formula (2)*

For instance, the quicker the velocity the longer the cursor movement displacement per cycle time.

---

[9] For more detailed technical information about implementing the positioning algorithms using an inertial sensor, please see the Freescale Semiconductor Application Note (Ref No. AN3397) (Seifert and Camacho, 2007i)

Furthermore, the following flow chart demonstrates how to produce four types of cursor movement speed according to the range of the displacement, namely *Formula (2):*

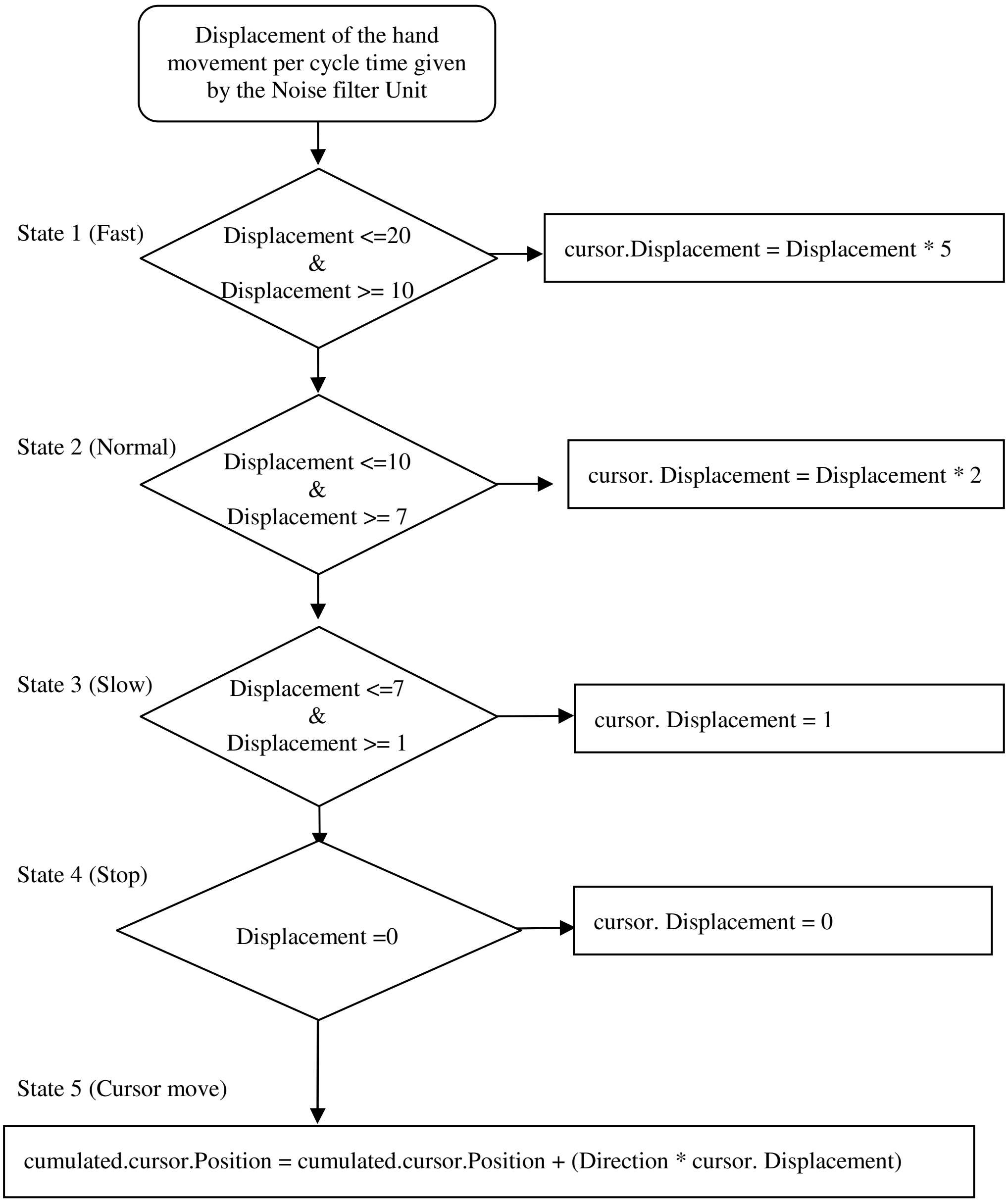


Figure.34 Flow chart of the four-speed cursor moveemnt fomular *(Formula. 2)*

where the cumulated.cursor.Position is is subject to the width and height of the screen. In Chapter 6, it is revealed that such a four-speed manner can be influenced by the peak noise and produce a cursor movement displacement of 250+ mm per cycle time. Therefore, the following fomula is proposed to remove the peak noise and at the same time produce the cursor movment displacement per cycle time instead of the four-speed cursor movement displacement formula, namely Peak Filter Unit and *Formula (3):*

```
IF (displacement.New –displacement.Old) >= 50                    // 50+mm is the peak noise
    THEN displacement.New = displacement.Old;                    //replacement of the old
        ELSE cumulated.cursor.Position = cumulated.cursor.Position + (Direction * displacement.New)
                                                                 //cursor moves
```

where the cumulated cursor position is subject to the width and height of the screen. In this regard, if the peak noise is detected, the current value of the displacement (i.e. displacement.New) will be replaced with the value obtained from the previous cycle (i.e. displacmeent.Old). The parameter 50 is the result of a series of trials, which requires further study by using an oscilloscope with the Zstar in the future.

(3) Stop

In order to recognize the non-movement state of the hand, it is necessary to restore the acceleration (*g force per sec*) when the hand is in the neutral posture prior to the use of the interface, namely the initial acceleration. Thus, if the current acceleration is equal to the initial acceleration, then the cursor stops. The formula is shown as follows:

Formula (4):

```
IF   Current Acceleration = Initial Acceleration
    ELSE Cursor stops
```

(4) Other design factors of the graphic user interfaces

The following factors are reported by ISO 9241-9 (ISO, 2000c), these factors are deemed as controlled variables in the following chapters.

- Gain: The gain of relative-positioning input devices should be appropriate to the task and should be user-adjustable.
- Cursor shape: In this research, the arrow cursor shape ⇖ is used in the following primary studies with gesture interfaces as the controlled experimental condition for participants.

2.2. Human Performance Modelling

2.2.1. Fitts' Law

There have been many theories and practices of human-computer interaction developed for studying human-centred performance. One famous theory is Fitts' Law. Early in 1954, Fitts introduced the mathematical relationship between speed, accuracy, amplitude of movement and target size for upper extremity tasks. Yang *et al.* (2002) stated that this relationship, known as Fitts' Law, provides a basis for objective measures of neuromuscular performance capacities as a one-dimensional description, which can be expressed by a simple linear regression equation as shown in Eq. (1):

$$MT = a + b \times ID \qquad (1)$$

$$ID = \log_2(2 \times D / W) \qquad (2)$$

where *ID* is the index of difficulty proposed by Fitts, *D* is the distance between targets, *W* is the target width, *MT* is the movement time and parameters *a* and *b* are calculated on the basis of a simple linear regression. As expected, movement time for hard tasks is longer than for easy tasks.

$$ID_e = \log_2(D / \mathrm{W} + 1) \qquad (3)$$

In fact, Fitts' *ID* in Eq. (2) was extended from the Shannon formulation of *ID* shown in Eq. (3) (Shannon, 1949). It provides a better fit with observations, is truer to the information theorem on which Fitts' Law is based, and because a negative ID value is not possible (Soukoreff, R. W. and MacKenzie, 2004d) with this formulation. Moreover, MacKenzie (1995b) recommended the use of the effective target width W_e instead of the nominal target width *W* to measure actual performance of either devices or tasks:

$$W_e = 4.133 \times S.D. \qquad (4)$$

$$ID_e = \log_2(D/W_e + 1) \qquad (5)$$

where *S.D.* is the standard deviation of endpoint over target region, and ID_e is the effective index of difficulty.

Recently, the ID_e model in Eq. (4) and Eq. (5) has been standardized in ISO 9241-9 (ISO, 2000c) as a design and testing guideline and as the specification for non-keyboard input devices (NKIDs), e.g. mouse, trackball, joystick, indirect touch panel and direct touch screen. In particular, Soukoreff and MacKenzie (2004) recommended that regression analysis on both *MT* and ID_e should indicate an adjusted R^2 value, which is ideally over 0.9 when testing on a normal mouse with a one-dimensional Graphic User Interface (1D GUI).

Furthermore, there is a speed-and-accuracy trade-off relation for a point-and-click task, MacKenzie *et al.* (2001) further defined the terms Speed and Accuracy with standard pointing devices (i.e. mouse, trackball, touch pad, and joystick):

- Speed: this is usually reported in its reciprocal form, movement time (*MT*). This is in fact the efficiency, which is also defined as “An input device is most efficient when it functions with the least amount of time and effort”, defined by ISO 9241-9 (ISO, 2000c). Speed can be represented as cursor movement time (ms).
- Accuracy: this is usually reported as an error rate - the percentage of selections with the pointer (i.e. cursor) outside the target - which can be deemed to be the effectiveness, defined as “A device is effective when its design takes into

consideration factors that lead to enhanced or optimized user performance by means of accuracy and completeness." by ISO 9241-9 (ISO, 2000c).

2.2.2. Sub-movement time

Regarding the movement time *MT*, various current studies suggest the use of the sub-movement time with Fitts' Law on the microstructure of positioning movement, instead of using the total movement time only. Among these studies, Akamatsu and MacKenzie (1996b) defined two intermediate points, i.e. 'cursor enters target' and 'cursor stops', and five dependent temporal time periods: movement time, approach time, selection time, stopping time and clicking time. Furthermore, three years later, Hsu *et al.* (1999c) defined one intermediate point, i.e. 'cursor enters target', and two dependent temporal time periods: 'initial phase', and 'adjustment phase'. Most recently, Sato *et al.* (2003c) defined one intermediate point and two phase-movement times for pointing tasks: 'approaching phase' and 'positioning phase'. In sum, since Sato *et al.* (2003c) provided a better explanation regarding the effect of the grasping operation related with the arm muscles as the main effect on the movement time and had invented a practical, flexible, grasping interface with an ordinary mouse, Sato's theory is adopted in this study, as shown in Figure 35.

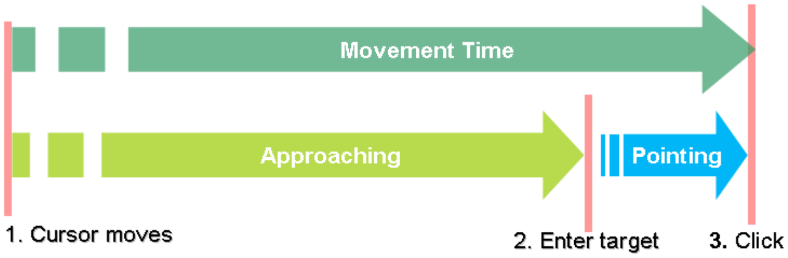


Figure.35 Sub-movement time

2.2.3 New accuracy measure: Cursor movement distance

In order to study the effects of the cursor movement on human performance with a gesture interface, the cursor movement distance should be measured based on the expansion of the current study about the movement behaviour (MacKenzie *et al.*, 2001). In addition, there is a similar theory model, namely the 'Steering Law', for the evaluation of trajectory-based tasks (Accot and Zhai, 1997a, 1999a). The model might be associated with the movement behaviour, but it is not involved in this research because the accuracy measure is based on fixed-trajectory tasks, such as drawing, writing and navigation, which differ from those of current Fitts' Law studies that are commonly target-acquisition tasks, such as point-and-click. Therefore, there could be a research opportunity for further study with various gesture interfaces based on the Steering Law.

In 2001, MacKenzie *et al.* (2001) proposed the use of cursor movement behaviours to explain natural human body motion in a two-dimensional environment. For instance, in order to perform a pointing task efficiently, an individual may suffer if movement control is difficult thus causing several attempts at target-entry before selection and an inability to match the cursor movement between targets onto a straight line. As expected, the cursor movement distance for hard tasks might be longer than that for easy tasks, and could be influenced by a product itself. In this study, the cursor movement distance is defined as the '*Two-dimensional cursor movement distance captured during a trial*':

$$D_e = \sum_{i=1}^{n} \sqrt{(x_i - x_{i-1})^2 + (y_i - y_{i-1})^2} \qquad (6)$$

where x_{i-1} and y_{i-1} are the coordinates of the start point and x_i and y_i those of the end point, *n* is number of times coordinate data are captured between the start point and the end point, and D_e is the cursor movement distance calculated by the sum of the micro distances between the coordinates of the start point and those of the end point, namely, in general terms, the '*Effective Target Distance*'. In particular, *n* is subject to the rate of data-capture of the testing platform, which is measured in Hz (times per second, i.e. per cycle time), which, ideally, should be as high as possible. Technically, capturing the coordinate data from start point to endpoint is a continuous process. Unlike movement time or the standard deviation of the endpoint, D_e is based on a single measurement per trial, which can be demonstrated in Figure 36.

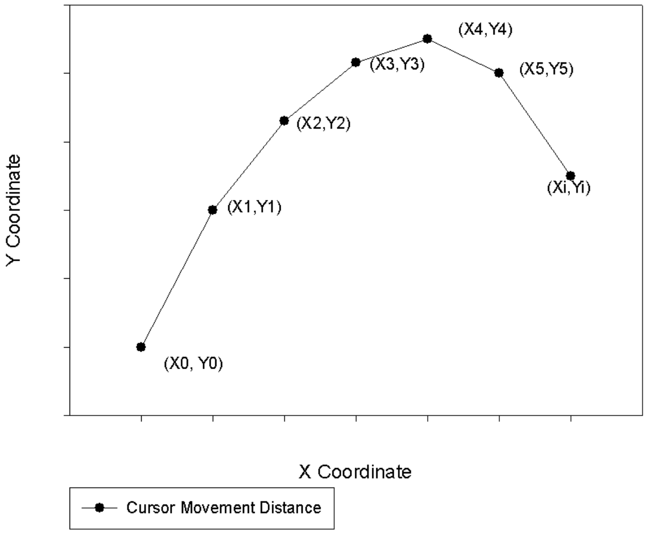


Figure.36 Cursor movement distance D_e for a trial

ID_{e2} is further proposed by using D_e instead of *D*, as shown in Eq. (7).

$$ID_{e2} = \log_2(D_e / W_e + 1) \qquad (7)$$

ID_{e2} could be used to explain *why* some devices, tasks or people are more efficient than others and is vital to the expansion of the theoretical knowledge base concerning the measurement of performance of natural human body motion.

2.3. Factors that affect human performance

Except for the design factors that can directly impact on human performance, the following factors are discussed:

2.3.1. Discrete cursor movement

According to ISO 9241-9 (ISO, 2000c, p 15), the cursor movement is the relation between the movement of the input device and the movement of the cursor on a display and follows user expectations in the cardinal directions. The position sensor can also produce noise, such as drift noise, and the nonlinear effects caused by gravity (Suh, 2003d) as well as the peak noise revealed in this research. If the cursor emulation programme ignores these noises, the input device produces a cursor movement that does not accord with user expectations in the cardinal directions, namely the discrete cursor movement referred to in this research.

2.3.2. Angle of approach

In this study, Fitts' Law is expanded into a two-dimensional description using a polar coordinate system. The angle of approach is deemed to be one of the target conditions (i.e. the target width W and the distance between targets D) for the usability test with pointing devices, measured in degrees (^{o}). Various types of angle of approach have been proposed in the current studies, which are discussed in this section.

In general, there are at least two types of experimental design for the study of multi-directional human performance on a two-dimensional GUI. One is proposed by MacKenzie and Buxton (1992) who reported an adjusted $R^2 = 0.95$ for movement time prediction, whilst the other one is proposed by Whisenand and Emurian (1999f), who reported an adjusted $R^2 = 0.43$ in 1996 and an adjusted $R^2 = 0.44$ in 1999, respectively, for movement time prediction. Obviously, Whisenand and Emurian's adjusted R^2 values were much lower in comparison with those of MacKenzie and Buxton in 1992. This may be because their studies differed in both experiment design and methods for adjusting accuracy, as shown in Table 5.

Table.5 Current studies of multi pointing performance

Current studies	Differences	
	Angles of approach	Adjustment of Data
MacKenzie and Buxton (1992)	0°, 45°	Eliminate cases where endpoint is outside 2 *S.D.*
Whisenand and Henry (1996, 1999)	0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°	Error cases were analyzed separately.

For example, MacKenzie's experiment design is based on the use of two angles of approach, i.e. 0° and 45°, in which the task difficulty is logically simpler than in Whisenand and Emurian's studies, which was based on the use of eight angles of approach, i.e. 0°, 45°, 90°, 135°, 180°, 215°, 270° and 315°. In fact, MacKenzie and Buxton had already emphasized that the angle of approach should be thought of as a bias to Fitts' model, which could be an explanation for Whisenand and Emurian obtaining lower movement-time predictions. Both methods expanded the knowledge base of Fitts' Law to modelling two-dimensional human body movement and validated that the angle of approach, the size of target and the distance to the target for pointing-and-clicking icon-like targets presented on a computer display screen significantly affect predictions based on Fitts' Law. In this research, all usability tests are based on Whisenand and Emurian's studies of human body motion.

2.3.3. Individual differences

This research intends to reveal and control the effects of the following factors as the experimental conditions for human performance study with various gesture interfaces.

In terms of the human performance model recorded in current Fitts' Law studies, the individual differences can be deemed as bias but the effects can be minimized and centrally normalized by an experiment design involving repeated measurement (Fitts, 1954, Mackenzie and Buxton, 1992, Whisenand and Emurian, 1999f). The studies of such factors as gender and age effects, were well established with conventional NKIDs, but have not yet been studied with gesture interfaces. These factors are discussed in the following, and those that are not involved in this research (e.g. cognitive science) should form the basis for further study:

(1) Gender

Recently, an argument has arisen about gender-related working injuries; Kiesler and Finholt (1988a) reported that females accounted for two-thirds of compensation cases involving repetitive strain injury (RSI) in Australia in the 1980s, and indicated that, in comparison with males, females cannot endure repetition. Wahlström *et al.* (2000f) reported that females applied higher forces to the computer mouse due to fixed button actuation forces since females tend to have smaller hands, which result in higher relative exertion levels to grip the mouse. Two years later, Woods *et al.* (2002c) stated that levels of reported musculoskeletal symptom disorders (MSDs) were more serious for females than males, especially of the upper limbs when working over a long period of time with a mouse. As a result, females involved in intense computer mouse work could be at a higher risk of experiencing fatigue and operational discomfort in the forearm than males.

In terms of HCI, the effectiveness, efficiency and satisfaction of the interaction, rely on the integration of the coordination of the visual loop, the acoustics loop and the haptic loop between a user and a computer (Burdea, 2000a). A human's ability to interact with a computer depends on human perception of sensing feedback, i.e. tactilt, auditory or visual, and of the kinaesthetic feeling of motion, i.e. sensations originating in muscles, tendons and joints (Oakley *et al.*, 2000e). Therefore, gender-related difference could be discussed in terms of the following: fingers and wrists, hand and body dimensions, muscle activity and body movement.

Pertaining to fingers and wrists, their control depends on many small muscles, which can easily become fatigued, particularly during prolonged work with inadequate rest periods and poorly-designed tools (Bridger, 2003a). Regarding hand and body dimensions, Pheasant (1997d) pointed out that gender is a significant factor. In particular, Chen (2000b) summarized that a female's grip power is 45% to 67% of males' and that this highlights the effects of gender difference on pointing performance.

As for muscle activity, earlier information came from Laubach (1976), who compared nine separate studies of static and dynamic muscle strength measurements of males and females. He reported that the genders differ in strength capabilities and upper extremity strength is greatest, i.e. grip, forearm, upper arm and shoulder musculature. The upper extremity strength in females was found to be 35% to 79% of that in males, and dynamic strength in females was measured to be 59 to 84% as strong as males. In 2004, Kee (2004b) used gender-based rankings for reflecting gender differences of postural stress and discovered that the discomfort levels of female subjects for the joint motions were larger by about 28% than those of males ($p<0.01$).

Based on the above evidence, this research will discuss the gender effects on the human performance with gesture interfaces. The number of female and male participants invited for the primary studies will be nearly equal for the group comparison study.

(2) Age

According to the World Population Prospects (DESA, 2008b), the global population aged 60 or over is the fastest growing group.

Although twenty per cent of today's population is aged sixty years or over in developed countries, by 2050 that proportion is projected to be thirty-two per cent. Population aging, which is becoming a pervasive reality in developed countries, is also inevitable in the developing world and will occur faster in developing countries.

In recent studies, the age effects can indeed affect human performance with various input devices. For instance, Fisk and Rogers (1997b) stated that physical condition in perception, vision, memory and muscles all degrade as people grow old. Freudenthal (1999b) suggested that the impact on vision is the most critically degraded aspect of peoples' physical condition as they age. Liao (2002b) suggested that research into the physical impacts of an aging population must be carried out in order to understand older peoples' needs.

Furthermore, Adler (1996a) and Goodman *et al.* (2003b) emphasised that older people do use and own computers, although this decreases with age. In this regard, Pagani *et al.* (2004c) highlighted that there is a significant difference between those aged 55-64 and those aged 18-24 in terms of perceived usefulness and ease of use of the computer devices. In addition, elderly participants may not be willing to mention physical difficulties in research based upon a subjective approach Goodman *et al.* (2003b), which increases the difficulty of validating the reliability of the results.

Based on the above evidence, the participants invited for the primary study all came from the same age segment in order to minimise the age effects on both the objective measurement of human performance and the subjective assessment with various pointing devices. Thus, the sample population in this research is aged between 17 and 32 years.

In the future, this research will expand its knowledge base to design gesture interfaces that are suitable for elder computer users' needs.

(3) Mouse experience

The world's first computer mouse was invented by Dr. Douglas C. Engelbart, who proposed the theory of "augmenting human intellect" which aims to increase the capability of a man to approach a complex problem situation, to gain comprehension to suit his particular needs and to derive solutions to problems (Engelbart, 1962). Ever since, the rapid development of information technology has been influencing user's behaviour in daily life, as well as such specialised abilities as the acquisition of skills for point-and-click tasks. For instance, in the 1990s, only 4% of a studied population used a mouse and the joystick was found to be the fastest of all devices in terms of throughput and accuracy. In contrast, the mouse was the most inefficient device. (Murata, 1991b). Since then, technology has been changing rapidly; indeed the mouse was reported to be the fastest and most accurate pointing device and the joystick the slowest in 2001 (MacKenzie *et al.*, 2001a). In this regard, Ichikawa *et al.* (1999d) argued that an ordinary mouse has become a friendly, ease-to-use device only because users operate it regularly. Therefore, the mouse experience should be deemed to be the factor that most influenced human performance with gesture interfaces.

(4) Experimenters' professional knowledge of usability tests

Based on ISO 9241-9 (ISO, 2000c), the usability test and assessment should be conducted by individuals who have appropriate knowledge of usability test techniques, statistical analysis and instrumentation.

2.4. Development of the measurement platform

In order to measure human performance, the recent development of practice-based measurement platforms must be reviewed. Amongst these measurement platforms, the Generalized Fitts' Law Model Builder (GFLMB) designed by Soukoreff and MacKenzie (1995c) is one of most famous and widely used. It provides the fundamental software framework of a measurement system for the study of human performance when using a two-dimensional graphic user interface. Since the advent of GFLMB, there has been a rapid development of information technology which has driven the design of the measurement platform to consider many aspects, for instance: the compatibility of the hardware drivers of various innovative pointing devices and the capability of various operating systems, e.g. Microsoft, Sun, Apple and Linux. Furthermore, the design of the GUI platform also requires the capability of exporting the raw data generated by the measurement system to many statistical analysis packages (Schedlbauer and Heines, 2007h). Also, based on the above reviewed literature, an innovative measurement platform should also be capable of recording real-time, complex, cursor movement distances and sub-movement times as well as the possibility of integration with a data server for mass data-processing. Therefore, a graphic-based measurement platform was designed and validated in an earlier study (Chen and Chen, 2008a) as described in Chapter 3.

2.5. Subjective assessment

In addition to post-task interviews, thinking-aloud and focus groups, subjective questionnaires are commonly used to measure various usability attributes such as user satisfaction, users' interest, attitudes, perceived usefulness and ease-of-use (Lee *et al*, 2006d). In this study, a five-point scale questionnaire with an open-ended comment section was used to collect the end-user's opinions and satisfaction with the design and the user experience (i.e. the higher the score, the greater the satisfaction), and the fatigue level in the body regions (i.e. the higher the score, the greater the fatigue), based on ISO 9241-9 (ISO, 2000c) and Woods *et al.* (2003d), described as follows:

- The participants will be requested to provide background information (e.g. age, preferred / dominant hand, gender, mouse experience, etc.).
- Operation: e.g. "It is obvious how to operate the device"; "The input device is easy to use".
- Performance: e.g. "This input device responds as I'd expect". "I had the right level of control over what I wanted to do".
- Design: e.g. "The design of the device prevents inadvertent button actuation", "The shape of the device is satisfactory".
- Comfort: e.g. "The input device can be operated without undue deviations of the wrist from a neutral posture", "The input device does not cause pressure points that lead to discomfort during use".

2.6. Direct observation

According to ISO 9241-9 (ISO, 2000c), direct observation is the perception or notation of specific characteristics of the input device by one or more independent observers. Direct observation typically results in a binary decision (such as Yes or No). This decision depends on observation of the presence or absence of a feature. This research employs either the digital camera for capturing the steady posture or a digital video recorder (DV) to record the complex body movements, depending on the complexity and the range of the working area associated with the specific type of gesture interface.

Chapter 3: Design of the Graphical Measurement Platform

3.1. Introduction

In 1995, Generalized Fitts' Law Model Builder (GFLMB) designed by Soukoreff and MacKenzie (1995c) is one of most famous and widely used tool to collect the objective human performance with non-keyboard input devices (NKIDs). It provides the fundamental software framework of a graphical measurement system for the study of human performance when using a graphic user interface (GUI). However, there has been a rapid development of information technology which has driven the design of the measurement platform to consider the compatibility of the hardware drivers of various NKIDs on the operating systems (OS). Furthermore, the design of the platform should be capable to explore the raw data for statistical analysis (Schedlbauer and Heines, 2007h).

In this research, Fitts' law is expanded into two-dimensional description in a polar coordinate system with gesture interfaces. Since the cursor movement is the only outcome of the gesture interfaces, a "poorly designed" gesture interface might reflect the device that generates the discrete cursor movement on the screen, and that might impact on both human performance and the subjective feelings about the device design and the discomfort in the particular body regions. Therefore, a new accuracy measure of the cursor movement distance D_e is proposed to provide an explanation of the cursor movement behavior, and a Five-point Likert scale questionnaire is conducted to gather associated subjective feelings.

To sum up, this chapter aims to firstly design a graphical measurement platform for the data gathering of the conventional human performance measures and D_e, secondly to validate the platform and the new model ID_{e2} based on a within-subject repeated measurement experiment with thirty-six participants with the ordinary mouse, and finally to validate the internal consistence of the subjective questionnaire. Based on the result analysis, a design implementation will also be recommended for the design innovation upon the ordinary mouse as future study.

3.2. Software Design: Fitts' Law Generator (FLG)

According to the background information in the Chapter 2, the following software requirement should be considered for the design of a novel graphical measurement platform[10]:

- Based on the international standard ISO 9241-9 (ISO, 2000c);
- Configurability of the independent variables associated with two-dimensional (2D) target condition, i.e. the target width W, the target distance D, and the angle of approaches;
- Data collection of the dependent variables, i.e. the approaching time AT (ms), the pointing time PT (ms), the error rate (%), and the target-re-entrance rate TRE (%) and the cursor movement distance D_e;
- Raw data can be exported for statistical analysis
- Allowing further integration to management information system (MIS).

Figure 37 presents the software architecture. The software consists of the client(s) and server. On the server site, the system allows data store, data analysis and information

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[10] The proposed system has been published (Chen and Chen, 2008a), as following:

Chen, R. C. C. and Chen, T.-K. (2008a) The effect of gender-related difference on human-centred performance using a Mass Assessment Method. *Journal of Computer Applications in Technology (IJCAT)(SCI),* 32**,** pp. 322-333.

sharing among departments in a company. The server is based on the use of PHP, MySQL and Apache server.

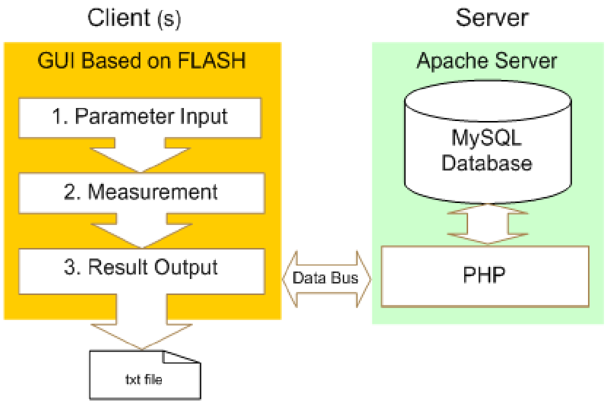


Figure.37 Software architecture of the FLG
(Source: Chen and Chen, 2008a)

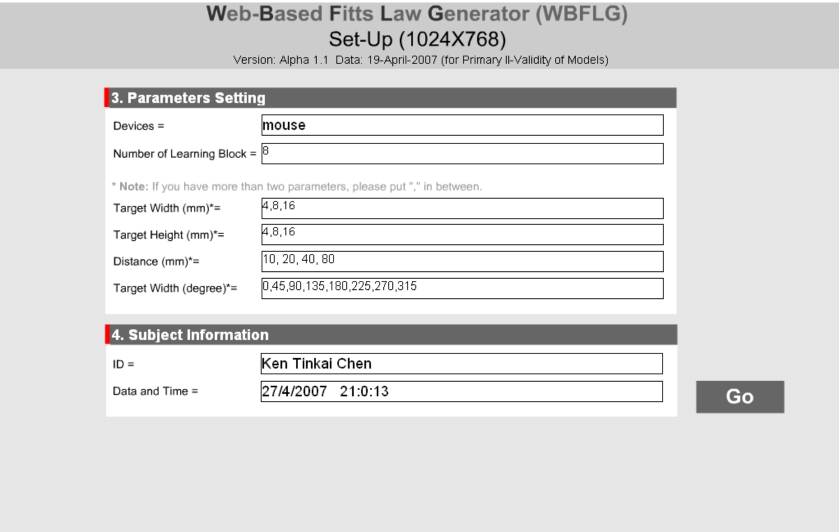
As for the client (s), a graphical user interface (GUI) was designed using FLASH and Action Script 2.0, namely Fitts' Law Generator (FLG) in this research (Chen and Chen, 2008a). It consists of the following three elements:

(1) Parameter Input Unit

As can be seen in Figure 38, participant's background information can be inputted and target conditions used to generate target stimulus can be setup, i.e. target width/height, target distance and angle of approach, and number of learning blocks, shown in Table 6:

Table.6 Target conditions

Dependent Factors
Target width (*W*) (mm)
Target distance (*D*) (mm)
Angle of approaches
Number of learning block



Web-Based Fitts Law Generator (WBFLG)
Set-Up (1024X768)
Version: Alpha 1.1 Data: 19-April-2007 (for Primary II-Validity of Models)

3. Parameters Setting

Devices = mouse
Number of Learning Block = 8

* **Note:** If you have more than two parameters, please put "," in between.

Target Width (mm)*= 4,8,16
Target Height (mm)*= 4,8,16
Distance (mm)*= 10, 20, 40, 80
Target Width (degree)*= 0,45,90,135,180,225,270,315

4. Subject Information

ID = Ken Tinkai Chen
Data and Time = 27/4/2007 21:0:13

Figure.38 Parameter Input Unit of FLG
(Source: Chen and Chen, 2008a)

(2) Measurement Unit

The system randomly generates a permanent blue square target and a red square target of varying target conditions for each trial, as illustrated in Figure 39. In order to prevent finger/wrist fatigue, the system informs the subject to take a one minute break between learning blocks throughout the measurement process. A beep sounded if the button was clicked while the cursor was outside of the target. Moreover, the system records variables such as movement time *MT*, approaching time *AT*, pointing time *PT*, cursor movement distance *De*, *Error*, Target Re-Entry *TRE*, and *x* and *y* coordinates of cursor movement:

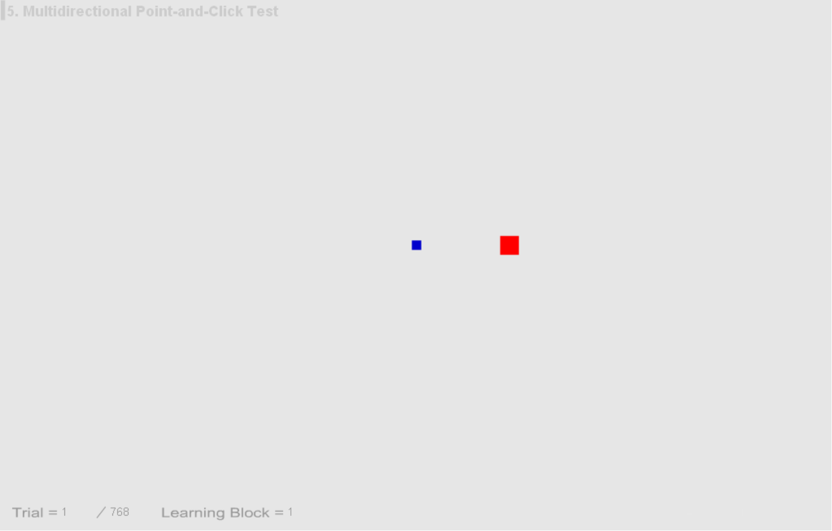
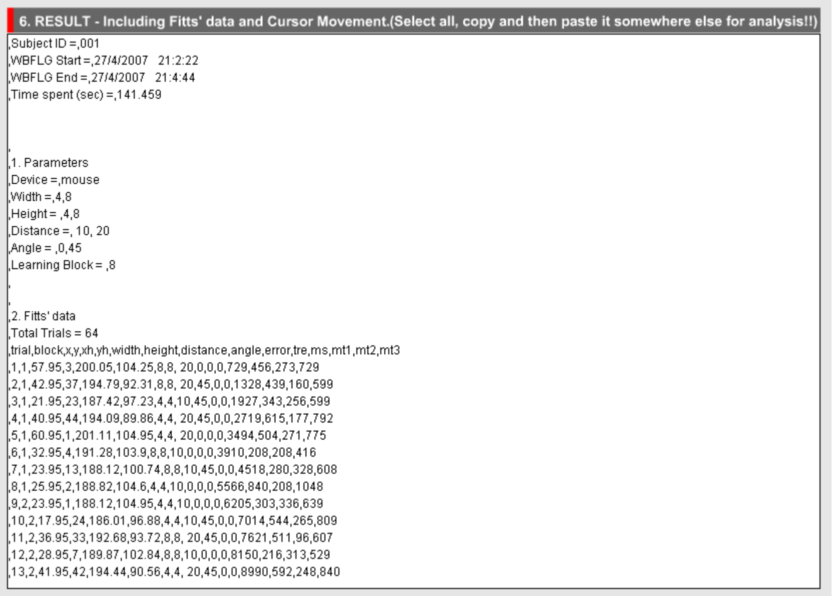


Figure.39 Measurement Unit of FLG
(Source: Chen and Chen, 2008a)

(3) Result Output Unit

As shown in Figure 40, the raw data in txt format is generated at the end of the experiment, and that is transferred to the server for the data storage and data analysis.



```
,Subject ID =,001
,WBFLG Start =,27/4/2007   21:2:22
,WBFLG End =,27/4/2007   21:4:44
,Time spent (sec) =,141.459



,
,1. Parameters
,Device =,mouse
,Width =,4,8
,Height = ,4,8
,Distance =, 10, 20
,Angle = ,0,45
,Learning Block = ,8
,
,
,2. Fitts' data
,Total Trials = 64
,trial,block,x,y,xh,yh,width,height,distance,angle,error,tre,ms,mt1,mt2,mt3
,1,1,57.95,3,200.05,104.25,8,8, 20,0,0,0,729,456,273,729
,2,1,42.95,37,194.79,92.31,8,8, 20,45,0,0,1328,439,160,599
,3,1,21.95,23,187.42,97.23,4,4,10,45,0,0,1927,343,256,599
,4,1,40.95,44,194.09,89.86,4,4, 20,45,0,0,2719,615,177,792
,5,1,60.95,1,201.11,104.95,4,4, 20,0,0,0,3494,504,271,775
,6,1,32.95,4,191.28,103.9,8,8,10,0,0,0,3910,208,208,416
,7,1,23.95,13,188.12,100.74,8,8,10,45,0,0,4518,280,328,608
,8,1,25.95,2,188.82,104.6,4,4,10,0,0,0,5566,840,208,1048
,9,2,23.95,1,188.12,104.95,4,4,10,0,0,0,6205,303,336,639
,10,2,17.95,24,186.01,96.88,4,4,10,45,0,0,7014,544,265,809
,11,2,36.95,33,192.68,93.72,8,8, 20,45,0,0,7621,511,96,607
,12,2,28.95,7,189.87,102.84,8,8,10,0,0,0,8150,216,313,529
,13,2,41.95,42,194.44,90.56,4,4, 20,45,0,0,8990,592,248,840
```

Figure.40 Measurement Unit of FLG
(Source: Chen and Chen, 2008a)

3.3. Hypothesis

H1: If the cursor movement continuous on the 2D GUI with the ordinary mouse, the movement time *MT* across the new model ID_{e2} is more predictable than across the conventional models (i.e. *ID* and ID_e);

H2: The effects of the target conditions (i.e. the target weight *W*, the target distance D and the angle of approaches) on the movement time *MT* are significant with the mouse ($p<0.01$);

H3: The effect of gender on human performance is significant with the mouse ($p<0.05$);

H4: The effect of the number of years using the mouse on human performance is significant ($p<0.05$).

3.4. Trial protocol

3.4.1. Subject selection

A total of thirty-six Chinese and Taiwanese students in Art & Design Faculty and in School of Computing volunteered. The participants consisted of fourteen males, i.e. age range from 19 to 33 years, and twenty-two females, i.e. age range from 19 to 32 years. The average weekly PC usage reported by females was 60.45 hours per week, and by males was 59.86. All participants used their preferred right hand to perform the tasks and reported over 6 years' experience with PCs. None of the participants reported uncorrected visual problems or physical limitations that would inhibit their use of the mouse as an input device.

3.3.2. Testing apparatus

The laboratory used for the experiment is a computer laboratory in Room 3.6 in Fletcher Building, De Montfort University. The max capability of the laboratory allows seven participants to be assessed in a single shot, shown in Figure 41a and 41b:

Figure.41a The computer laboratory Room 3.6

Figure.41b The computer laboratory Room 3.6

This experiment was conducted based on the following equipments:

- Client PC with a P4 3.0GHz CPU, 512MB of RAM;

- 19” LCD monitors;
- Standard four-button optic mouse with 800 dpi, manufactured by Microsoft®;
- The FLG software, used to generate the target stimuli and measure objective human-centred performance;
- A Five-point Likert scale questionnaire (see Appendix C), used to collect the user profile (i.e. age, gender, etc.) and subjective feeling about the device design and the discomfort in the particular body region;
- The data analysis is performed using SPSS version 13.

3.3.3. Independent variables

As shown in Table 7, the objective measurement was a $3 \times 4 \times 8$ fully within-subjects repeated measures design. The target conditions were based on Whisenand and Emurian’s study (1999f) for comparative study of fitness-of-models, which the target representation could be seen in Figure 42.

Table 7. Target condition (Ch3)

Factors/Parameters	Levels
Width/Height (mm)	4,8,16
Target distance (mm)	10, 20, 40, 80
Angle of Approach (degree)	0,45,90,135,180,225,270,315

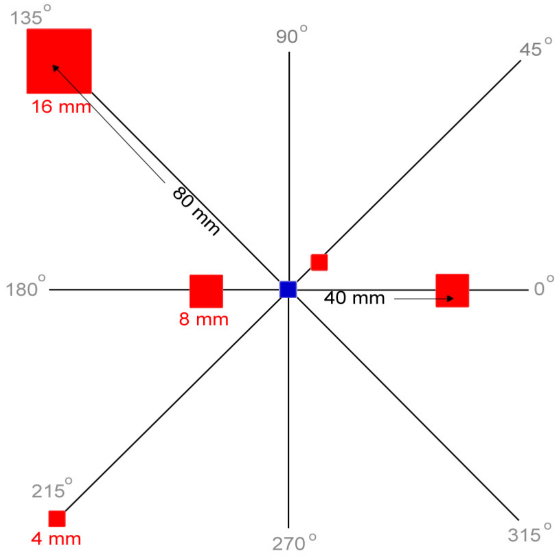


Figure.42 Targets representation on the measurement unit of the FLG software in Chapter 3

3.3.4. Dependent variables

The dependent variables consisted of the following three clusters/levels: the objective human performance, the subjective feelings about the device design and the discomfort in the particular body regions, and the user profile:

In regards to the objective human performance, these objective measures were collected by the FLG software during the experiment with the ordinary mouse, summarized in Table 8.

Table.8 Objective measures of the human performance in Chapter 3

Independent Variable	Description
error (%)	A error attempt is recorded
Target Re-Entry *TRE* (%)	When the cursor enters the target, it will be counted.
Cursor movement distance D_e (mm)	The cursor movement distance is calculated for each trial.
Approaching time *AT* (ms)	The time length between the start point and the time the cursor enters the target is measured.
Pointing Time *PT* (ms)	The time length between the time the cursor enters the target and the time a attempt is success is measured.
Movement time *MT* (ms)	$MT = AT + PT$

At each learning block, all combinations of 96 target conditions were represented in random order, followed by a one minute break section, which allows the participant to reduce finger and wrist fatigue. Eight learning blocks were administered for a total of 768 trials per participant. In total, n = 36 subjects × 96 target conditions × 8 blocks = 27,648 pairs of dependent variables were collected, i.e. approximately 22 MB of data was recorded successfully.

As for the subjective feelings, these subjective attributes were collected by using a Five-point Likert scale questionnaire (i.e. see Appendix C), shown in Table 9:

Table.9 Subjective attributes of the Five-point Likert scale subjective assessment in Chapter 3

Cluster/Level	Factor	Current studies
Design	C1:smooth C2:effort C3:accuracy C4:speed C5:comfort C6:overall	Subjective assessment for NKIDs (ISO, 2000c, 2003e)
Discomfort	C7:finger fatigue C8:wrist fatigue C9:arm fatigue C10:shoulder fatigue C11:neck fatigue C12:back fatigue C13:eye strain	

In order to reveal the effect of the interactive effect of the gender by the weekly computer usage, the user profile was also collected, including age, gender (female/male), user handedness (i.e. preferred domain right hand or left hand), and experience in using a ordinary mouse (year).

3.3.5. Standard Operation Procedure (SOP)

A standard operation procedure (SOP), shown in Figure 43, is developed using a checklist to allow each participant to follow the same procedure during the experiment, which could help in reducing process bias during the experiment and to ensure reliability of the study.

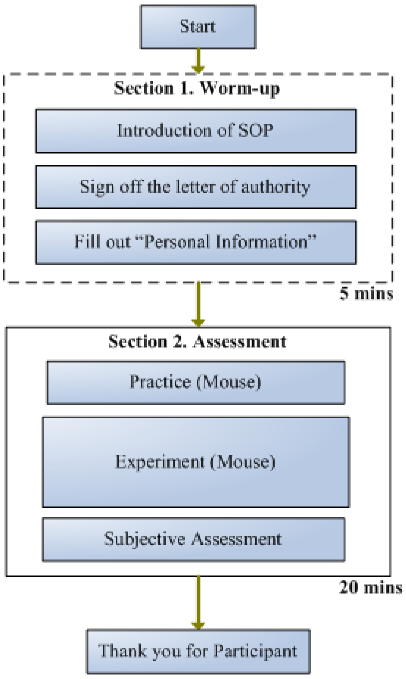


Figure.43 Standard Operation Procedure (SOP) in Chapter 3

There were two sections in the experiment: In the section 1 of the SOP, the experimenter introduced the SOP to participants and demonstrated each task to familiarize the participants with the task and the laboratory environment. After that, participants were asked to sign off a letter of authority to make commitment to the experiment. Participants were then interviewed and filled out 'personal information' to gather demographic data, i.e. age, gender, preferred hand, and visual and physical limitations, and experiential data such as computer experience and weekly computer usage.

In the section 2 of the SOP, participants were allowed to practice based on a mouse for 96 trials, i.e. a learning block. After the practice, participants were instructed to perform each task “as accurately as possible and as fast as possible” before the experiment (Zhar *et al.*, 2004f). During the experiment in the section 2, The FLG software randomly generated red target stimulus; a diagrammatic representation of several red square targets, displayed at different amplitudes from the measurement page of the FLG: participants made simple point-and-click between a permanent blue square target and a red square target of varying target conditions. A beep sounded if the button was clicked while the cursor was outside of the target. The FLG recorded the angle of approach, target width, amplitude, x and y coordinates of start point and end pointing, MT, AT, PT, $Error$, TRE in about 170 Hz, and D_e in about 50 Hz. At the end of the experiment, each subject was asked to fill out a Five-point Likert scale questionnaire.

3.5. Result Analysis

3.5.1 Data Adjustment

According to Whisenand and Emurian (1999f), an error occurred when a participant registered a target acquisition while the cursor was out side the target. However, the FLG software continued to measure variables, i.e. movement time, cursor movement distance, and it stopped only upon successful acquisition of the target. Therefore, error cases are analyzed separately. A total of 1,370 errors occurred out of 27,648 total trials. The mean *MT* for all trials is 719 ms, and the removal of the error trials reduces the mean *MT* to 692 ms.

3.5.2. Fitness-of-models (*H1* test)

> *H1: If the cursor movement is continue on the 2D GUI with the ordinary mouse, the movement time MT across the new model* ID_{e2} *is more predictable than across the conventional models (i.e. ID and* ID_e*);*

First of all, the basic ID_e model in Eq. (5) is applied to the adjusted data as a baseline for the fitness-of-models test. As can be seen in Figure 44, the regression analysis obtains an adjusted $R^2 = 0.572$ to the prediction of the movement time across ID_e. Therefore, our study is consistent with current studies done by Whisenand and Emurian (1999f) who reported an adjusted $R^2 = 0.44$.

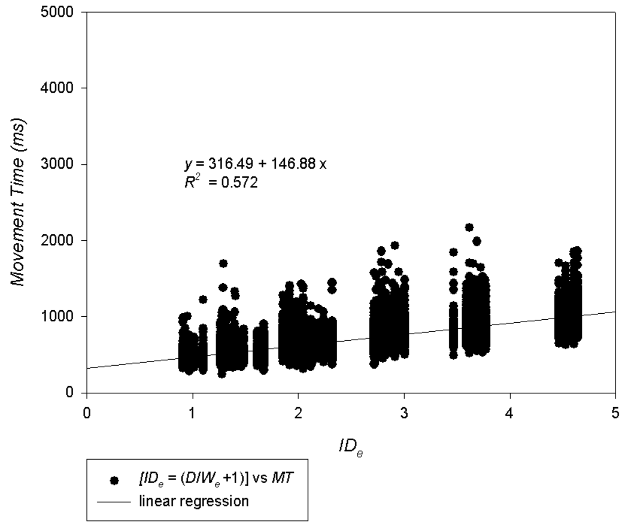


Figure.44 Linear regression *MT* vs ID_e

Moreover, the regression analysis is also applied based on the proposed new model ID_{e2} model in Eq. (7). As can be seen in Figure 45, the regression analysis indicates an adjusted $R^2 = 0.638$ to the prediction of movement time across ID_{e2}.

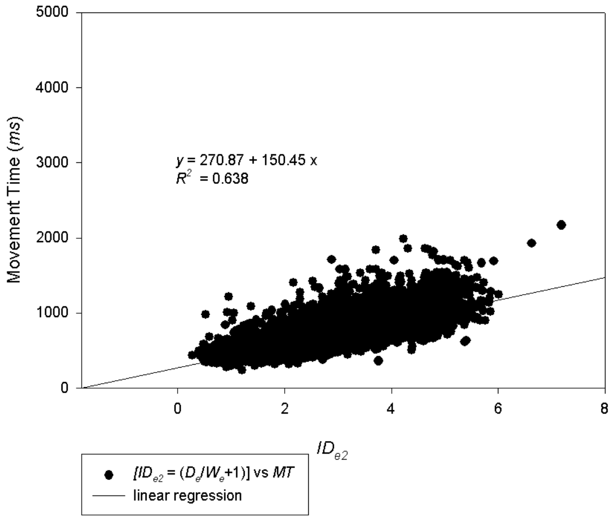


Figure.45 Linear regression *MT* vs ID_{e2}

Thus, the *H1* is accepted since the new model ID_{e2} obtains a higher prediction rate than the conventional models. In addition, an adjusted $R^2 = 0.97$ is also discovered for the prediction of mean of the movement time using Eq. (5). It is also consistent with current finding that of Thompson *et al.* (2004e) who reported a value of 0.942 and that of Whisenand and Emurian (1999f) who found a value of 0.97.

3.5.3. Target condition (H2 test)

> *H2: The effects of the target conditions (i.e. the target weight W, the target distance D and the angle of approaches) on the movement time MT are significant with the mouse (p<0.01);*

With reference to the target conditions, the analysis of variance shows significant effects on the movement time of target angle (F = 3.95, $p<0.01$), the target weight (F = 4496.96, $p<0.01$) and the target distance (F= 4361.26, $p<0.01$). The result is consistent with current studies (Whisenand and Emurian, 1999f; Thompson *et al.*, 2004e). Hence, the *H2* is accepted since the effects of the target condition on the movement time *MT* are significant ($p<0.01$).

3.5.4. Gender-related effect (*H3* Test)

> *H3: The effect of gender on the human performance is significant with the mouse ($p<0.05$);*

Since the females differ to the males in terms of the muscle and the hand shape, it is assumed that there is a significant effect of the gender on the human performance.

As a result, the descriptive statistic is summated in the Table 10:

Table.10 The effect of the gender on the human performance with the mouse (Chapter 3)

Human Performance	Gender	n	Mean	Std. Deviation	P value
Error Rate (%)	Females	16,896	5.26%	0.24	p=0.9
	Males	10,752	5.22%	0.24	
Target Re-Entry TRE (%)*	Females	16,056	11.5%↑	0.329	p<0.01**
	Males	10,222	9.8%	0.302	
Cursor movement distance D_e (mm)*	Females	16,056	46	33	p=0.9
	Males	10,222	46	31	
Approaching time *AT* (ms)*	Females	16,056	501↑	204	p<0.01**
	Males	10,222	484	187	
Pointing time *PT* (ms)*	Females	16,056	203↑	85	p<0.01**
	Males	10,222	189	78	
Total movement time *MT* (ms)*	Females	16,056	704↑	211	p<0.01**
	Males	10,222	673	192	

* The error trials were excluded for the analysis.
** The difference between the groups is statistically significant.

Furthermore, the Independent T test is employed to examine the significance of the difference. As regards, the effect of the gender on the human performance, the Independent T test shows the following results:

- Mean *AT* for female subjects, i.e. 501 ms, is significantly shorter (p<0.01) than for male subjects, i.e. 484 ms.

- Mean *PT* for female subjects, i.e. 203 ms, is significantly shorter ($p<0.01$) than for male subjects, i.e. 189 ms.
- Mean *MT* for female subjects, 704 ms, is significantly shorter ($p<0.01$) than for male subjects, 673 ms.
- No significant difference of the gender is found on Mean D_e p= 0.9.
- No significant difference of the gender is found on *error rate*, p= 0.9.

Based on the result analysis, there are two conclusions could be made: firstly the *error rate* and the cursor movement distance D_e are robust with no significant influenced by the gender. Secondly, when the female could suffer from 3.5% longer approaching time *AT*, 6.9 % longer pointing time *PT*, 4.5% longer total movement time *MT* and 14.5% higher target re-entry *TRE* than the males when using the same ordinary mouse. Hence, the hypothesis *H3* is accepted. However, the differences are very small between two groups of the participants. For instance, the difference of Mean *MT* is only 31 ms. Nevertheless, the result indicated that the FLG measurement platform is very sensitive to detect the difference among different participants in terms of the micros- structure of the human performance.

3.5.5. Number of years using the mouse (*H4* Test)

H4: The effect of the years using the mouse on the human performance is significant with the mouse ($p<0.05$);

The motor skill gained from practising is positively proportion to the time spent on it. Thus, initially, it is assumed that an individual using the mouse for many years will perform better than a person who has used the mouse for a shorter period. However, the human performance might be impacted by a working-injury, Repetitive Stress Injury (RSI), around the wrist. Whether the number of years using the mouse could increase the chance of developing RSI in the wrist and whether that in turn impacts on the human performance, has not yet been studied. In fact, the Health and Safety Executive (HSE) has funded a two-year study by researchers at the University of Surrey and Loughborough University in the U.K. (Woods *et al.*, 2002c) to examine possible health risks of various computer input devices such as mice, touch screens and joysticks. The researchers specifically analyzed the health effects of non-keyboard devices as well as generating new approaches to their design and use. It was claimed that, although studies have been conducted on the effects of working with computers, little research has been done on some of the recently developed alternative methods of inputting information and their effects on health. Therefore, this analysis aims to reveal the relation between the motor skill gained from using the mouse, i.e. previous mouse-using experience in years, and human performance with the mouse.

Thus, the participants were divided into two groups in terms of the previous mouse using experience (years):

- Mature mouse users, i.e. the mean previous mouse-using experience of females is 13 years and of males is 12 years;
- Learner mouse users, i.e. the mean previous mouse-using experience of females is 10 years and of males is 8 years.

The descriptive statistics demonstrate the difference between the mature mouse users and the learner mouse users in terms of the human performance, (see the summary in the Table 11).

Table.11 The effect of the previous mouse experience on the human performance with the mouse (Chapter 3)

Human Performance	Previous mouse experience group***	n	Mean****	Std. Deviation	P value
Error Rate (%)	Mature mouse users	13,824	5.10%	0.23	p=0.321
	Learning mouse users	13,824	5.38%	0.24	
Target Re-Entry TRE (%)*	Mature mouse users	13,157	11.31%↑	0.32	P<0.01
	Learning mouse users	13,121	10.42%	0.31	
Cursor movement distance D_e (mm)*	Mature mouse users	13,157	46	32	p=0.389
	Learning mouse users	13,121	46	32	
Approaching time AT (ms)*	Mature mouse users	13,157	507↑	207	P<0.01
	Learning mouse users	13,121	482	187	
Pointing time PT (ms)*	Mature mouse users	13,157	208↑	88	P<0.01
	Learning mouse users	13,121	187	75	
Total movement time MT (ms)*	Mature mouse users	13,157	715↑	214	P<0.01
	Learning mouse users	13,121	670	192	

* The error trials were excluded for the analysis.

** The difference between the devices is statistically significant.

*** Mature mouse users are those who have previous mouse experience >=11 years; and the Learning mouse users are those who have previous mouse experience <11 years.

**** The red arrow ↑ denotes the group having a poorer performance than another.

As regards the effect of the previous mouse experience on human performance, the Independent T test shows the following results:

- Target Re-Entry TRE for the mature mouse user group, 11.31%, is significantly greater (p<0.01) than for the learner user group, 10.42% (p<0.01).
- Mean AT for the mature mouse user group, 507 ms, is significantly longer (p<0.01) than for the learner user group, 482 ms.
- Mean PT for the mature mouse user group, 208 ms, is significantly longer (p<0.01) than for the learner user group, 187 ms.
- Mean MT for the mature mouse user group, 715 ms, is significantly longer (p<0.01) than for the learner user group, 670 ms.
- No significant difference is found on Mean D_e between the groups (p= 0.389).

- No significant difference is found on *error rate* between the groups (p= 0.321).

Based on the results analysis, there are two conclusions that can be made: firstly the *error rate* and the *cursor movement distance* D_e are robust with no significant influence from the number of years using the mouse. Secondly, when the participants have used the mouse for over 11 years, he/she could suffer from 5% longer approaching time *AT*, 10.9% longer pointing time *PT*, 6.7% longer total movement time *MT* and 8.6% higher target re-entry *TRE* than those who have used the mouse less than 11 years. Therefore, the hypothesis *H4* is accepted. However, the differences are very small between two groups, for instance, the difference of Mean *MT* is only 45 ms. Nevertheless, the result indicates that the FLG measurement platform is very sensitive and can detect differences between participants in terms of the micro-structure of their performance.

3.5.6. Subjective assessment

The inter-reliability test is applied on the subjective raw data giving a Cronbach's Alpha = 0.715 on the cluster of the device design and Cronbach's Alpha = 0.612 on the cluster of the discomfort in the particular body regions.

In addition, the Mann-Whitney U test indicates that the device design and the operational discomfort of female subjects are not significantly different from those of male subjects ($p>0.05$). Moreover, both female and male subjects highlight particular discomfort to the eye - a score of 3.86.

3.6. Discussion

3.6.1. Validity of the study

Based on the use of the FLG software, the study has achieved an adjusted $R^2 = 0.638$ to the prediction of the movement time MT across ID_{e2} with the ordinary mouse, which is better than for the current studies. The result highlights the validity of the FLG software and the associated new model $ID_{e2.}$

Based on the result analysis, the hypothesis $H1$ is accepted, which validates that when the cursor movement is continuous on the 2D GUI with the ordinary mouse, the movement time MT across the new model ID_{e2} is more predictable than across the conventional models (i.e. ID and ID_e). Moreover, the hypothesis $H2$ is also accepted, which validates that the effects of the target conditions (i.e. the target weight W, the target distance D and the angle of approach) on the movement time MT are significant ($p<0.01$). Therefore, it is likely that the new model ID_{e2} could be a better explanation of a natural human body motion involved in a participant’s behaviour when the cursor movement is continuous. Furthermore, the hypotheses $H3$ and $H4$ reveal that the cursor movement distance D_e is a robust evaluator which is not significantly influenced ($p \doteqdot 1$) by either the gender or the years spent using the mouse. It could be the major reason to explain why the new model ID_{e2} achieves a better prediction rate, adjusted R^2, for the prediction of the movement time across the total movement time, *MT*, than the conventional models *ID* and *IDe* with the mouse. Furthermore, the result indicated that the FLG measurement platform is very sensitive and able to detect the differences among different participants in terms of the microstructure of their performance. Therefore, the FLG software is recommended for the study of human performance with various types of Non-Keyboard Input Devices (NKIDs).

3.6.2. Design Implementation with the ordinary mouse

Based on the results analysis, the hypothesis *H3* is accepted, which validates that there is a significant effect of gender on human performance. In this regard, the female could suffer from a 3.5% longer approaching time *AT*, a 6.9% longer pointing time *PT*, a 4.5% longer total movement time *MT* and a 14.5% higher target re-entry *TRE* than the males when using the same ordinary mouse. It might be that females apply higher forces to the computer mouse than do male subjects, owing to the fixed button actuation forces. In particular, the result of the subject assessment indicates that females might not satisfy with operational effort than males.

Furthermore, the more years using the mouse, the poorer the performance a participant tends to have. This highlights that the mature mouse user group who have over approximately nine years experience in using the mouse have a greater risk of experiencing a work-related injury. Although the differences are small, this study has highlighted a potential opportunity for future study of a design innovation involving the ordinary mouse. This should focus on the design factors that require further investigation when designing an alternative mouse, especially for female subjects and the mature user group, since they can be expected to gain the greatest benefit from such innovation.

(1) Position sensing

Since embedded system and sensor technology have been developed rapidly, the signal sensitivity of a pointing device can enable the system to differentiate between the user's commands and involuntary tremor. Thus, it is suggested that developer shall pay attention to low-cost sensors and "off the shelf" embedded system that could provide the conditions for the introduction of alternative human-computer interaction techniques in the domestic market.

(2) Button actuation

Since the level of force required to operate NKID may be a factor affecting pain or discomfort, the force of button should be comfortable, while offering a degree of resistance and feedback to the user. Moreover, it is recommended to find out the substitute of conventional mechanism type of button without losing sense of force feedback for alternative human-computer interaction techniques.

(3) Display/control (D/C) Gain

It is one of most widely used parameters to improve human performance on two-dimensional GUI. However, there is no standard at present for D/C gain. Hence, there is research opportunity towards it.

(4) Size and Shape of pointing device and of button(s)

Because female computer users have smaller hands, which results in higher relative exertion levels to grip the mouse. This could be a design opportunity for an ergonomic mouse.

Chapter 4: Sweep-based gesture interface

4.1. Introduction[11]

In this chapter, one of sweep-based gesture interfaces will be investigated, namely an existing, commercial gesture interface known as the ‘P5 Glove’, which is based on computer-vision technology. As can been seen in Figure 46, the P5 Glove consists of two pieces of hardware: the receiver with two digital cameras inside and the glove with seven IR-LED markers on it. The glove can be worn on the hand and the receiver needs to be placed on the desk. The positioning approach used by the P5 Glove is based on the receiver sampling the seven IR-LED markers in order to calculate the position and orientation of the arm movement being used to generate the cursor movement on the screen.

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[11] The result findings produced from this chapter are published in the followings:

Chen, T. K., Chen, C. C. and Yang, H. J. (2007c) Ethic Issue on Gender Difference in Pointing Performance. *in Proceeding of the ETHICOMP Working Conference*, Yunnan University, Kunming, China, pp. 85-91.

Chen, C. C., Chu, C. C., Yang, H. J. and Chen, T. K. (2007b) Possible Design Failures of Body-based Multimodal Interaction. *in Proceeding of 2007 SIWN International Conference on Complex Open Distributed Systems (CODS’2007),* 22-24 July 2007, Chengdu, China, The Systemics and Informatics World Network, pp. 288-291.

Chen, C. C., Chen, T. K., Yang, H. J. and Hsu, H. W. (2007a) A Systematic Evaluation Approach for Study of Human Performance of Body-based Interfaces. *in Proceeding of the 2007 Symposium on Digital Life Technologies-Building a Safe, Secured and Sound (3S) Living Environment*, Tainan, Taiwan R.O.C., pp. 212-217.

The receiver with two digital cameras inside

Glove with seven IR-LED markers

Figure.46 The hardware interface of the P5 Glove consists of the receiver and the glove
(Source: Alliance Distributor, 2006a)

Based on the product development case study of the P5 Glove (NASD, 2007g), the original manufacturer, Essential Reality, Inc, launched production lines for the P5 Glove in 2002. In November 2004, the company changed its name to Alliance Distributors Holding Inc. During this period of time, the unit price of a P5 Glove had been falling from approximately $140 until it was on sale for $30 on EBay in 2006. Despite this disaster, there were more than 1,000 members still discussing the uses of this device in the P5 Glove Community on Yahoo (see Figure 47).

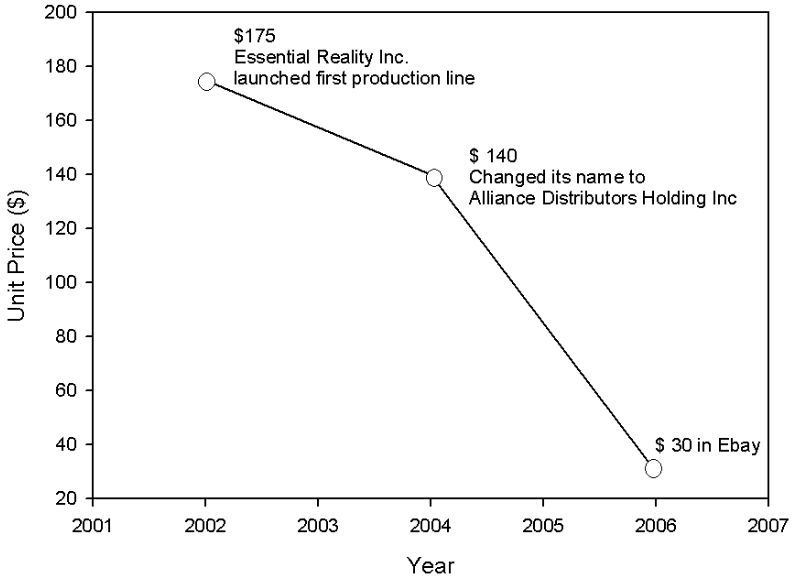

Figure.47 The unit price of the P5 Glove had fallen from
the original 175 U.S.D. to 30 U.S.D.
(The data source: NASD, 2007g)

In order to answer the research questions, a systematic evaluation approach is proposed, as shown in Figure 48:

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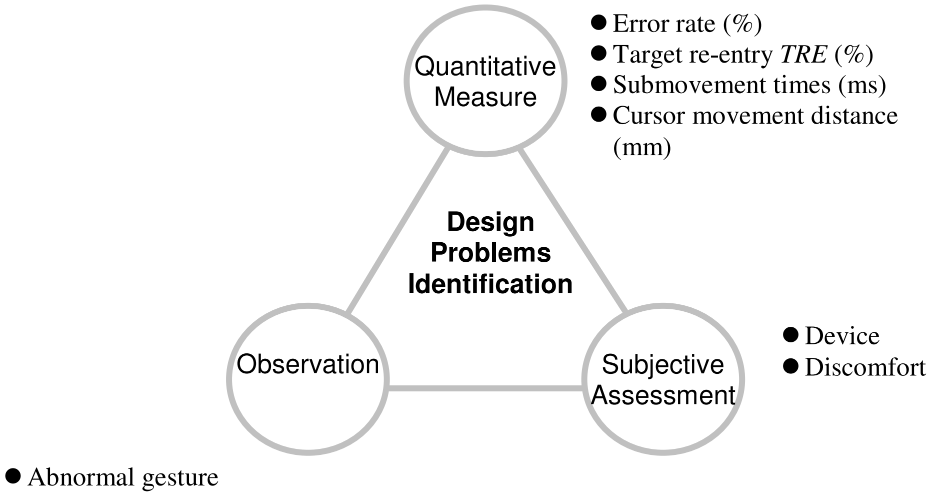

Figure.48 The triangulation strategy of the user-centred
design methodology

This approach uses a triangulation strategy based on the integration of three methodologies, i.e. quantitative measurement, subjective assessment and observation. The quantitative measurement employs a testing tool based on ISO 9241 for measurement of the human performance of non-keyboard input devices (ISO, 2000c). Furthermore, the observation, via post-task video analysis of participants' body posture, also allows the further analysis of abnormal postures and the related causes. Moreover, subjective assessment is also used to assess the device and operational discomfort.

Based on the systematic evaluation approach, it is possible to identify the possible causes and effects on human performance using the following procedures:

- Based on the result analysis obtained by the quantitative measurement, it is possible to identify effects of target conditions and device differences on complex, body-based, human performance.
- Based on the result analysis obtained from the subjective assessment, it is possible to explain effects and causes at a surface level.
- Based on the result analysis for the observation, it is possible to identify users' abnormal postures and their causes on an empirical basis.
- By gathering together the identified causes and effects, it is possible to draw up a problem causality list for further study.

Therefore, this chapter aims to investigate an existing sweep-based gesture interface namely the "P5 Glove" by using a repeat-measured experiment for the study of the design problems that lead to the discrete cursor movement and associated effects on human performance and the fitness-of-models test based on the proposed systematic evaluation approach with ten participants.

4.2. Hypothesis

H1: The movement time MT across the new models (i.e. ID, ID_e and ID_{e2}) is unpredictable with the P5 Glove (adjusted $R^2 \fallingdotseq 0$), but is predictable with the mouse (adjusted $R^2 > 0.2$),

H2: The human performance with the P5 Glove is significantly lower than of the mouse ($P<0.01$),

H3: The effect of gender on human performance is not significant with the P5 Glove ($p>0.05$),

H4: The effect of the years using a mouse on human performance is not significant with the P5 Glove ($p>0.05$).

4.3. Trial Protocol

4.3.1. Subject Selection

Law and Vanderheiden (2000d) suggested that it is possible to run fewer subjects to reduce costs of usability testing of mainstream product based on previous researches. In their study, 80% of usability problems were found by the first 5 or 6 subjects. Therefore, ten participants are considered to be invited for this exploration study.

A total of ten Taiwanese Postgraduate students in Art & Design Faculty volunteered. The participants consisted of five males, i.e. age range from 24 to 28 years, and five females, i.e. age range from 23 to 30 years. All participants used their preferred right hand to perform the tasks, and reported over 6 years' experience with PCs. The average weekly pc usage reported was approximately 60.3 hours per week. None of the participants reported uncorrected visual problems or physical limitations that would inhibit their use of the mouse as an input device.

4.3.2. Testing apparatus

The laboratory used for the experiment is a computer laboratory in Room 3.6 in Fletcher Building, De Montfort University. The max capability of the laboratory allows seven participants to be assessed in a single shot, shown in Figure 49:

Figure.49 Workshop in Room 3.1, Fletcher building, De Montfort University

This experiment was conducted based on the following equipments:

- Client PC with a P4 3.0GHz CPU, 512MB of RAM;
- 17" CRT monitors;
- A standard two-button optic mouse with 800 dpi, manufactured by Logitech®;
- The FLG software, used to generate the target stimuli and measure objective human-centred performance;
- A Five-point Likert scale questionnaire (see Appendix C), used to collect the user profile (i.e. age, gender, etc.) and subjective feeling about the device design and the discomfort in the particular body region;
- A digital Video (DV) to record participants' performance during the experiment, shown in Figure xxx.
- The data analysis is performed using SPSS version 13.

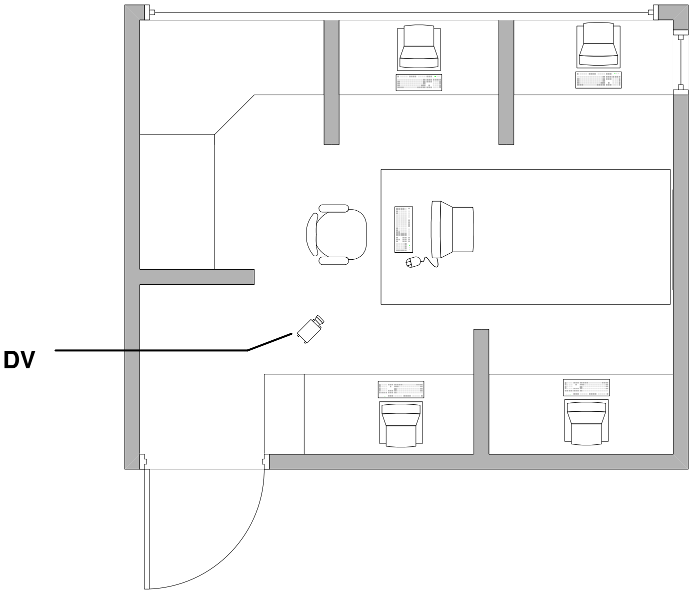

Figure.50 The placement of the digital video recorder (DV) in Room 3.1, Fletcher building, De Montfort University

4.3.3. Independent variables

As shown in Table 12, the objective measurement was a 3 × 2 × 8 fully within-subjects repeated measures design. The target conditions were based on Whisenand and Emurian's study (1999f) with larger target width in order to reduce the task difficulty for novel participants with the P5 Glove[12]. The target representation could be seen in Figure 51.

Table 12. Target condition used in Chapter 4

Factors/Parameters	Levels
Width/Height (mm)	15, 30, 45
Target distance (mm)	45, 90
Angle of Approach (degree)	0,45,90,135,180,225,270,315

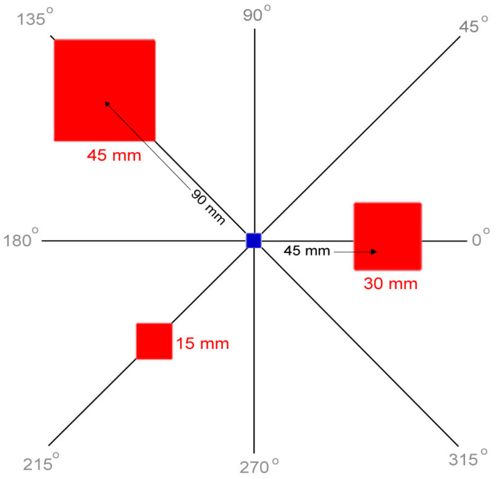

Figure.51 Targets Representation on the measurement unit of the FLG software in Chapter 4

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[12] According to the international standard ISO 9241-9 (ISO, 2000c) the appropriate length of time take for a user test should within 15 min. If the target width is too small, it increase the time length which might not be desired by participants, as well. Therefore, it decided to reduce the target width and further reduced the learning block in the following sessions, that needs to consider the participant's discomfort as top priority, rather than gathering data only.

4.3.4. Dependent variables

The dependent variables consisted of the following three clusters: the objective human performance, the subjective feelings about the device design and the discomfort in the particular body regions, and the user profile:

In regards to the objective human performance, these objective measures were collected by the FLG software during the experiment with the mouse, summarized in Table 13.

Table.13 Objective measures of the human performance

Independent Variable	Description
error (%)	A error attempt is recorded
Target Re-Entry *TRE* (%)	When the cursor enters the target, it will be counted.
Cursor movement distance D_e (mm)	The cursor movement distance is calculated for each trial.
Approaching time *AT* (ms)	The time length between the start point and the time the cursor enters the target is measured.
Pointing Time *PT* (ms)	The time length between the time the cursor enters the target and the time an attempt is success is measured.
Movement time *MT* (ms)	$MT = AT + PT$

At each learning block, all combinations of 48 target conditions were represented in random order, followed by a one minute break section, which allows the participant to reduce finger and wrist fatigue. Eight learning blocks were administered for a total of 768 trials per participant. Totally, there were n = 10 subjects × 2 devices × 8 blocks × 48 target conditions = 7,680 pairs of dependent variables being observed by a measurement platform Fitts' Law Generator (FLG) designed in the previous session.

As for the subjective feelings, these subjective attributes were collected by using a Five-point Likert scale questionnaire, shown in Table 14:

Table.14 Subjective attributes of the Five-point Likert scale subjective assessment (Chapter 4)

Cluster/Level	Factor	Current studies
Design	C1:smooth C2:effort C3:accuracy C4:speed C5:comfort C6:overall	Subjective assessment for NKIDs (ISO, 2000c, Woods *et al.*, 2003e)
Discomfort	C7:finger fatigue C8:wrist fatigue C9:arm fatigue C10:shoulder fatigue C11:neck fatigue C12:back fatigue C13:eye strain	

As for the user profile, in order to reveal the effect of the interactive effect of the gender by the weekly computer usage, the user's background information are collected, including age, gender (female/male), user handedness (i.e. preferred domain right hand or left hand), experience in using a mouse (year) and the weekly computer usage (month).

4.3.5. Standard Operation Procedure (SOP)

A standard operation procedure (SOP), shown in Figure 52, is developed using a checklist to allow each participant to follow the same procedure during the experiment, which could help in reducing process bias during the experiment and to ensure reliability of the study.

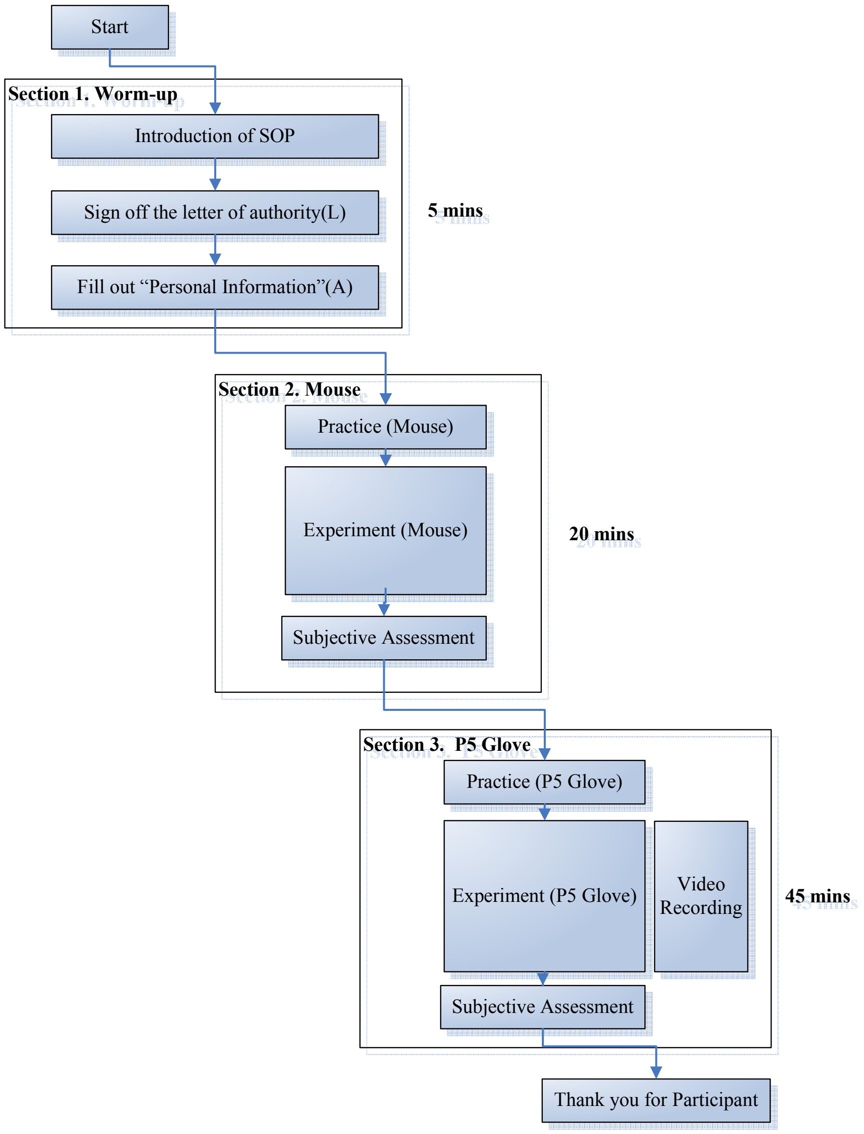

Figure.52 Standard Operation Procedure (SOP) in Chapter 4

There were three sections in the experiment: In the section 1, the experimenter introduced the SOP to participants and demonstrated each task to familiarize the participants with the task and the laboratory environment. After that, participants were asked to sign off a letter of authority to make commitment to the experiment. Participants were then interviewed and filled out 'personal information' to gather demographic data, i.e. age, gender, preferred hand, and visual and physical limitations, and experiential data such as computer experience and weekly computer usage.

In the section 2 of the SOP, participants were allowed to practice based on a mouse for 96 trials, i.e. a learning block. After the practice, participants were instructed to perform each task "as accurately as possible and as fast as possible" before the experiment (Zhai *et al.*, 2004f). During the experiment, the FLG software randomly generated red target stimulus; a diagrammatic representation of several red square targets, displayed at different amplitudes from the measurement page of the FLG: participants made simple point-and-click between a permanent blue square target and a red square target of varying target conditions. A beep sounded if the button was clicked while the cursor was outside of the target. The FLG recorded the angle of approach, target width, amplitude, x and y coordinates of start point and end pointing, MT, AT, PT, $Error$, TRE in about 170 Hz, and D_e in about 50 Hz. At the end of the experiment, each subject was asked to fill out a Five-point Likert scale questionnaire.

In the section 3, the same procedure will be repeated with the P5 Glove. 10 min break is allowed between sections. The time taken to complete these three section is 1 hour, approximately.

With regards to research limitation, since the experiment requested participants to operate pointing devices repetitively during a short period of time, the degree of tiredness depending on individuals' physical conditions, although a one-minute break between testing blocks had been introduced.

4.4. Result Analysis

4.4.1 Data Adjustment

According to Whisenand and Emurian (1999f), an error occurred when a participant registered a target acquisition while the cursor was out side the target. However, the FLG software continued to measure variables, i.e. movement time, cursor movement distance, and it stopped only upon successful acquisition of the target. Therefore, error cases are analyzed separately. Since there are two pointing device being tested, a total of 188 errors occurred out of 3,840 total trials with the mouse (5% error rate) and a total of 205 errors occurred out of 3,840 total trials with the mouse (5.3% error rate). As for the mouse, the mean *MT* for all trials is 612 ms, and the removal of the error trials reduces the mean *MT* to 597 ms. With regards to the P5 Glove, the mean *MT* for all trials is 1,460 ms, and the removal of the error trials reduces the mean *MT* to 1,396 ms[13].

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[13] Obviously, the mouse is two time faster than of the P5 Glove.

4.4.2. Fitness-of-models (*H1* Test)

*H1: The movement time, MT, across the new models (i.e. ID, ID_e and ID_{e2}) is unpredictable with the P5 Glove (*adjusted *$R^2 \doteqdot 0$), but is predictable with the mouse (*adjusted *$R^2 > 0.2$).*

There are three indices of difficulty used for the prediction of the movement time, *MT*, these are Fitts' original formula *ID* in Eq. (2) (Fitts, 1954), the Shannon formulation (Shannon, 1949) with the revision by Mackenzie (1991a) ID_e shown in Eq. (5) and the new model proposed in this research ID_{e2} in Eq. (7).

As can be seen in Table 15, the linear regression analysis indicates the different predictions for an adjusted R^2 values across the different models (*ID*, ID_e, ID_{e2}). As for the mouse, there is a linear relation between the movement time *MT* and three models (adjusted R^2=0.31). However, for the P5 Glove, there is no linear relation between the movement time *MT* and three models (adjusted R^2=0.06). Thus, the hypothesis *H1* is accepted. Since the experimental conditions are the same with both devices, there is a serious usability problem with the P5 Glove, which requires further explanation from the subjective assessment and the observation on the body movement with the P5 Glove.

Table.15 The prediction of the total movement time (*MT*) (ms) across models (*ID*, ID_e, ID_{e2}) (Chapter 4)

Device	N*	Models' prediction rate (adjusted R^2) **			
		ID	ID_e	ID_{e2}	Predictable?
Mouse	3,652	0.31	0.31	0.31	Yes
P5	3,635	0.06	0.06	0.06	No

* The error trials were excluded for the analysis.

** The linear regression analysis was applied on the adjusted data for the prediction of the movement time *MT* across models (*ID*, ID_e and ID_{e2}). The adjusted R^2 value was used since the sample size was difference among these studies.

4.4.3. Device difference (H2 Test)

> *H2: The human performance with the P5 Glove is significantly lower than for the mouse (P<0.01).*

Since the study employed the mouse as the base line, it is possible to compare the difference between the P5 Glove and the mouse. The hypothesis *H2* is based on the fact that the participants did not have previous experience in using the tilt-based gesture interfaces, at the same time, they have 6+ previous experiences in using the mouse. Therefore, it can be expected that the human performance with the P5 Glove will be slower than with the mouse in terms of skill acquisition.

As can be seen in Table 16, the descriptive statistics indicate that the total movement time of the mouse (597 ± 159 ms) is two-times faster than for the P5 Glove (1,396 ± 1,176 ms). In terms of the standard deviation, the working model V2 is more stable than the P5 Glove and the working model V2, since it had less than 45% of standard deviation of both devices. Generally speaking, the participants suffered from significantly higher target re-entry *TRE* (p<0.01), longer cursor movement distance D_e (p<0.01), longer approaching time *AT* (p<0.01), longer pointing time *PT* (p<0.01) and longer total movement time *MT* (p =0.84) with the P5 Glove than with the mouse. Furthermore, the huge *S.D.* is caused by the gesture interfaces. For instance, a smaller *S.D.* is produced with the ordinary mouse by the same sample population. Similar results are also obtained by the current study with a novel remote pointing device (Hsu *et al.*, 1999c). It is one of the reasons which causes the absence of a linear relation between the movement time *MT* and three models with the P5 Glove (Chen *et al.*, 2007a, 2007b).

Table.16 The effect of the device difference (mouse and P5 Glove) on the human performance based on the Independent T test on the adjusted data (Chapter 4)

Human Performance	Device	n*	Mean	Std. Deviation	P value (2-tailed Sig.)
Error Rate (%)	Mouse	3,840	5.1%	0.2	p=0.96
	P5 Glove	3,840	6.0%↑	0.3	
Target Re-Entry TRE (%)	Mouse	3,652	5.8%	0.2	p<0.01**
	P5 Glove	3,635	18.3%↑	0.5	
Cursor movement distance D_e (mm)	Mouse	3,652	78	31	p<0.01**
	P5 Glove	3,635	118↑	161	
Approaching time AT (ms)	Mouse	3,652	419	146	p<0.01**
	P5 Glove	3,635	1,113↑	1,151	
Pointing time PT (ms)	Mouse	3,652	173	72	p<0.01**
	P5 Glove	3,635	278↑	150	
Total movement time MT (ms)	Mouse	3,652	597	159	p<0.01**
	P5 Glove	3,635	1,396↑	1,176	

* The error trials were excluded for the analysis.

** The difference between the devices is statistically significant.

*** The red arrow↑ denotes the device having a poorer performance than another.

4.4.4. Gender-related effect (*H3* Test)

H3: The effect of the gender on the human performance is not significant with the P5 Glove (p>0.05).

Since both females and males had no previous experience using the P5 Glove, it is assumed that there is no gender effect on human performance with the P5 Glove.

As can be seen in Table 17, the independent T test indicated that there is no significant difference in the human performance between females and males in terms of the target re-entry *TRE* (p=0.11), the cursor movement distance D_e (p=0.4), the approaching time *AT* (p=0.4), the pointing time *PT* (p=0.7) and longer total movement time *MT* (p=0.4) with the P5 Glove than with the mouse. Therefore, the hypothesis *H3* is accepted except for the error rate, i.e. the female tends to make more error attempts (*error* = 6.3%) than males (*error* = 5.7%) with a significance (p<0.05).

Table.17 The effect of gender difference on the human performance based on the Independent T test on the adjusted data (Chapter 4)

Human Performance	Gender	n	Mean	Std. Deviation	P value
Error Rate (%)	Female	1,920	6.3%	0.3	p=0.04**
	Male	1,920	5.7%	0.3	
Target Re-Entry TRE (%)*	Female	1,811	19.5%	0.5	p=0.11
	Male	1,824	17.1%	0.5	
Cursor movement distance D_e (mm)*	Female	1,811	116	141	p=0.4
	Male	1,824	120	178	
Approaching time *AT* (ms)*	Female	1,811	1098	1,085	p=0.4
	Male	1,824	1129	1,214	
Pointing time *PT* (ms)*	Female	1,811	278	145	p=0.7
	Male	1,824	279	155	
Total movement time *MT* (ms)*	Female	1,811	1380	1,108	p=0.4
	Male	1,824	1412	1,241	

* The error trials were excluded for the analysis.
** The difference between the groups is statistically significant.

It is likely that there are no gender effects on human performance with sweep-based gesture interfaces like the P5 Glove except that females tend to make more error attempts than males. However, these are the short-term, lab-based tests which might require a long-term investigation to definitively confirm the presence or absence of any gender effects.

4.4.5. Number of years using the mouse (*H4* Test)

> *H4: The effect of the years using the mouse on the human performance is not significant with the P5 Glove ($p>0.05$).*

One of the research questions is whether the previous motor skill with the mouse could contribute to the human performance with either the sweep-based or/and tilt-based gesture interfaces. The motor skill gained from practising with the mouse is based on the tilt movement of the wrist movement, which differs for the P5 Glove, which involves a more complex sweeping movement of the arm. Therefore, it is assumed that the motor skill to use the mouse will not contribute to the human performance with the P5 Glove.

Hence, participants were divided into two groups for the study of the effect of the long-term mouse experience on human performance with the P5 Glove:

- Learning mouse users, i.e. mouse experience less than 9 year: The average age is 26 ± 3 years; the mean experience is 7 ± 1 years.
- Mature mouse users, i.e. Mouse experience 9 plus: the average age is 26 ± 1 years; the mean experience is 10 ± 0.3 years.

As a result, the descriptive statistics reveal the difference between the groups in terms of human performance, as summarised in Table 18:

Table.18 The effect of the mouse experience on the human performance based on the Independent T test on the adjusted data (Chapter 4)

Human Performance	Mouse Experience**	n	Mean	Std. Deviation	P value
Error Rate (%)	Mature mouse users	2,304	5.8%	0.3	0.536
	Learning mouse users	1,536	6.3%	0.3	
Target Re-Entry TRE (%)*	Mature mouse users	2,186	18.8%	0.5	0.383
	Learning mouse users	1,449	17.5%	0.4	
Cursor movement distance D_e (mm)*	Mature mouse users	2,186	117	164	0.914
	Learning mouse users	1,449	118	155	
Approaching time *AT* (ms)*	Mature mouse users	2,186	1,115	1,087	0.904
	Learning mouse users	1,449	1,110	1,242	
Pointing time *PT* (ms)*	Mature mouse users	2,186	280	156	0.509
	Learning mouse users	1,449	276	141	
Total movement time *MT* (ms)*	Mature mouse users	2,186	1,399	1,116	0.840
	Learning mouse users	1,449	1,391	1,262	

* The error trials were excluded for the analysis.

** Mature mouse users are those who have previous mouse experience >=9 years; and the Learning mouse users are those who have previous mouse experience <9 years.

The Independent T test indicates that there is no significant effect of the mouse experience on the *error rate* (p =0.5), target re-entry rate *TRE* (p=0.4), cursor movement distance D_e (p=0.9), approaching time *AT* (p =0.9), pointing time *PT* (p =0.51) and the total movement time *MT* (p =0.84). Thus, hypothesis H4 is accepted. It can therefore be concluded that the motor skill gained by using the mouse does not contribute to the human performance with the P5 Glove, as well as with other types of sweep-based gesture interface.

4.4.6. Subjective assessment

The inter-reliability test is applied on the subjective raw data which gives Cronbach's Alpha = 0.6 for the mouse and 0.74 for the P5 Glove on the device design cluster and Cronbach's Alpha = 0.4 for the mouse and -0.6 for the P5 Glove on the discomfort in the particular body regions cluster. Therefore, this session only discusses the subjective assessment of the device design since this is the only result that achieved an acceptable reliability[14].

As can be seen in Table 19, the Mann-Whitney U test indicates that overall operation performance of the P5 Glove, i.e. a mean score of 2.2, is significantly lower than that of the mouse, i.e. a mean score of 3.4, $p < 0.01$.

Table.19 The effect of the device difference (mouse and P5 Glove) on the subjective feelings based on the I Mann-Whitney U test on the raw data of the subjective assessment (Chapter 4)

Subjective feeling	N	Device		P value (2-tailed Sig.)
		Mouse	P5 Glove	
C1: Operation Smoothness	10	3.2	2.1	0.02*
C2: Operation Effort	10	3.6	2.4	0.01*
C3: Accuracy	10	3.5	2.2	0.00*
C4: Operation Speed	10	3.4	2	0.00*
C5: General Comfort	10	3.2	2.2	0.01*
C6: Overall Operation	10	3.4	2.2	0.00*
C7: Finger fatigue	10	3.4	3.2	0.63
C8: Wrist fatigue	10	2.5	2.8	0.58
C9: Arm fatigue	10	2.8	1.9	0.12
C10: Shoulder fatigue	10	2.8	2.1	0.05
C11: Neck fatigue	10	3	3.1	0.91
C12: Back fatigue	10	3.7	3.1	0.17
C13: Eye Strain	10	2.7	3.2	0.39

* The difference between the devices is statistically significant.

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[14] The low internal consistency might indicate the differences among individuals have significantly biased the result. Increasing the number of participants might solve this problem by normalising the bias.

4.4.7. Direct observation

Since there were greater sub-movement times, higher target re-entry, *TRE*, longer cursor movement distance, D_e and a poor subjective feeling about the design with P5 Glove in comparison with the mouse, the related problem causality could only be revealed by the observation of the users' movement pattern during the experiment.

Since the participants' complex body movement of the upper limb has been recorded by the digital video recorder (DV), it is possible to identify the abnormal movement with a subjective explanation about the movement pattern and possible usability problems by an analysis of these video clips after the experiment. First of all, a total of 202 nodes are identified as having an abnormal movement pattern. After that, by summing the nodes having the same descriptor in terms of the abnormal movement pattern, 54% of these abnormal movements were identified as 'User raises right arm or even stands up during the experiment', followed by 'User shakes right hand' (37%), 'User changes sitting position and/or arm support to better position' (3%), etc., as shown in Table 20.

Table.20 Abnormal movement (n = 202) (Chapter 4)

Code	Abnormal Postures/Activities (descriptor)	count	%
A	Raising right arm to change operational approach because the sensor is out of sensory range.	110	54%
B	Shaking right hand to change operational approach because the user cannot control cursor on the screen.	74	37%
F	Changing sitting position to a better position.	7	3%
D	Finger button press serial times because it cannot activate the click activity.	6	3%
G	Switch off and on the glove to centre the cursor position. Attempted to apply different approach to centre the cursor position.	3	1%
C	Arrange the cable since it causes problems for controlling the cursor movement.	1	0.5%
E	Glove does not fit the hand dimensions.	1	0.5%
	Sum	202	100%

By further analysis of these 202 nodes, the possible design problems that might lead to the abnormal movement could be identified, as summarized in Table 21.

Table.21 The abnormal movement and associate possible problem that lead to the abnormal movement (Chapter 4)

Abnormal movement		Associated usability problems		Count (Node)	Count (%)
Code	Description (with sub-code)	Code	Description (with sub-code)		
A	A: raising right arm to change operational approach because the sensor is out of sensory range.	P1	Sensors are out of range	26	13%
	A1: raising right arm and body to change operational approach because the sensor is out of sensory range.	P1	Sensors are out of range	15	7%
	A2: raising right arm and body to change operational approach because the sensor is higher than the tower.	P2	Sensors are higher than the receiver	6	3%
	A3: raising right arm to change operational approach because the sensor is higher than the tower.	P2	Sensors are higher than the receiver	34	17%
	A4: raising right arm to change operational approach because the sensor is lower than the tower.	P3	Sensors are lower than the receiver	11	5%
	A5: raising right arm to change operational approach to right hand side of the tower because the sensor is out of range.	P4	Sensors are out of range at right hand side of the receiver	18	9%
B	B: shaking right hand to change operational approach because the user cannot control cursor on the screen.	P5	Unknown reason that causes out of control of cursor position	24	12%
	B1: shaking right hand to change operational approach because the sensor is higher than the tower.	P2	Sensors are higher than the receiver	13	6%
	B2: shaking right hand to change operational approach because the sensor is out of sensory range.	P1	Sensors are out of range	17	8%
	B4: shaking right hand to change operational approach because the sensor is too close to the tower.	P6	Sensors are out of range and higher than the receiver	6	3%
	B5: shaking right hand to change operational approach because the sensor is lower than the tower.	P7	Sensors are too close to the receiver	3	1%
	B: shaking right hand to change operational approach because the user cannot control cursor on the screen.	P3	Sensors are lower than the receiver	11	5%
C	C: arrange the cable since it causes problems for controlling the cursor movement.	P8	The cable causes problem to control cursor position	1	0%
D	D: finger button press serial times because it cannot activate the click activity.	P9	Finger button can not activate the click activity.	6	3%
E	E1: glove does not fit the hand dimensions.	P10	Glove do not fit to hand dimension	1	0%
F	F1: move the arm support to a better position.	P11	Move the arm support to better position	3	1%
	F2: changing sitting position to a better position.	P12	Changing sitting position to better position	2	1%
	F3: Changing sitting position and arm support to a better position.	P13	Changing sitting position and arm support to better position	2	1%
G	G1: Switch off and on the glove to centre the cursor position. Attempted to apply different approach to centre the cursor position.	P14	Switch off and on the glove to centre the cursor position	2	1%
	G2: Move back forward and forward to centre the cursor position.	P15	Move back forward and forward to centre the cursor position	1	0%
Sum				202	100%

Moreover, according to Table 22, 28.7% of the problem causality results from ‘Out of sensor range - The LED lights attached to the hand seem to be far away from the sensor range’, followed by ‘The LED lights attached on the hand are over than the top of the receiver’ (26.2%) and ‘Unknown reason that causes an out-of-control cursor position’ (11.9%), etc. Interestingly, the finger buttons and the cable have little connection with the problem causality.

Table.22 Possible Problem Causality (n = 202)(Chapter 4)

Code	Problem Description	count	%
P1	Sensors are out of range	58	28.7%
P2	Sensors are higher than receivers	53	26.2%
P5	Unknown reason that causes out of control of cursor position	24	11.9%
P3	Sensors are lower than receivers	22	10.9%
P4	Sensors are out of range at right hand side of receivers	18	8.9%
P6	Sensors are out of range and higher than receivers	6	3.0%
P9	Finger button can not activate the click activity.	6	3.0%
P7	Sensors are too close to receivers	3	1.5%
P11	Move the arm support to better position	3	1.5%
P14	Switch off and on the glove to centre the cursor position	3	1.5%
P12	Changing sitting position to better position	2	1.0%
P13	Changing sitting position and arm support to better position	2	1.0%
P8	The cable causes problem to control cursor position	1	0.5%
P10	Glove do not fit to hand dimension	1	0.5%
	Sum	202	100%

Based on the observation, users tend to change operational approaches in order to take control of a cursor position, especially when the target’s angles of approach appear on the top of the screen, i.e. 45^o, 90^o and 130^o. This is because the receiver that is fixed on the desk cannot reach the LED lights attached to the hand and the hand’s position changes on a real-time basis in three-dimensional space. This situation could get worse and worse since the user unconsciously changes operational approaches even when the target conditions are not related to the upper angles of an approach. Therefore, a longer cursor movement distance is most likely to be created.

4.5. Discussion

4.5.1. Fitness-of-models

The hypothesis *H1* is accepted, which further proves that the models (ID, ID_e, ID_{e2}) can be used to identify the devices having the discrete cursor movement on the screen. However, the main causes of the discrete cursor movement still required the observation and subjective assessment to offer an explanation associated with the design factors.

4.5.2. Usability problems with the sweep-based gesture interfaces

In this research, whether the discrete visual feedback could lead to the abnormal movement lengthening the difference between the planned working area and the actual working area and that this consequently impacts on both human performance and subjective feelings, has been answered by the results of the following hypotheses tests.

Firstly, the hypothesis test *H1* indicated that the models (i.e. ID, ID_e, ID_{e2}) become unpredictable with the P5 Glove (i.e. adjusted $R^2 \doteqdot 0$) whilst at the same time being predictable with the mouse (i.e. adjusted R^2=0.31). Since the experimental conditions are the same with both devices, it is logically assumed that there is something wrong with the P5 Glove.

Secondly, the hypothesis test *H2* revealed that the P5 Glove has poorer human performance than the mouse in terms of higher target-re-entry (*TRE*), longer cursor movement distance and longer sub-movement time. It further states that there is something wrong with the P5 Glove and leads to three assumptions about the poor human performance with the P5 Glove: (1) the mouse experience might not contribute to the human performance with the sweep-based gesture interfaces in general; (2) the cursor movement with the P5 Glove might be caused by both the arm trembling and the usability problems associated with visual feedback of the cursor movement on the screen; (3)

although the pointing time *PT* differs between devices significantly, the difference is very small, i.e. 78 ms only, which indicates there is a potential to innovate the flex finger button in the future.

Thirdly, as for gender effects on human performance with the sweep-based interfaces, the hypothesis *H3* indicates that there is no significant difference between the human performances of females and males. Along with the result of hypothesis *H4,* which postulates that the motor skill with the mouse cannot contribute to the human performance with the sweep-based gesture interfaces, it is likely to conclude that the both female and male participants require more time to be spent on training with the sweep-based gesture interfaces for point-and-click tasks in order to improve their performance.

Fourthly, the subjective assessment discovered that the participants subjectively feel significantly more discomfort in the arm and the shoulder with the P5 Glove than with the mouse. It is likely that the sweeping movement style relies on the repetitive movement in the arm and the shoulder, which can contribute to the development of discomfort in these particular body regions.

Finally, the observation of the movement pattern identifies the fact that the one of most critical design problems causing the discrete cursor movement on the screen derives from the fact that the markers on the hand can easily move out of the optical visual zone (OVZ) of the receiver for the P5 Glove on the desk. The discomfort development accumulates in the arm and the shoulder owning to the participants unconsciously changing their movement strategy in order to take control of the discrete cursor movement on the screen[15].

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[15] The participant eventually takes control of the cursor movement on the screen with the P5 Glove only because the experiment requires him/her to do so, thus the participant took a longer time and more effort to do this than with the mouse.

To sum up, these results reveal that participants tend to adopt different movement strategies in order to take control of the cursor movement with the sweep-based interfaces. This is because the receiver of the P5 Glove fixed on the desk cannot reach the markers (i.e. seven LED lights) attached on the hand. This situation could worsen since users unconsciously change their movement strategy when the cursor disappears and reappears irregularly so that the cursor movement cannot properly map to a participant's intention and their physical movement. Consequently, the discrete visual feedback of the cursor movement, the so called 'discrete cursor movement', impacts on the human performance with the P5 Glove.

In addition, whether the discrete cursor movement with the sweep-based gesture interface could contribute to the discomfort development in particular body regions might need further study in the future since the subjective assessment of the discomfort gained very low scores for internal consistency.

4.5.3. Design Implementation

Based on the result analysis, the study suggests that the sweep-based gesture interface is greatly affected by the limited working area resulting from its being restricted to the optical visual zone (OVZ) of the camera. In turn that causes the discreet visual cursor movement on the screen. This usability problem forces participants frequently to adopt unusual and abnormal arm movements. Other disadvantages include greater arm and shoulder fatigue, longer cursor movement distance and longer movement time in comparison with the mouse. Based on the result analysis, the study suggests the following design implementation for further study with the sweep-based gesture interface:

- A computer-vision tracker should consider a new solution to predict the transmitter's position and expand the sensor range in order to solve the major design failure of the sensor system. Alternatively, add-on features used to centralize the cursor position might be considered when the signal sensor is out of range.

- A flexible finger sensor may possibly have an advantage in terms of the same operational discomfort as the mouse, which should be further investigated in a different direction.
- The effect of the shape and material of the body-based multimodal interface on the gender difference should be considered since men differ from women in their hand dimensions.
- The proposed mixed-method combining the use of observation of the body movement, quantitative measurement of human performance and subjective assessment, is essential to design research into body-based multimodal interaction. However, a future study will need to employ advanced ergonomic techniques, such as 3D, passive, optical, motion-capture systems, might offer an objective explanation for the abnormal movement associated with complex sweep-based gesture interfaces.
- There are still various interactive effects among the design factors affecting the usability of the sweep-based gesture interface which require further investigation, such as the button participants, the shape of the glove, etc.
- Long-term learning effects on the human performance with the sweep-base gesture interface requires further study.
- Based on the result, the sweep-based gesture interface might not be suitable for the point-and-click task, but it might have some benefits for active game play and rehabilitation since it requires arm and shoulder movement.

Chapter 5: Design and Evaluation of the Tilt-Based Gesture Interfaces (Working Model V1)

5.1. Introduction[16]

In this section, the focus of the study is to investigate the critical design factors and associated usability problems with another type of gesture interface, namely the tilt-based gesture interface, using the inertial sensor technology. Its concept differs from the sweep-based gesture interfaces in terms of the narrow working area and the requirement for smaller joint ROMs since only the wrist movement is used in comparison with the sweep-based gesture interaction, which uses a broader working area and the complex joint movement of the arm.

However, there is no tilt-based gesture interface on the market at the current point in time. Furthermore, none of the current researchers and the international standards offer the product requirement and specification for the design and evaluation of the tilt-based gesture interfaces. Therefore, this session has the following five aims:

(1) To design a tilt-based gesture interface using the inertial sensor technology with the implementation of the tilt movement of the wrist, namely the working model V1, known simply as the V1;
(2) To identify the design problems as an iterative design process for the further improvement of the V1 in the next session
(3) To investigate the effects of the individual differences in human performance in terms of the gender and the previous motor skill using the mouse, i.e. the previous mouse experience (in years);
(4) To provide the database for the comparative study with the working model V2 and the P5 Glove (i.e. the sweep-based gesture interfaces);

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[16] Together with Chapter 6, the result findings are published in the following conference.

Wu, F. G., Chen, C. C. and Chen, T. K. (2008i) A user-centred design case study of a novel gesture-based pointing device. *CREATE 2008 on Embedding People-centred Design in the Process of Innovation*, London, U.K., Ergonomics Society HCI Group & British computer Society.

(5) To provide the database for the comparative study with the working model V2 and the P5 Glove (i.e. the sweep-based gesture interfaces);

5.1.1. Design of the working model V1

Firstly, the hardware and the software of a working model are designed in this section. As regards the hardware, it is based on the flex finger sensor of the P5 Glove and the tilt-based electronic l board attached right on the top of the Zstar (shown in Figure 53) In respect of the software, a pack of function units has been developed, including a decoding unit, noise filtering unit and the cursor emulation unit. These are designed using the C# programming language. The decoding unit and the noise filter unit are developed and verified prior to the cursor emulation unit.

Figure.53 The hardware of the working model V1 is based on the flex finger sensor of the P5 Glove and the tilt-based electronic l board attached right upon the top of the Zstar

5.1.2. The triangular strategy of the user-centred design methodology

Secondly, the user-centred design methodology needs to be implemented for the identification of the critical design problems for the future improvement as an iterative design process integrated with the next session[17]. The same systematic evaluation approach used in the previous session is employed in this session.

The structure of the approach and the quantitative measurement are the same with these used in the previous session, therefore the objective measurement of the human performance could be compared among the P5 Glove and the tilt-based gesture interfaces (i.e. two version of the working models were developed). However, since the V1 differs to the P5 Glove in terms of the movement style, the subjective assessment and the observation manner needs to be adjusted, described in the following sections:

(1) Subjective Assessment

The subjective assessment is to add on the subjective attributes from the user experience, i.e. tidy, potential, fun, usefulness, ease-of-use. Furthermore, the usability problems will be discovered by the participants' opinions written in the open-ended section of the subjective questionnaire[18]. At the end of the test, the participants will be encouraged to write down an opinion about the 'usability problems' based on their self-definition since they have no technical background.

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17. The next section is to produce the working model V2 for the comparative study based on tackling the critical usability problems revealed in this section as an iterative design process, which aims to validate and discuss the difference in usability of the tilt-based gesture interfaces with respect to having a discrete cursor movement and having a continuous cursor movement. It will be revealed that the button participant might also contribute to the development of discomfort as well as human performance. This will require further study in the future.

18. Despite the critical design factors of the specific gesture interfaces, such as the cursor emulation and the button participant, another design factor is the forearm posture. Prior to the session, the effect of both 'palm-down' and the 'hand-shank' postures had been examined with V1 of the working model in a pilot study. As a result, the pilot study indicated that the 'palm-down' posture has a significantly higher accuracy and effectiveness than the 'hand-shank' posture with the working model V1 since the users might be familiar with the motor skills required from their use of the ordinary mouse which is also based on the 'palm-down' forearm posture. However, there were few participants, i.e. five. Therefore, the effect of the forearm posture on the usability of the various types of gesture-based interface needs to be further validated with a larger number of users in the future.

(2) Open-ended Comments

First of all, the design factors identified from the reviewed literature and the previous session with the P5 Glove are listed in Table 23:

Table.23 Design factors of the gesture interfaces

P1:Manner
P2: Sensitivity
P3:Cursor emulation
P4:Initial calibration
P5:Sensor position on the hand
P6:Button actuation
P7:Shape
P8:Cable
P9:User manual
P10:Experiement design
P11:Duraction
P12:Arm rest
P13:Suggestion for future development

Based on QFD and the 20-80 ratio, the systematic evaluation procedure is proposed which aims to identify the critical design factors based on the classification and weighting of the comments (Chen and Chen, 2008a):

- Step 1: To total the number of positive comments, *Pc, and* the number of negative comments, *Nc*, for each of the product features;
- Step 2: To calculate the critical margin *Cm* = *Pc* – *Nc* for each design factor;
- Step 3: To prioritise the design factors in terms of the critical margin. In this research, the top three critical design factors will be tackled in order to produce the working model V2 and that will be evaluated in the next session.

In addition, the above systemic evaluation procedure is that it does not consider the *Isolated score* with the critical margin, i.e. *Conventional Cm* = (*Pc* – *Nc)* × *Isolated score*. The Isolated score is the weight to these design factors based on the designers' and experts' knowledge. In this session, the classification and weighting of the comments are already based on the authors' knowledge, therefore the *Isolated score* is equal to 1. However, if there are more than two experts to weight the comments, the *Isolated score* might be used to distinguish the opinions from different experts. For instance, the *Isolated score* might be ranked from 1 to 3 or higher.

(3) Observation

With respect to the observation manner, since the gesture movement is narrow and simple with the tilt movement of the wrist, the digital camera was used for the video recording via Digital Video. The steady photo of the gesture is captured and analyzed in terms of the following two joint ROMs, as shown in Figure 54:

- *θ1*: The flexion of the forearm;
- *θ2*: The flexion of the wrist;

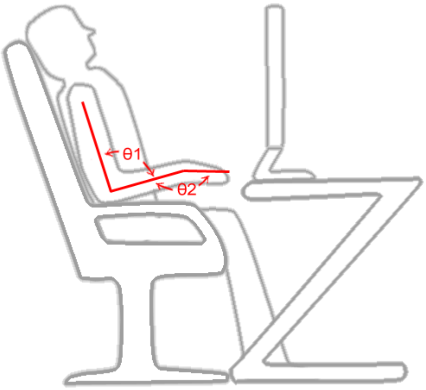

Figure.54. The elbow joint *θ1* and the wrist joint *θ2*

5.2. Hypotheses

H1: The movement time *MT* across the new models (i.e. *ID*, ID_e and ID_{e2}) is unpredictable with the working model V1 (adjusted $R^2 \doteqdot 0$), but is predictable with the mouse (adjusted $R^2 > 0.1$)

H2: The human performance with the working model V1 is significantly lower than with the mouse ($p < 0.01$);

H3: The effect of gender on human performance is significant with the working model V1 ($p < 0.05$);

H4: The effect of the years using the mouse on the human performance is not significant with the working model V1 ($p > 0.05$).

5.3. Trial protocol

5.3.1. Subject selection

A total of one-hundred Taiwanese students volunteered in Workshop in the Department of Styling & Cosmetology at Transworld University, Taiwan. The participants consisted of fifty-two females, age range from 17 to 32 years, and forty-eight males, age range from 18 to 32 years. The average weekly pc usage reported by females was 31.2 hours per week, and by males was 35.4. All participants used their preferred right hand to perform the tasks, and reported over six years' experience with PCs. None of the participants reported uncorrected visual problems or physical limitations that would inhibit their use of the input device. None of these had previous experience of using the tangible pointing device.

5.3.2. Testing apparatus

The laboratory used for the experiment is a workshop at Transworld University, shown in Figure 55:

Figure.55 Workshop in the Department of Styling & Cosmetology at Transworld University, Taiwan

This experiment was conducted based on the following equipments:

- Client PC with a P4 3.0GHz CPU, 512MB of RAM;
- 17” CRT monitors;
- A standard two-button optic mouse with 800 dpi, manufactured by Logitech®;
- The FLG software, used to generate the target stimuli and measure objective human-centred performance;
- A Five-point Likert scale questionnaire (see Appendix C);
- A digital camera used to capture the posture change during the experiment, shown in Figure 56.
- The data analysis is performed using SPSS version 13.

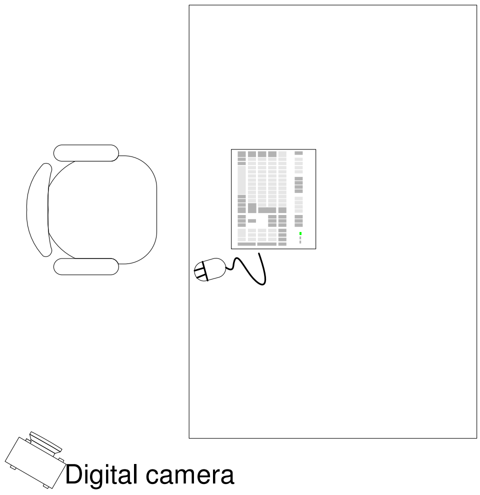

Figure.56 The placement of the digital camera in the workshop

5.3.3. Independent variables

As shown in Table 24, the objective measurement design was a 2 × 2 × 8 fully within-subjects repeated measures. The target condition is based on Whisenand and Emurian's study (1999f), which is the same as that of the previous section with the P5 Glove with the elimination of the target width W=15mm. The reason for doing so is because the target width W=15mm was too small for the novice users to click on the target during the previous session, which extended the time length for the experiment over 30 mins and might contribute to the fatigue in the specific body regions and that might consequently bias the study. By elimination of the target width W=15mm, the time length of the study can be shortened to within 15~30 mins, subjected to the individual performance. The target representation can be seen in Figure 25.

Table.25 Target condition used in Chapter 5

Factors/Parameters	Levels
Width/Height (mm)	30, 45
Target distance (mm)	45, 90
Angle of Approach (degree)	0,45,90,135,180,225,270,315

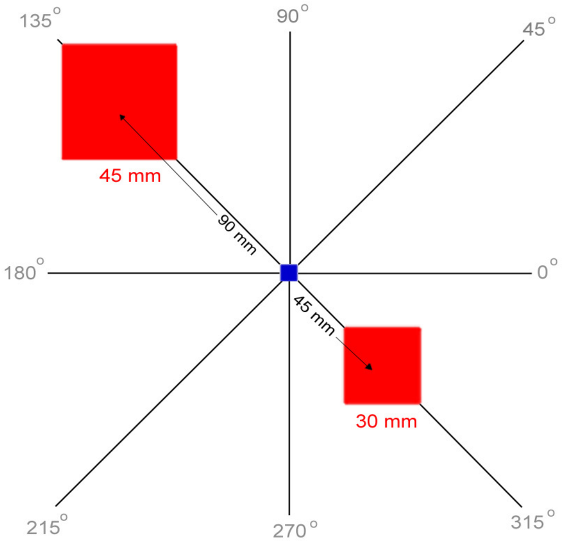

Figure.57 Targets Representation on the Measurement Unit of the FLG software with the working models V1 in Chapter 5

5.3.4. Dependent variables

The dependent variables consisted of the following three clusters: the objective human performance, the subjective feelings about the device design and the discomfort in the particular body regions, and the user profile:

In regards to the objective human performance, these objective measures were collected by the FLG software during the experiment with the mouse, summarized in Table 25.

Table.25 Objective measures of the human performance

Independent Variable	Description
error (%)	A error attempt is recorded
Target Re-Entry *TRE* (%)	When the cursor enters the target, it will be counted.
Cursor movement distance D_e (mm)	The cursor movement distance is calculated for each trial.
Approaching time *AT* (ms)	The time length between the start point and the time the cursor enters the target is measured.
Pointing Time *PT* (ms)	The time length between the time the cursor enters the target and the time a attempt is success is measured.
Movement time *MT* (ms)	$MT = AT + PT$

At each learning block, all combinations of 32 target conditions were represented in random order, followed by a one minute break section, which allows the participant to reduce finger and wrist fatigue. Three learning blocks are administered for a total of 96 trials per participant. Totally, there were n = 100 subjects × 3 blocks × 32 target conditions = 9,600 pairs of dependent variables being observed by the measurement platform Fitts' Law Generator (FLG).

As for the subjective feelings, these subjective attributes were collected by using a five-point scale questionnaire, as shown in Table 26:

Table.26 Subjective attributes of the Five-point Likert scale subjective assessment wit the working model V1

Cluster/Level	Factor	Current studies
Design	C1:smooth C2:effort C3:accuracy C4:speed C5:comfort C6:overall	Subjective assessment for NKIDs (ISO, 2000c, 2003e)
Discomfort	C7:finger fatigue C8:wrist fatigue C9:arm fatigue C10:shoulder fatigue C11:neck fatigue C12:back fatigue C13:eye strain	
User Experience	F1: Clear F2: Suitable on desktop F3: Relax F4: Tense F5: Difference F6: Fun F7: Safety F8: Ease of use F9: Usefulness F10: Potential	

As for the user profile, in order to reveal the interactive effect of the gender and weekly computer usage, the user's background information was collected, including age, gender (female/male), user handedness (i.e. preferred domain right hand or left hand) and the number of years spent on using the mouse (i.e. previous experience in using a mouse).

5.3.5. Standard Operation Procedure (SOP)

A standard operation procedure (SOP), shown in Figure 58, is developed using a checklist to allow each participant to follow the same procedure during the experiment, which could help in reducing process bias during the experiment and to ensure reliability of the study.

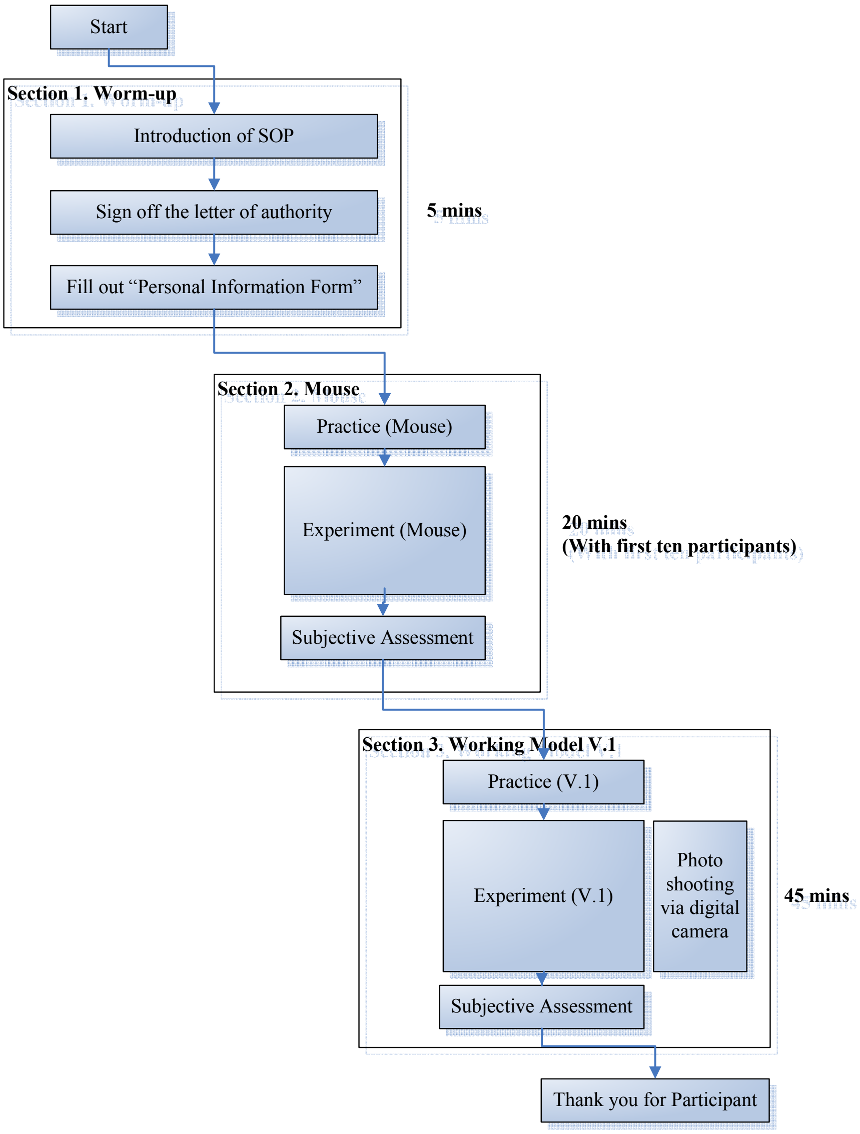

Figure.58 Standard Operation Procedure (SOP) in Chapter 5

There were three sections in the experiment: In the section 1, the experimenter introduced the SOP to participants and demonstrated each task to familiarize the participants with the task and the laboratory environment. After that, participants were asked to sign off a letter of authority to make commitment to the experiment.

Participants were then interviewed and filled out ‘personal information’ to gather demographic data, i.e. age, gender, preferred hand, and visual and physical limitations, and experiential data.

In the section 2 of the SOP, participants were allowed to practice based on a mouse for 32 trials, i.e. a learning block. After the practice, participants were instructed to perform each task “as accurately as possible and as fast as possible” before the experiment (Zhai *et al.*, 2004f). During the experiment, the FLG software randomly generated red target stimulus; a diagrammatic representation of several red square targets, displayed at different amplitudes from the measurement page of the FLG: participants made simple point-and-click between a permanent blue square target and a red square target of varying target conditions. A beep sounded if the button was clicked while the cursor was outside of the target. The FLG recorded the angle of approach, target width, amplitude, x and y coordinates of start point and end pointing, MT, AT, PT, $Error$, TRE in about 170 Hz, and D_e in about 50 Hz. At the end of the experiment, each subject was asked to fill out a Five-point Likert scale questionnaire.

In the section 3, the same procedure will be repeated with the P5 Glove. 10 min break is allowed between sections. The time taken to complete these three section is 1 hour, approximately.

With regards to research limitation, since the experiment requested participants to operate pointing devices repetitively during a short period of time, the degree of tiredness depending on individuals’ physical conditions, although a one-minute break between testing blocks had been introduced.

5.4. Result Analysis

5.4.1. Adjustment of objective data

According to Whisenand and Emurian (1999f), error cases are analyzed separately with two devices involved in this study, there are the mouse and the working model V1.

In this session, the mouse is tested with first ten participants (ID 0~10) which the result is used for the comparative study. A total of 151 errors occurred out of 3,840 total trials with the mouse (3.9% error rate). By the removal of the error trials, the total movement time *MT* reduces the mean *MT* from 579 ms to 564 ms wit the mouse. As for the study with the working model V1, a total of 986 errors occurred out of 9.600 total trials (10.3% error rate). By the removal of the error trials, the total movement time *MT* reduces the mean *MT* from 1,595 ms to 1,401 ms with the working model V1.

5.4.2. Fitness-of-models (*H1* test)

*H1: The movement time MT across the new models (i.e. ID, ID_e and ID_{e2}) is unpredictable with the V1. (*adjusted $R^2 \fallingdotseq 0$*), but is predictable with the mouse (*adjusted $R^2>0.1$*).*

As can be seen in Table 27, the linear regression analysis indicates the different predicted R^2 values across different models (*ID*, ID_e, ID_{e2}) with the mouse and the working model V1. As for the mouse, there is a linear relation between the movement time *MT* and the three models (adjusted $R^2>0.48$). However, for the V1, there is no linear relation between the movement time *MT* and the three models (adjusted $R^2=0.02$). Thus, the hypothesis *H1* is accepted. Since the experimental conditions are the same with both devices, there are indeed serious usability problems with the V1, which require further explanation from the subjective assessment and the observation of the body movement with the V1.

Table.27 The prediction of the total movement time *MT* (ms) across models (*ID*, ID_e, ID_{e2}) (Chapter 5)

Device	N*	Models' prediction rate (adjusted R^2) **			
		ID	ID_e	ID_{e2}	Predictable?
Mouse	3,689	0.48	0.49	0.49	Yes
V1	8,614	0.02	0.02	0.06	No

* The error trials were excluded for the analysis.

** The linear regression analysis was applied on the adjusted data for the prediction of the movement time *MT* across models (*ID*, ID_e, ID_{e2}). The adjusted R^2 value was used since the sample size was difference among these studies.

5.4.3. Device difference (*H2* test)

> *H2: The human performance with the working model V1 is significantly lower than with the mouse (P<0.01).*

Since the study employed the mouse as the base line, it is possible to compare the difference between the working model V1 and the mouse. The hypothesis *H2* is based on the fact that the participants did not have previous experience in using the tilt-based gesture interfaces, at the same time they have 6+ previous experiences in using the mouse. Therefore, it can be expected that the human performance with working model V1 is slower than with the mouse.

As can be seen in Table 28, the descriptive statistics indicate that the total movement time of the mouse (564 ± 134 ms) is almost four time faster than that of the working model V1 (1,963 ± 1,401 ms). Furthermore, the Independent T test is applied on the raw material to examine the significance of the difference, this indicates that participants suffered from significantly higher *error rate* ($p<0.01$), higher target re-entry *TRE* ($p<0.01$), longer approaching time *AT* ($p<0.01$), longer pointing time *PT* ($p<0.01$) and longer total movement time *MT* with the working model V1 than with the mouse. Thus, the hypothesis *H2* is accepted. Furthermore, the huge *S.D.* is caused by the gesture interfaces. For instance, a smaller *S.D.* is produced with the ordinary mouse by the same sample population (Hsu *et al.*, 1999c).

Table. 28 The effect of the device difference (mouse and V1) on the human performance based on the Independent T test on the adjusted data (Chapter 5)

Human Performance	Device	n*	Mean	Std. Deviation	P value (2-tailed Sig.)
Error Rate (%)	mouse	3,689	4.1%	0.20	<0.01
	V1	8,614	14.6%↑	0.49	
Target Re-Entry *TRE* (%)	mouse	3,689	4.3%	0.2	<0.01
	V1	8,614	12.9%↑	0.4	
Cursor movement distance D_e (mm)	mouse	3,689	128↑	116	<0.01
	V1	8,614	118	161	
Approaching time *AT* (ms)	mouse	3,689	404	124	<0.01
	V1	8,614	2,855↑	15,098	
Pointing time *PT* (ms)	mouse	3,689	155	58	<0.01
	V1	8,614	258↑	279	
Total movement time *MT* (ms)	mouse	3,689	564	134	<0.01
	V1	8,614	1,963↑	1,401	

* The error trials were excluded for the analysis.
** The difference between the devices is statistically significant.
**** The red arrow ↑ denotes the device having a poorer performance than another.

5.4.4. Gender-related effect (H3 test)

H3: The effect of gender on the human performance is significant with the working model V1 ($p<0.05$).

Since females differ from males in terms of muscle development and hand shape, it is assumed that there is a significant effect of the gender on human performance. However, although it is a matter of fact that the working model V1 has usability problems producing the discrete cursor movement, it is possible that the more sensitive and small muscles of the female hand and arm might give them an advantage over the males, thus achieving better human performance with the problem tilt-based gesture interaction. As a result, the descriptive statistics are summarised in Table 29.

Table. 29 The effect of gender on the human performance with the working model V1 (Chapter 5)

Human Performance	Gender	n	Mean	Std. Deviation	P value
Error Rate (%)	Females	4,896	13.6%↓	0.48	p <0.05**
	Males	4,704	15.6%	0.51	
Target Re-Entry TRE (%)*	Females	4,435	12.5%	0.41	p=0.47
	Males	4,179	13.2%	0.45	
Cursor movement distance D_e (mm)*	Females	4,435	124↓	113	p <0.01**
	Males	4,179	133	119	
Approaching time *AT* (ms)*	Females	4,435	1,772↓	1,372	p <0.01**
	Males	4,179	4,004	21,573	
Pointing time *PT* (ms)*	Females	4,435	261	234	p=0.33
	Males	4,179	255	320	
Total movement time *MT* (ms)*	Females	4,435	2,058	1,458	p <0.01**
	Males	4,179	1,861↓	1,330	

* The error trials were excluded for the analysis.
** The difference between the groups is statistically significant.

Furthermore, the Independent T test is employed to examine the significance of the difference. As regards the effect of the gender on human performance, the Independent T test shows the following results:

- *Error Rate* for female participants, 13.6%, is significantly lower ($p<0.05$) than for males, 15.6%.
- Mean D_e for female participants, 124 mm, is significantly shorter ($p<0.01$) than for males, 133 mm.
- Mean *AT* for female participants, i.e. 1,772 ms, is significantly shorter ($p<0.01$) than for males, 4,004 ms.

- Mean *MT* for female participants, 2,058 ms, is significantly greater ($p<0.01$) than for male subjects, 1,861 ms.
- The gender causes no significant difference on Mean *TRE,* p= 0.47.
- The gender causes no significant difference on Mean *PT*, p= 0.33.

Based on the result analysis, there are two conclusions that can be drawn: firstly, the female participants have better human performance than the males in terms of the significantly lower *error rate*, shorter cursor movement distance D_e, shorter approaching time *AT* and shorter pointing time *PT*. In particular, for the time spent on approaching the target, *AT*, the females tends to overcome the discrete cursor movement problems nearly three times faster than the males. Therefore, the hypothesis *H3* is accepted. Secondly, the mean total movement time, *MT,* for the females, is significantly longer than for the males, which reflects the fact that the conventional human performance study based on the macro-structure of the human performance could lead to a totally different conclusion. Furthermore, the result indicated that the FLG measurement platform is very sensitive and able to detect the differences among the different participants in terms of the micro-structure of the human performance.

5.4.5. Number of years using the mouse (*H4* Test)

H4: The effect of the years using the mouse on the human performance is significant with the working model V1 ($p<0.05$).

The hypothesis *H4* is based on an assumption that since the motor skill to use the mouse is based on the same wrist movement as the working model V1, then the number of years using a mouse can affect the human performance with the working model V1.

Thus, the participants were divided into two groups in terms of the previous mouse using experience (years):

- Mature mouse users, i.e. the mean number of years using the mouse for both females and males is 11 years, the average age is 26 ± 3 years;
- Learning mouse users, i.e. the mean previous mouse using experience for both females and males is 7 years, the average age is 26 ± 1 years.

As can be seen in Table 30, the descriptive statistics indicate the difference in human performance between female and male participants with the working model V1:

Table. 30 The effect of the previous mouse experience on the human performance with the working model V1, based on the Independent T test on the adjusted data (Chapter 5)

Human Performance	Previous mouse experience group***	n	Mean	Std. Deviation	P value
Error Rate (%)	Mature mouse users	6,624	13.5%↓	0.47	0.01**
	Learning mouse users	2,976	17.0%	0.54	
Target Re-Entry TRE (%)*	Mature mouse users	5,990	13.3%	0.44	0.12
	Learning mouse users	2,624	11.8%	0.42	
Cursor movement distance D_e (mm)*	Mature mouse users	5,990	132	123	0.01**
	Learning mouse users	2,624	121↓	98	
Approaching time *AT* (ms)*	Mature mouse users	5,990	1,773↓	1,452	0.01**
	Learning mouse users	2,624	5,325	27,110	
Pointing time *PT* (ms)*	Mature mouse users	5,990	255	228	0.22
	Learning mouse users	2,624	265	369	
Total movement time *MT* (ms)*	Mature mouse users	5,990	2,048	1,521	0.01**
	Learning mouse users	2,624	1,769↓	1,052	

* The error trials were excluded for the analysis.

** The difference between the devices is statistically significant.

*** Mature mouse users are those who have previous mouse experience >=11 years; and the Learning mouse users are those who have previous mouse experience <11 years.

**** The blue arrow ↓ indicates the user group having a significantly better human performance than another.

As regards the effect of the previous mouse experience on the human performance, the Independent T test shows the following results:

- *Error Rate* for the mature mouse user group, 13.5%, is significantly lower ($p<0.01$) than for the learner user group, 17.00%.
- Mean D_e for the mature mouse user group, 132 mm, is significantly longer ($p<0.01$) than for the learner user group, 12 mm.
- Mean *AT* for the mature mouse user group, 1,773 ms, is significantly shorter ($p<0.01$) than for the learner user group, 5,325 ms.
- Mean *MT* for the mature mouse user group, 2,048 ms, is significantly longer ($p<0.01$) than for the learner user group, 1,769 ms.
- No significant difference is found on Mean *TRE* between groups ($p= 0.12$).
- No significant difference is found on Mean *PT* between groups ($p= 0.22$).

Based on the result analysis, there are two conclusions that can be drawn: firstly, mature mouse users have better human performance than the learner mouse users in terms of a significantly lower *error rate*, shorter approaching time *AT* and shorter pointing time *PT*, but this might impact on the length of the cursor movement distance, D_e. Therefore, the hypothesis *H4* is accepted. Secondly, the mean total movement time, *MT,* for the mature mouse user group, is significantly longer than that of the learner user group, which reflects the fact that the conventional human performance study based on the macro-structure of the human performance could lead to a totally different conclusion. Furthermore, the result indicated that the FLG measurement platform is very sensitive and able to detect the differences among the different participants in terms of the micro-structure of the human performance.

Therefore, it is likely that the more years spent on using the mouse might contribute to the human performance with the tilt-based gesture interface, the working model V1. It is a matter of fact that both the mouse and the tilt-based gesture interface use the same wrist movement, thus the motor skill is transferable between them. This happens even if the cursor movement is discrete and the fact that the mouse is used on the 2D desk and the working model V1 is used in the air in 3D.

5.4.6. Subjective feelings about the design

Firstly, the inter-reliability test discovered that the inter-reliability of the design is very high with both the mouse (Cronbach's Alpha = 0.8) and the working model V1 (Cronbach's Alpha = 0.824), thus the result of the subjective assessment of both devices will be comparable in terms of the design. However, the inter-reliability for the discomfort with the mouse is very low, i.e. Cronbach's Alpha = 0.04, therefore the difference of the discomfort between of the mouse and the working model V1 cannot be discussed since the data is not internally consistent. The descriptive statistics of the subjective feeling about the design are summarised in Table 31:

Table.31 Selected result analysis of the Five-point Likert scale subjective assessment for the mouse and the working model V1 (Chapter 5)

Usability Classes		Working models		
Levels	Factors	Mouse (n=10)	V1. (n=100)	*P value*
Design	C1:smooth	3.2	3.1	0.57
	C2:effort	3.6	3.0	0.02*
	C3:accuracy	3.5	2.8	0.02*
	C4:speed	3.4	3.3	0.63
	C5:comfort	3.2	3.1	0.74
	C6:overall	3.4	3.2	0.66

*The improvement was significant ($p<0.05$)

Furthermore, the Mann-Whitney U test is applied on the raw data to examine the significance of the difference. As a result, it indicates that the subjective feeling about *C2: Effort* with the mouse (3.6) is more satisfied with the V1 (3), followed by the *C3: accuracy* (mouse=3.5, V1=2.8). Except for these two attributes having a significant difference, other subjective feelings about the *C1: smooth*, *C4: speed*, *C5: comfort* and *C6: overall performance*, are not significantly different between the mouse and the V1. It might be because the participants feel familiar with the mouse and the working model V1. Furthermore, lower accuracy might be caused by the discrete cursor movement on the screen which increases the difficulty when pointing at the target, thus more time is spent on the pointing activity and that impacts on the subjective feeling about the effort since more time would take more effort when applied to the same task.

5.4.7. Open-ended comments

Since there are greater sub-movement times, higher target re-entry *TRE*, longer cursor movement distance, D_e, and poor subjective feelings about the accuracy and the effort, in comparison with the mouse, the related problem causality could only be revealed by both the observation of the user's movement pattern during the experiment and by the subjective comments. Thus, these open-ended comments collected from the subjective questionnaire are weighted based on the author's knowledge. In total, 202 comments were collected from the open-comment section of the subjective questionnaire. It is possible to weight these comments in order to identify the top three critical design factors based the following systematic evaluation procedure:

(1) Step 1: Weight the comments

This aims to total the number of positive comments, *Pc and* the number of the negative comments, *Nc*, for each of the design factors; Since a comment might be associated with two or more than two sentences, these comments were broken down into 279 nodes (i.e. sentences). Acceding to the self-interpretation of the meaning of the node, each node could be related to multiple design factors, thus each related design factor will be weighted accordingly. As a result, the total number of positive comments, *Pc* and the total number of the negative comments, *Nc*, for each of the design factors, are summarised in Table 32 and Table 33.

Table 32. Positive comments (*Pc*) for the working model V1 (Chapter 5)

Design Factors	*Pc* (nodes)	*Pc* (%)	Cumulative %
P1:Manner	22	33.3%	33.3%
P13:Suggestion for future development	14	21.2%	54.5%
P2: Sensitivity	6	9.1%	63.6%
P11:Duraction	5	7.6%	71.2%
P3:Cursor emulation	4	6.1%	77.3%
P4:Initial calibration	4	6.1%	83.3%
P5:Sensor position on the hand	4	6.1%	89.4%
P7:Shape	3	4.5%	93.9%
P6:Button actuation	2	3.0%	97.0%
P10:Experiement design	2	3.0%	100.0%
P8:Cable	0	0.0%	100.0%
P9:User manual	0	0.0%	100.0%
P2:Arm rest	0	0.0%	100.0%
	66	100.0%	

Table.33 Negative comments (*Nc*) for the working model V1 (Chapter 5)

Design Factors	*Nc* (nodes)	*Nc* (%)	Cumulative %
P6:Button actuation	45	16.1%	16.1%
P1:Manner	38	13.6%	29.7%
P2:Sensitivity	35	12.5%	42.3%
P3:Cursor emulation	33	11.8%	54.1%
P11:Duraction	20	7.2%	61.3%
P7:Shape	19	6.8%	68.1%
P10:Experiement design	19	6.8%	74.9%
P4:Initial calibration	18	6.5%	81.4%
P5:Sensor position on the hand	15	5.4%	86.7%
P13:Suggestion for future development	15	5.4%	92.1%
P9:User manual	12	4.3%	96.4%
P2:Arm rest	9	3.2%	99.6%
P8:Cable	1	0.4%	100.0%
	279	100.0%	

(2) Step 2: Sum-up the critical margin

This aimed to calculate the critical margin $Cm = Pc - Nc$ for each design factor, summarised in Table 34.

Table.34 Sum-up the critical margin for the working model V1 (Chapter 5)

Product Specification	*Pc* (nodes)	*Nc* (nodes)	*Critical Margin (Pc-Nc)*
P1:Manner	22	-38	-16
P2: Sensitivity	6	-35	-29
P3:Cursor emulation	4	-33	-29
P4:Initial calibration	4	-18	-14
P5:Sensor position on the hand	4	-15	-11
P6:Button actuation	2	-45	-43
P7:Shape	3	-19	-16
P8:Cable	0	-1	-1
P9:User manual	0	-12	-12
P10:Experiement design	2	-19	-17
P11:Duraction	5	-20	-15
P12:Arm rest	0	-9	-9
P13:Suggestion for future development	14	-15	-1
	66	279	-213

Step 3: Priority of the design factor

Based on the Table 34, it is possible to calculate the cumulative percentage of the total weight of each design factor, as shown in Table 35.

Table.35 Priority of the design factor of the working model V1 (Chapter 5)

Product Specification	*Pc* (nodes)	*Nc* (nodes)	*Critical Margin (Pc-Nc)*	Cumulated (nodes)	Cumulated (%)	Priority
P6:Button actuation	2	-45	-43	20%	20%	1
P2: Sensitivity	6	-35	-29	14%	34%	2
P3:Cursor emulation	4	-33	-29	14%	47%	3
P10: Experiment design	2	-19	-17	8%	55%	4
P1:Manner	22	-38	-16	8%	63%	5
P7: Shape	3	-19	-16	8%	70%	6
P11:Duraction	5	-20	-15	7%	77%	7
P4:Initial calibration	4	-18	-14	7%	84%	8
P9: User manual	0	-12	-12	6%	90%	9
P5:Sensor position on the hand	4	-15	-11	5%	95%	10
P12: Arm rest	0	-9	-9	4%	99%	11
P13: Suggestion	14	-15	-1	0%	100%	12
P8: Cable	0	-1	-1	0%	100%	13
	66	279	-213	100%		

Based on “80-20 rule", the design problems consuming 80% of the cumulated weights can possibly be solved by tackling 20% of the design factors. Thus, the most critical design factor is identified as the *P6: button actuation* (20%), following by *P2: Sensitivity (14%)* and *P3: Cursor emulation* (14%). As for the sensitivity, the participants were not familiar with the use of the device, thus it requires more training and practice, which is left for a future study since it concerns the long-term investigation about the learning effect on the human performance.

In addition to *P10: Experiment design*, most of the comments related to concerns with the time length of the experiment, which is just too long, i.e. over 30 mins and which was also caused by these design problems. Therefore, solving these design problems can in turn be expected to improve the subjective comments on the experimental design.

5.4.8. Direct observation

With respect to the observation manner, since the gesture movement is narrow and simple with the tilt movement of the wrist, the digital camera was used for the video recoding via Digital Video. The steady photo of the gesture is captured and analyzed in terms of the following two joint ROMs, as shown in Figure 54:

- $\theta 1$: The flexion of the forearm;
- $\theta 2$: The flexion of the wrist;

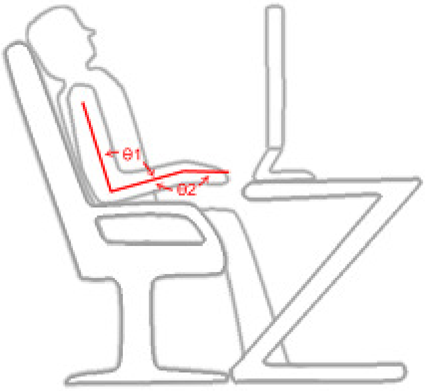

Figure 54. The elbow joint angle $\theta 1$ and the wrist joint angle$\theta 2$.

Based on the observation, there were four operational postures being defined, shown as followings:

- Type I: It is the neutral position where $\theta 1$ and $\theta 2$ are approaching to 0^o, shown in Figure 59.
- Type II: Where $\theta 1 \doteqdot \theta 2 > 10^o$ AND $< 30^o$, shown in Figure 60.
- Type III: Where $\theta 1 \doteqdot \theta 2 > 30^o$, shown in Figure 61.
- Type IV: IF subjects swing the pointing device, then the posture is defined as “Type IV”, shown in Figure 62.

Figure.59 Posture Type I with working model V1

Figure.60 Posture Type II with working model V1

Figure. 61 Posture Type III with working model V1

Figure.62 Posture Type IV with working model V1 (i.e. a sequence of the “swing” activity)

Totally, there were n = 3 learning blocks × 93 subjects = 279 cases being collected. As a result, the descriptive statistics are summarised in Table 36. As can be seen, 72.8% of postures were identified as the type I, following by the type II (15.8%), the type III (9.3%) and the type IV (2.2%). It was obvious that subjects preferred to use the postures for which the angle $\theta 1$ and the angle $\theta 2$ were zero to avoid the arm and wrist fatigue.

Table.36 Operational Postures with the working model V1 (n = 279 cases) (Chapter 5)

Learning Block	#1	#2	#3	Sum	%
Posture I	69	68	66	203	72.8%
Posture II	13	15	16	44	15.8%
Posture III	9	8	9	26	9.3%
Posture IV	2	2	2	6	2.2%
Sum				279	100%

5.5. Discussion

5.5.1. Fitness-of-models

The hypothesis *H1* is accepted which proves that the models (*ID*, ID_e, ID_{e2}) can be used to identify the devices having the discrete cursor movement on the screen with the working model V1, that is, the tilt-based gesture interface. For instance, if the adjusted R^2 is dropped to zero for the prediction of the total movement time *MT* across models, the devices might have a very high possibility of critical usability problems over the discrete visual feedback on the cursor movement, caused by multiple design factors, the cursor emulation program in this session in particular.

Furthermore, an adjusted $R^2 = 0.48$ for the prediction of the total movement time *MT* across *ID*, is better than in the current studies by Whisenand and Emurian (1999f), an adjusted $R^2 = 0.44$. It is therefore likely that this study is valid. However, the adjusted R^2 is lower than the one obtained in the previous session described in Chapter 3, the adjusted $R^2 = 0.68$. The differences between both studies are the target condition and the number of the participants, thus it can be said that the elimination of the small target width *W*=15 and having fewer participants, is likely to give the adjusted $R^2 = 0.48$ for the total movement time, *MT*, across *ID* if the same experimental design is used in both sessions (i.e. Chapters 4 and 6).

5.5.2. The usability problems and possible solutions

This study has achieved its aims: Firstly, a tilt-based gesture interface is designed using the inertial sensor technology with the implementation of the tilt movement of the wrist, namely the working model V1. Secondly, the critical design factors are identified to be the button actuation/participant and the cursor emulation, which needs to be further improved and evaluated in the next session as part of the iterative design process. Thirdly, the effects of gender and the previous motor skills learned from using the mouse are revealed. Finally, this session has provided the database for the comparative study with the working model V2 and the P5 Glove (i.e. the sweep-based gesture interfaces).

The result analysis of the device difference (*H2* test) indicated that the working model V1 resulted in poorer human performance than with the mouse in terms of greater sub-movement times, higher target re-entry, *TRE,* and longer cursor movement distance, D_e, with the significance ($p<0.01$). Furthermore, the result analysis of the subjective assessment also discovers that the participants feel significantly negative about the effort and the accuracy when working with the model V1 rather than with the mouse. This session offers the following explanations about 'why' the poor human performance and the negative subjective feelings are caused with the working model V1. This rationale can benefit the design implementation for the further improvement of the tilt-based gesture interaction as an iterative design process.

Firstly, the *sensitivity* is one of the critical usability problems with the tilt-based gesture interface and it is related to the design factors of the button actuation and the cursor emulation. In fact, the sensitivity problems reflect the fact that participants have to learn how to handle the tilt-based gesture interface, other problems are associated with the arm trembling and the displeasing manner of using the wrist movement in the air as well as the lack of the experience in using the tilt-based gesture interface.

Secondly, the tilt-based gesture interface might have the benefit in maintaining a neutral posture, thus it can prevent the discomfort in the specific body regions over the upper limb. For instance, 72.8% of postures are nearly neutral postures in which the angle $\theta 1$ and the angle $\theta 2$ approach zero to avoid the arm and wrist fatigue.

Finally, there might be a chance to beat the mouse in terms of the fact that the motor skill learning from the mouse might contribute to the human performance with the tilt-based gesture interfaces. Based on the result of the hypothesis test *H4*: it indicates that the more years using the mouse, the higher the human performance with the working model V1, even if the cursor movement is discrete and the fact that the mouse is used on the 2D desk and the working model V1 is used in the air. This might be owing to the fact that both devices use the same wrist movement, thus the motor skill is transferable between them. However, the result of the subjective assessment does not agree with the objective measurement. It is also discovered that the *button actuation/participant*, the *sensitivity* and the *cursor emulation* are three critical design factors reported by the participants. In this regard, the participants tend to dislike the working model V1 because it is objectively and subjectively harder to use than the mouse. Therefore, this session suggests that further improvements should be made to the working model V1 by tackling both the button actuation and the cursor emulation program, which might effectively improve the usability of the tilt-based gesture interaction.

In addition, this session does not intend to analyse the interactive effect of the gender and the mouse experience on the human performance since this session has achieved its main aim, which was to identity the critical design factors for the further improvement of the tilt-based gesture interaction as an iterative design process.

5.5.3. Design implementation

According to the result analysis, since the button actuation and the cursor emulation program are two of the most critical design factors with the working model V1, it is proposed to improve both factors by:

(1) The replacement of the flex finger sensor with the mouse button mechanism by grasping the mouse with the palm;

(2) A new cursor emulation program that produces the same nearly continuous cursor movement as the mouse.

The improved working model will be named the working model V2 in the next session.

Chapter 6: Design and Evaluation of the Tilt-Based Gesture Interfaces (Working Model V2)

6.1. Introduction[19]

In the previous session, the working model V1 has been designed and evaluated. The result analysis indicates there are two critical design problems that need to be solved in order to improve the usability of the tilt-based gesture interface; these are the button actuation and the cursor movement emulation program. It also revealed that the malfunction of the cursor emulation program produces the discrete cursor movement on the screen. However, what the problem with the cursor emulation program is remains unknown.

Furthermore, the study of the working model V1 cannot answer the research question about whether the discrete cursor movement can lengthen the elbow and wrist joint angles unless a comparison can be made with the device that produces the continuous cursor movement.

Therefore, this session has the following aims:

(1) To install the new button actuation and improve the cursor emulation program in order to produce the continuous cursor movement, namely the working model V2, known simply as the V2;

(2) To identify the design problems for a further study with the V2 in the future;

(3) To investigate the effects of the individual differences on the human performance in terms of the gender and the previous motor skill in using the mouse, i.e. the previous mouse experience (years);

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[19] Together with Chapter 5, the result findings are published in the following conference:

Wu, F. G., Chen, C. C. and Chen, T. K. (2008i) A user-centred design case study of a novel gesture-based pointing device. *CREATE 2008 on Embedding People-centred Design in the Process of Innovation*, London, U.K., Ergonomics Society HCI Group & British computer Society.

(4) To validate that there is a relation among the design problems of the gesture interfaces, the discrete cursor movement, the joint ROMs and the discomfort in particular body regions.

6.1.1. Improvement with the button actuation

In the working model V2, the original flex finger sensor button is replaced by the mouse button mechanism. As can be seen in Figure 63, the participant is asked to grasp the mouse by the thumb and the ring finger, where the mouse is the within the palm. A belt is required to fix the Zstar on the top of the hand[20].

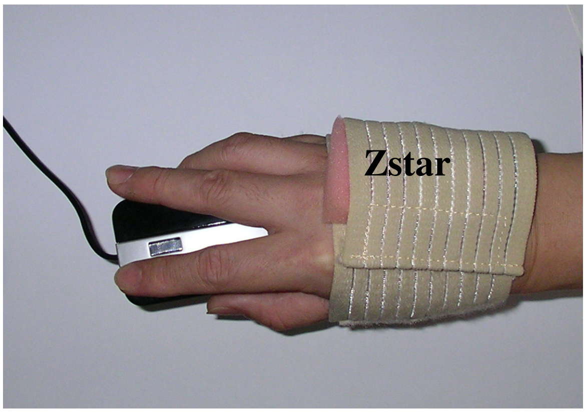

Figure.63 Button actuation manner with the working model V2

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[20] However, the button actuation method adopted in the V2 is only the template replacement of the flex sensor buttons for experimental purposes within the limited budget and time. This cannot be used in a real-world situation because such a design can produce a force on the muscle groups and tendons in the hand. A further design innovation with the button participant is needed in the future.

6.1.2. Problem of the original cursor emulation program

Based on the reviewed literature in Chapter 2, there are three problems with the inertial sensor system, there are the drift noise (Suh, 2003d; Cheok *et al.*, 2002a), nonlinear effects caused by gravity (Suh, 2003d) and peak noise. In particular for the peak noise, there are no studies that mention its effect on the cursor movement and the current studies do not propose an error compensation method to deal with it. In this regard, a displacement test was conducted to examine if a drift had occurred on the non-movement stage (Cheok *et al.*, 2002a)[21]. As a result, two displacement charts are produced, shown in Figure 64 and Figure 65:

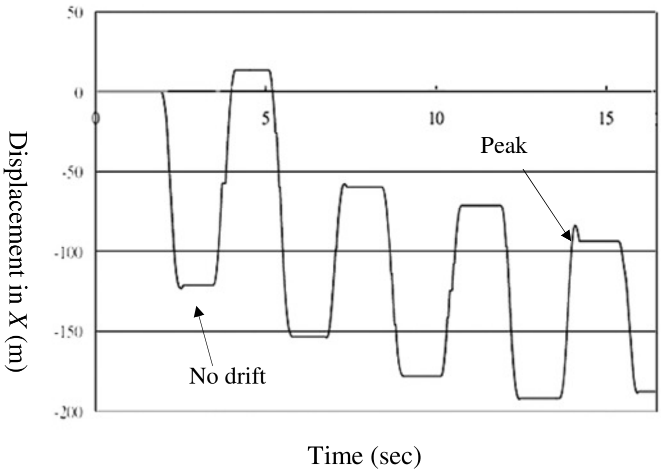

Figure.64 Displacement calculated from the noise filter at the x-axis (moving to- and for for four times)

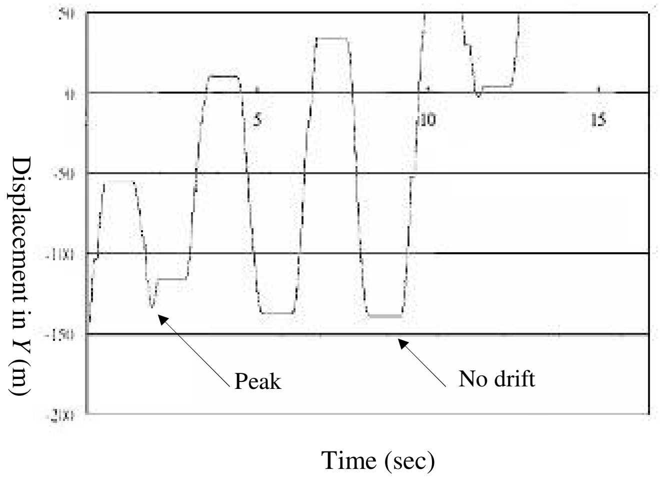

Figure.65 Displacement calculated from the noise filter at the y-axis (moving to- and for for four times)

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[21] The displacement test is a to-and-fro displacement carried along the x and y-axes of the accelerometer over the slider for four times.

As can be seen, both charts indicate that no drift has occurred with the original decoding unit and the noise filtering unit. In turn, it verifies that there is no failure with the cursor movement emulation to stop the cursor at the non-movement stage. Furthermore, both charts point out that peak noise can occur during to-and-fro displacements along both axes randomly[22].

Since there is no problem with the original decoding unit and the noise filter unit, it is likely that the peak noise is caused by the mechanism sensor. Moreover, because the original cursor emulation program does not have the error compensation function to deal with the peak noise, peak noise is indeed the problem that leads to the discrete cursor movement on the screen with the working model V1. Even worse, the cursor emulation unit employing the four-speed displacement function used to speed up the cursor movement (i.e. *Formula (2)* in Chapter 2) produces over 250 mm of the displacement per cycle time when the peak noise occurs.

6.1.3. New cursor emulation programme

In order to deal with the peak noise and at the same time to generate proper displacement, *Formula (3)* is proposed to replace *Formula (2)*, namely the Peak Noise Compensation Unit.

```
IF (displacement.New –displacement.Old) >= 50                  // 50+mm is the peak noise
    THEN displacement.New = displacement.Old;                  //replacement of the old
        ELSE cumulated.cursor.Position = cumulated.cursor.Position + (Direction * displacement.New)
                                                               //cursor moves
```

Here the cumulated cursor position is subject to the width and height of the screen. Thus, if the peak is detected, the current value of the displacement (i.e. displacement.New) will be replaced with the value obtained from the previous cycle (i.e. displacement.Old). In addition. the parameter 50mm is the minimum displacement value caused by the peak noise, based on the result of a series of trials. Hence, further study is required by using an oscilloscope with the Zstar to measure the error displacement parameter more accurately.

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22. Based on serial trials, the peak(s) could be 50+mm per cycle time. However, owing to the lack of experimental equipment, the final displacement is not zero, as the device returns to the original position. According to Cheok *et al.* (2002b), a 26 cm × 26 cm aluminium platform with two strips forming an L-shaped structure should be made to restrict the motion of the board in exactly one dimension. In the pilot study, the movement is freehand, resulting in some bias. Nevertheless, the drift and the peak are revealed.

Based on the use of the Peak Noise Compensation Unit with the original decoding unit and the noise filter unit, a pre-test is conducted based on the same experiment design used in the previous session. The result shows that the new cursor emulation program produces the nearly continuous cursor movement based on the aurthor's subjective feeling. Furthermore, the approaching time is also reducing 27% in comparison with the result produced by the working model V1 in the previous session. Moreover, by replacement of the flex finger buttons with the mouse mechanism button, the point time *PT* is reduced by 16%.

6.1.4. User-centred design methodology

The user-centred design methodology needed in the previous session is implemented for the identification of the critical design problems for the future study as part of the iterative design process With respect to the observation method, this session employs the digital video recorder (DV) to record the dynamic movement of the arm as an mpeg video file. After the test, the steady photo of the posture is captured and analyzed from the video.

6.2. Hypothesis

H1: The movement time *MT* across the new models (i.e. ID, ID_e and ID_{e2}) is predictable with the working model V2 (adjusted $R^2>0.1$);

H2: The human performance with the working model V2 is significantly better than with the V1 ($p<0.05$);

H3: The effect of gender on the human performance is significant with the working model V2 (p<0.05);

H4: The effect of the years using the mouse on the human performance is significant with the working model V2 (p<0.05).

6.3. Trial Protocol

6.3.1. Subject Selection

A total of forty-three Taiwanese students volunteered in Worksop in the Department of Styling & Cosmetology at Transworld University, Taiwan, who attended the previous session with the working model V1[23]. The participants consisted of twenty-seven females, age range from 18 to 25 years, and sixteen males, age range from 18 to 23 years. The average weekly pc usage reported by females was 32 hours per week, and by males was 37.

6.3.2. Testing apparatus

The laboratory used for the experiment is in an office at Transworld University, shown in Figure 66:

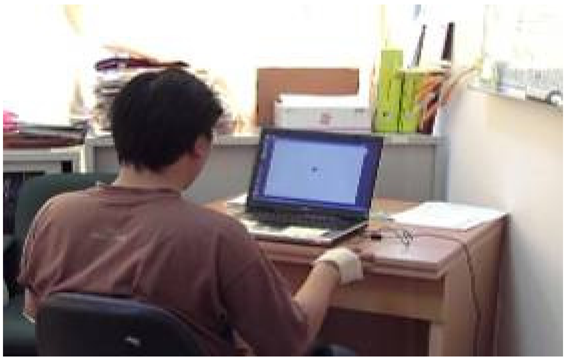

Figure.66 Office in the Department of Styling & Cosmetology at Transworld University, Taiwan

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[23] These participants were invited one month after the working model V2 was designed. Thus, the research limitation is that the effect of the motor skill gained from the use of the working model V1 might still affect the human performance with the working model V2.

This experiment was conducted based on the following equipments, which are the same with of the previous session[24].

- Client PC with a P4 3.0GHz CPU, 512MB of RAM;
- 17” CRT monitors;
- The FLG software, used to generate the target stimuli and measure objective human-centred performance;
- A Five-point Likert scale questionnaire (see Appendix C);
- A digital video recorder (DV) used to capture the posture change during the experiment, shown in Figure 67.
- The data analysis is performed using SPSS version 13.

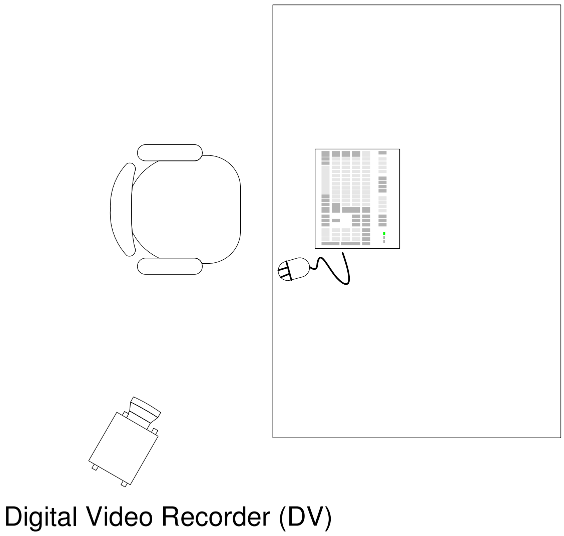

Figure.67 The placement of the digital video recorder (DV) in the office

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[24] However, the place in which the working model V2 was studied is different to that of the previous session. Nonetheless, the experiment design is the same, thus the difference in the laboratory place and conditions might not be too significant.

6.3.3. Independent variables

As shown in Table 37, the objective measurement design was a 2 × 2 × 8 fully within-subjects repeated measures. Furthermore, the target representation can be seen in Figure 68.

Table.37 Target condition used in Chapter 6

Factors/Parameters	Levels
Width/Height (mm)	30, 45
Target distance (mm)	45, 90
Angle of Approach (degree)	0,45,90,135,180,225,270,315

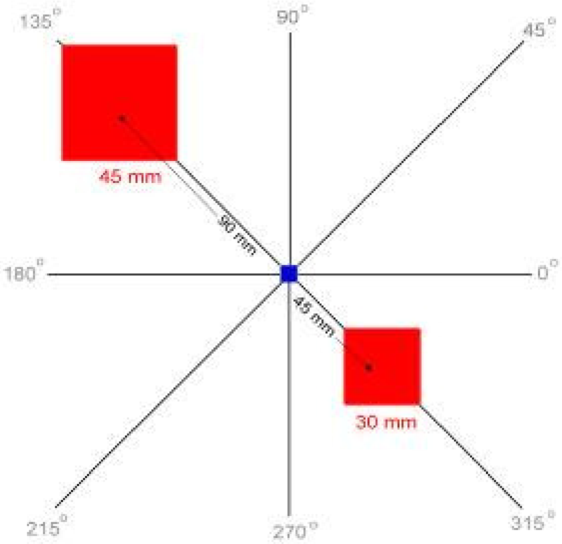

Figure.68 Targets representation on the measurement unit of the FLG software with the working models V2 in Chapter 6

Because the target condition is the same as in the previous session, the result obtained in this session could be compared with the data obtained in the previous session. In turn, the device difference between the working models V1 and V2 can be identified in this session in terms of the human performance, the subjective feelings and the posture change.

6.3.4. Dependent variables

The dependent variables consisted of the following three clusters: the objective human performance, the subjective feelings about the device design and the discomfort in the particular body regions, and the user profile:

In regards to the objective human performance, these objective measures were collected by the FLG software during the experiment with the mouse, summarized in Table 38.

Table.38 Objective measures of the human performance

Independent Variable	Description
error (%)	A error attempt is recorded
Target Re-Entry *TRE* (%)	When the cursor enters the target, it will be counted.
Cursor movement distance D_e (mm)	The cursor movement distance is calculated for each trial.
Approaching time *AT* (ms)	The time length between the start point and the time the cursor enters the target is measured.
Pointing Time *PT* (ms)	The time length between the time the cursor enters the target and the time a attempt is success is measured.
Movement time *MT* (ms)	$MT = AT + PT$

At each learning block, all combinations of 32 target conditions were represented in random order, followed by a one minute break section, which allows the participant to reduce finger and wrist fatigue. Three learning blocks are administered for a total of 96 trials per participant. Totally, there were n = 43 subjects × 3 blocks × 32 target conditions = 4,128 pairs of dependent variables being observed by the measurement platform Fitts' Law Generator (FLG).

As for the subjective feelings, these subjective attributes were collected by using a Five-point Likert scale questionnaire, shown in Table 39:

Table.39 Subjective attributes of the Five-point Likert scale subjective assessment wit the working model V2

Cluster/Level	Factor	Current studies
Design	C1:smooth C2:effort C3:accuracy C4:speed C5:comfort C6:overall	Subjective assessment for NKIDs (ISO, 2000c, 2003e)
Discomfort	C7:finger fatigue C8:wrist fatigue C9:arm fatigue C10:shoulder fatigue C11:neck fatigue C12:back fatigue C13:eye strain	
User Experience	F1: Clear F2: Suitable on desktop F3: Relax F4: Tense F5: Difference F6: Fun F7: Safety F8: Ease of use F9: Usefulness F10: Potential	

As for the user profile, in order to reveal the effect of the interactive effect of the gender by the weekly computer usage, the user's background information are collected, including age, gender (female/male), user handedness (i.e. preferred domain right hand or left hand), the number of the year spent on using the mouse (i.e. previous experience in using a mouse).

6.3.5. Standard Operation Procedure (SOP)

A standard operation procedure (SOP), shown in Figure 69, is developed using a checklist to allow each participant to follow the same procedure during the experiment, which could help in reducing process bias during the experiment and to ensure reliability of the study. The SOP is also the same as the previous session with the working model V1.

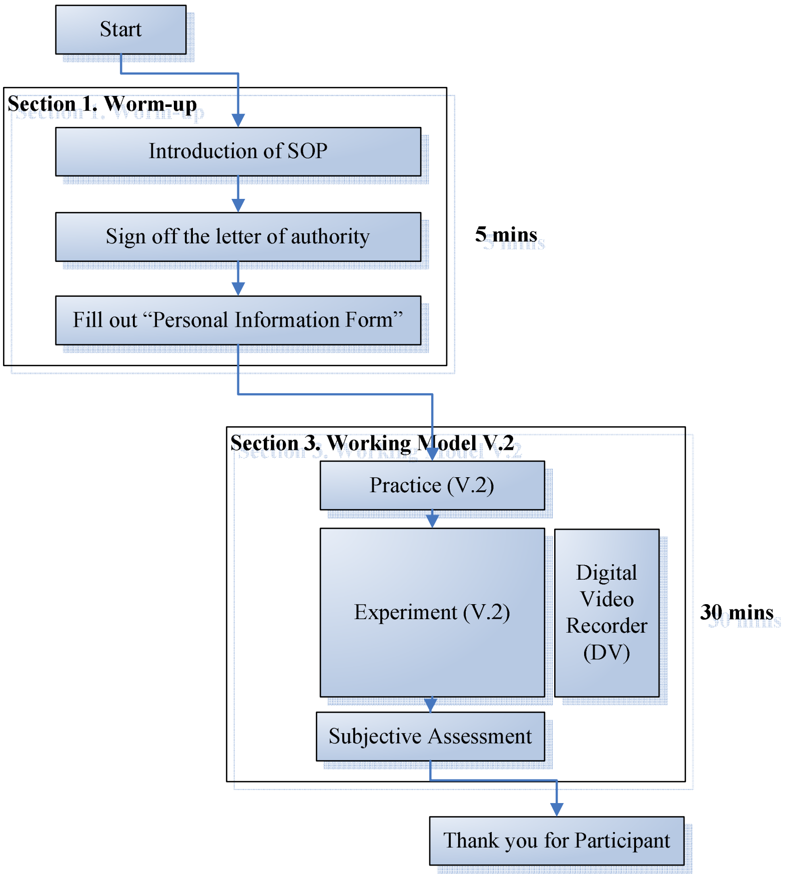

Figure.69 Standard Operation Procedure (SOP) in Chapter 6

Since the study did not involve the ordinary mouse, there were two sections in the experiment: In the section 1, the experimenter introduced the SOP to participants and demonstrated each task to familiarize the participants with the task and the laboratory environment. After that, participants were asked to sign off a letter of authority to make commitment to the experiment. Participants then filled out 'personal information' to gather demographic data, i.e. age, gender, preferred hand, and visual and physical limitations, and experiential data.

In the section 2 of the SOP, participants were allowed to practice with the working model V2 for 32 trials, i.e. a learning block. After the practice, participants were instructed to perform each task “as accurately as possible and as fast as possible” before the experiment (Zhai *et al.*, 2004f).

With regards to research limitation, since the experiment requested participants to operate pointing devices repetitively during a short period of time, the degree of tiredness depending on individuals’ physical conditions, although a one-minute break between testing blocks had been introduced.

6.4. Result Analysis

6.4.1. Adjustment of objective data

According to Whisenand and Emurian (1999f), error cases are analyzed separately. A total of 249 errors occurred out of 4,128 total trials. By the removal of the error trials, the total movement time *MT* reduces the mean *MT* from 1,398 ms to 1,349 ms with the working model V2.

6.4.2. Fitness-of-models (H1 test)

> *H1: The movement time MT across the new models (i.e. ID, ID_e and ID_{e2}) is predictable with both the mouse and the V.2. (*adjusted $R^2 > 0.1$*).*

As can be seen in Table 40, the linear regression analysis indicates the different adjusted R^2 values across different models (ID, ID_e, ID_{e2}) with the mouse and the working model V.2. For the V.2, there is a linear relation between the movement time *MT* and three models (adjusted $R^2 = 0.15$). Thus, the hypothesis *H1* is accepted. It is likely that the working model V2 produces a nearly continuous cursor movement because the adjusted R^2 is approaching that of the ordinary mouse.

Table.40 The prediction of the total movement time *MT* (ms) across models (ID, ID_e, ID_{e2}) among the mouse (in Ch.5), the V1 and V2 (Chapter 6)

Device	N*	Models' prediction rate (adjusted R^2) **			
		ID	ID_e	ID_{e2}	Predictable?
Mouse	3,689	0.43	0.41	0.48	Yes
V.1	8,614	0.02	0.02	0.02	No
V.2	3,879	0.15	0.12	0.15	Yes

* The error trials were excluded for the analysis.

** The linear regression analysis was applied on the adjusted data for the prediction of the movement time *MT* across models (ID, ID_e and ID_{e2}). The adjusted R^2 value was used since the sample size was difference among these studies.

6.4.3. Device difference (*H2* test)

> *H2: The human performance with the working model V.2 is significantly better than with the V.1 ($P<0.01$).*

The hypothesis *H2* is based on the fact that the working model V1 had usability problems involving discrete cursor movement caused by the malfunction of the cursor emulation program, thus its human performance is likely to be poorer than with the V2, which produces a nearly continuous cursor movement by using the mouse buttons.

As can be seen in Table 41, the descriptive statistics indicate that the total movement time with the V2 (1,349 ms ± 569) is 31% faster than with the V1 (1,963 ms ± 1,401). Furthermore, the Independent T test is applied on the raw material to examine the significance of the difference. As result, it indicates that the human performance with the V2 is better than with the V1 in terms of a significantly higher *error rate* ($p<0.01$), higher target re-entry *TRE* ($p<0.01$), longer cursor movement distance D_e ($p<0.01$), longer approaching time *AT* ($p<0.01$), longer pointing time *PT* ($p<0.01$) and longer total movement time, *MT,* with the working model V1 than with the V2. Therefore, the hypothesis *H2* is accepted. Furthermore, the huge *S.D.* is caused by the gesture interfaces. For instance, a smaller *S.D.* is produced with the ordinary mouse by the same sample population. Similar results are also obtained by the current study with a novel remote pointing device (Hsu *et al.*, 1999c).

Table.41 The difference of the human performance between the working model V1 and V2 (Chapter 6)

Human Performance	Working models ***		*P value*
	V1 (n=8,614)	V.2 (n=3,879)	
Error Rate (%)	14.6% ± 0.49	6.8% ± 0.29↓	<0.01**
Target Re-Entry *TRE* (%)*	12.9% ± 0.43	4.3% ± 0.23↓	<0.01**
Cursor movement distance D_e (mm)*	128 ± 116	90 ± 47↓	<0.01**
Approaching time *AT* (ms)*	2,855 ± 15,098	1,179 ± 535↓	<0.01**
Pointing time *PT* (ms)*	258 ± 279	165 ± 113↓	<0.01**
Total movement time *MT* (ms)*	1,963 ± 1,401	1,349 ± 569↓	<0.01**

* The error trials were excluded for the analysis.
** The difference between the devices is statistically significant.
*** The blue arrow ↓ means the improvement was made

6.4.5. Gender-related effect (*H3* test)

H3: The effect of gender on the human performance is significant with the working model V2 (p<0.05).

Since the females differ from the males in terms of the muscle development and the hand shape, it is assumed that gender has a significant effect on human performance. As a result, the descriptive statistics are summarised in Table 42:

Table.42 The effect of the gender on the human performance with the working model V2 (Chapter 6)

Human Performance	Gender	n	Mean***	Std. Deviation	P value
Error Rate (%)	Females	2,592	6.7%	28.0%	p=0.65
	Males	1,536	7.1%	30.1%	
Target Re-Entry TRE (%)*	Females	2,437	4.8%	0.24	p<0.05**
	Males	1,442	3.3%↓	0.20	
Cursor movement distance D_e (mm)*	Females	2,437	91	50	p=0.29
	Males	1,442	89	41	
Approaching time AT (ms)*	Females	2,437	1,237	580	p<0.01**
	Males	1,442	1,082↓	430	
Pointing time PT (ms)*	Females	2,437	178	122	p<0.01**
	Males	1,442	144↓	89	
Total movement time MT (ms)*	Females	2,437	1,420	612	p<0.01**
	Males	1,442	1,231↓	464	

* The error trials were excluded for the analysis.
** The difference between the groups is statistically significant.
*** The blue arrow ↓ means the group having the better performance than another.

Furthermore, the Independent T test is employed to examine the significance of the difference, shown as follows:

- Mean *TRE* for female participants, 4.8% is significantly greater (p<0.05) than for males, 3.3%.
- Mean *AT* for female participants, 1,237 ms, is significantly greater (p<0.01) than for males, 1,082 ms.
- Mean *PT* for female participants, i.e. 178 ms, is significantly greater (p<0.01) than for males, 144 ms.
- Mean *MT* for female participants, 1,420 ms, is significantly greater (p<0.01) than for male subjects, 1,231 ms.
- No significant difference between the genders is found on Mean *Error Rate,* p= 0.65.
- No significant difference between the genders is found on Mean D_e p= 0.29.

To sum up, although the hypothesis *H3* is accepted, the difference is very small, e.g. the difference of mean *MT* is only 189 ms, which highlights that the FLG measurement platform is very sensitive and able to detect the differences among the different participants.

Secondly, comparison with the result analysis obtained in the previous session with the V1, reveals that the cursor movement distance D_e is not influenced by the gender difference. Thus D_e might be a constant to the Fitts' model and can enhance the prediction of the movement time *MT* across models (*ID*, ID_e and ID_{e2}).

Thirdly, although *H3* is accepted, the result is opposite to that from the previous section with the V1 where the females had better human performance than the males. In fact, the working model V2 requires participants to grasp the mouse and the belt needs to be used to tighten the Zstar sensor pack on the hand. Both requirements produce a force to the muscle groups and the tendons in the hand and that may have impacted on the performance of females in particular because females have smaller hands and muscle groups, thus making it easier for them to be influenced by the force.

6.4.6. Number of years using the mouse (*H4* Test)

> *H4: The effect of the years using the mouse on the human performance is significant with the working model V2 ($p<0.05$).*

The hypothesis *H4* is based on the fact that the motor skill gained by using the mouse for many years is based on the same wrist movement as that used by the working model V2, thus it is logical to assume that the number of years using the mouse (i.e. the mouse experience), might affect the human performance with the V2.

In this regard, participants were further divided into two groups for the study of the effect of the mouse experience on the human performance with the working model V2:

- Learner mouse users' average age ranged from 18 to 23 years, the mean experience is 7 ± 1 years.
- Mature mouse users' average age ranged between 18 and 25 years, the mean experience is 11 ± 2 years.

As can be seen in Table 43, the descriptive statistics indicate the difference in human performance between both groups of participants with the working model V2:

Table.43 The effect of the previous mouse experience on the human performance with the working model V2, based on the Independent T test on the adjusted data

Human Performance	Previous mouse experience group***	n	Mean	Std. Deviation	P value
Error Rate (%)	Mature mouse users	2,400	5.2%↓	0.24	p<0.01**
	Learning mouse users	1,728	9.1%	0.35	
Target Re-Entry TRE (%)*	Mature mouse users	2,282	4.4%	0.24	p=0.67
	Learning mouse users	1,597	4.1%	0.20	
Cursor movement distance D_e (mm)*	Mature mouse users	2,282	90	49	p=0.32
	Learning mouse users	1,597	91	44	
Approaching time *AT* (ms)*	Mature mouse users	2,282	1,252	552	p<0.01**
	Learning mouse users	1,597	1,075↓	491	
Pointing time *PT* (ms)*	Mature mouse users	2,282	180	119	p<0.01**
	Learning mouse users	1,597	144↓	98	
Total movement time *MT* (ms)*	Mature mouse users	2,282	1,437	585	p<0.01**
	Learning mouse users	1,597	1,224↓	520	

* The error trials were excluded for the analysis.
** The difference between the devices is statistically significant.
*** Mature mouse users are those who have previous mouse experience >=9 years; and the Learning mouse users are those who have previous mouse experience <9 years.
**** The blue arrow ↓ indicates the user group having a significantly better human performance than another.

Furthermore, the Independent T test is employed to examine the significance of the difference, shown in the following:

- *Error Rate* for the mature mouse user group, 5.2%, is significantly lower ($p<0.01$) than for the learner user group, 9.1%.
- Mean *AT* for the mature mouse user group, 1,252 mm, is significantly longer ($p<0.01$) than for the learner user group, 1,075 mm.
- Mean *PT* for the mature mouse user group, 180 ms, is significantly longer ($p<0.01$) than for the learner user group, 144 ms.
- Mean *MT* for the mature mouse user group, 1,437 ms, is significantly longer ($p<0.01$) than for the learner user group, 1,224 ms.
- No significant difference is found on Mean *TRE* between the groups ($p= 0.67$).
- No significant difference is found on Mean D_e between the groups ($p= 0.32$).

Based on the result analysis, there are three conclusions that can be drawn: firstly, mature mouse users have significantly poorer human performance than the learner mouse user in terms of greater *error rate*, greater approaching time *AT*, greater pointing time *PT* and greater total movement time *MT*. Hence, the hypothesis *H4* is accepted.

However, the differences are very small between the two groups of participants. For instance, the difference in Mean *MT* is only 213 ms.

Secondly, the mature user group tends to have significantly fewer error attempts than the learner user group, thus it is likely that the motor skill gained from using the mouse can contribute to the accuracy with the working model V2.

Finally, the result is similar to of that in Chapter 4, which is the study of the human performance with the ordinary mouse, which highlights that the mature mouse user group has a greater risk of experiencing a work-related injury. Thus, it is likely that the motor skill and the potential for a work-related injury with the mouse can impact on the human performance with the working model V2.

6.4.7. Subjective feelings

As can be seen in Table 44, the inter-reliability test discovered that inter-reliability about the design is very high with both the working models V.1 and V.2, thus the comparison can be made for both devices in terms of the design, the discomfort and the user experience, as summarised in Table 45.

Table.44 Inter Reliability Statistics with the working model V1 and V2

Subjective feeling	Cronbach's Alpha	
	V.1	V.2
Design	0.82	0.89
Discomfort	0.79	0.90
User Experience	0.89	0.85

Table.45 Result analysis of the Five-point Likert scale subjective assessment with the working models V1 and V2

Usability Classes		Working models***		*P value*
Levels	Factors	V.1 (n=100)	V.2 (n=43)	
Design	C1:smooth	3.1	3.9 ↑	<0.01**
	C2:effort	3.0	3.9 ↑	<0.01**
	C3:accuracy	2.8	3.7 ↑	<0.01**
	C4:speed	3.3	3.8 ↑	<0.01**
	C5:comfort	3.1	3.5 ↑	<0.01**
	C6:overall	3.2	3.7 ↑	<0.01**
Operational discomfort	C7:finger fatigue	2.3	1.9 ↓	0.06
	C8:wrist fatigue	2.6	2.3 ↓	0.11
	C9:arm fatigue	2.4	2.1 ↓	0.20
	C10:shoulder fatigue	2.1	1.9 ↓	0.39
	C11:neck fatigue	1.7	1.6 ↓	0.68
	C12:back fatigue	1.6	1.7 ↑	0.72
	C13:eye strain	2.9	2.6 ↓	0.16
User experience	F1:clear	3.4	3.9 ↑	<0.01**
	F2:suitable on desktop	2.9	3.1 ↑	0.28
	F3:relax	2.9	3.4 ↑	<0.01**
	F4:tense	4.2	4.2	0.68
	F5:difference	4.4	4.4	0.62
	F6:fun	4.3	4.4 ↑	0.69
	F7:safety	3.8	4.0 ↑	0.38
	F8:ease of use	3.3	3.9 ↑	<0.01**
	F9:usefulness	3.3	3.7 ↑	<0.05*
	F10:potential	4.2	4.3 ↓	0.97

* The difference was significant (p<0.05)
** The difference was very significant (p<0.01)
*** The blue arrow ↑means the improvement was made, the red arrow ↓ means that it get worse.

As for the design, the Mann-Whitney U test indicates that the subjective feeling about the smoothness is significantly better with the working model V.2 (3.9) than with the mouse (3.2)(p<0.05). This indicates that the cursor movement with V.2 is a great improvement over the V1. In terms of the design, all seven indicators (i.e. smoothness, effort, accuracy, speed, comfort and overall performance) are increased significantly, which indicates that the new cursor movement emulator has led to a better subjective feeling about the tilt-based gesture interface.

In regards to the discomfort, although there are no significant improvements, all indicators show that the fatigue levels of the various body regions with the V.2 are all lower than with V1, except for the back but its fatigue is still lower than the average (2.5).

In respect of the user experience, the participants felt more clear with the V.2 (3.9) than with the V1 (3.4), which might be due to the fact that the V1 is the glove and the V2 is the belt, thus the participants felt more tidy with the glove (V1) than with the belt (V2). Nevertheless, it requires further study of the textile and material. Furthermore, the participants also felt more relaxed and experienced greater ease-of-use and usefulness with the V2 than with the V1.

6.4.8. Open-ended comments

In total, seven comments were collected from the open-comment section of the subjective questionnaire, shown in Table 46, whilst 35 participants made no comments on it. It is possible to weight these comments in order to identify the top three critical design factors for future improvements of the V2.

Table.46 Positive and negative comments wit the working model V2 (Chapter 6)

ID	Comment	P1:Manner	P2:Senseritiy	P3:Cursor emulation	P6:Button actuation	P10:experiement design	P13: Fatigue
117	It is better than the previous one in terms of less over-sensitive.	◎	◎	◎	◎	◎	
119	My arm is little discomfort.				●		●
120	This device is better than previous one in terms of east-to-control. Overall, it is fun.	◎	◎	◎	●		●
120	My wrist get discomfort	◎	◎	◎	●		●
124	It is really easy-to-use and my arm is not discomfort and the moving speed is very fast.	◎	◎	◎	◎		◎
128	To control the cursor moving at 0 and 180 angles of approach is easy, but is difficulty at 90 and 270 angles of approaches	●			●		
134	I can feel the difference between this one and the previous one, as the matter of the fact, this one is easy-to-control and easy to learn.	◎	◎	◎	◎		
148	My wrist is discomfort.				●		●
149	My wrist is discomfort.				●		●
151	This device is much better than the previous one.	◎	◎	◎	●		●
151	The comfortability needs to be improved.	◎	◎	◎	●		●
Sum	Positive comment (◎mark)	7	7	7	3	1	1
	Negative comment (●mark)	1	0	0	8	0	7

In comparison with the number of subjective comments collected from the previous session with the working model V1 (node n = 207), the comments collected in this session are very few. In fact, the usability problems with the V2 become very precise and not easy to describe in writing.

(3) Step 1: Weight the comments

In total, seven comments were found and broken down into 30 positive comments and 16 negative comments. They are summarised in Table 47 and Table 48:

Table.47 Positive comments (*Pc*) with the working model V2 (Chapter 6)

Design Factors	*Pc* (nodes)	*Pc* (%)	Cumulative %
P1:Manner	7	23.3%	23.30%
P2:Senseritiy	7	23.3%	46.60%
P3:Cursor emulation	7	23.3%	69.90%
P6:Button actuation	7	23.3%	93.20%
P13: Fatigue	1	3.3%	96.50%
P10:experiement design	1	3.3%	99.80%
P12:Arm rest	0	0.0%	100.00%
P5:Sensor position on the hand	0	0.0%	100.00%
P9:User manual	0	0.0%	100.00%
P4:Initial calibration	0	0.0%	100.00%
P7:Shape	0	0.0%	100.00%
P8:Cable	0	0.0%	100.00%
P11:duraction	0	0.0%	100.00%
Sum	30	100%	

Table.48 Negative comments (*Nc*) with the working model V2 (Chapter 6)

Design Factors	*Nc* (nodes)	*Nc* (%)	Cumulative %
P6:Button actuation	8	50.0%	50.00%
P13: Fatigue	7	43.8%	93.80%
P1:Manner	1	6.3%	100.10%
P5:Sensor position on the hand	0	0.0%	100.10%
P11:duraction	0	0.0%	100.10%
P12:Arm rest	0	0.0%	100.10%
P2:Senseritiy	0	0.0%	100.00%
P3:Cursor emulation	0	0.0%	100.00%
P4:Initial calibration	0	0.0%	100.00%
P7:Shape	0	0.0%	100.00%
P8:Cable	0	0.0%	100.00%
P9:User manual	0	0.0%	100.00%
P10:experiement design	0	0.0%	100.00%
Sum	16	100%%	

(2) Step 2: Sum-up the critical margin

This aims to calculate the critical margin *Cm* = *Pc* – *Nc* for each design factor, as summarised in the Table 49.

Table.49 Sum-up the critical margin with the working model V2 (Chapter 6)

Product Specification	*Pc* (nodes)	*Nc* (nodes)	*Critical Margin (Pc-Nc)*
P13: Fatigue	1	7	-6
P6: Button actuation	7	8	-1
P4:Initial calibration	0	0	0
P5:Sensor position on the hand	0	0	0
P7:Shape	0	0	0
P8:Cable	0	0	0
P9:User manual	0	0	0
P11:duraction	0	0	0
P12:Arm rest	0	0	0
P10:experiement design	1	0	1
P1:Manner	7	1	6
P2: Sensitivity	7	0	7
P3:Cursor emulation	7	0	7
Sum	30	16	14

Since the number of nodes is few, it is not considered appropriate to calculate the cumulative percentage. As a result, the most critical design factors are identified as *P13: Fatigue* (-6) and *P2: Button actuation (-1) (14%).* Therefore, both design factors should be tackled to achieve better quality-in-use.

In addition, *P5: Cursor emulation* (7) gets the highest positive margin, which highlights that the working model V2 has produced a continuous cursor movement that is acceptable to participants.

6.4.9. Direct observation

When using the tilt-based gesture interfaces, various arm postures of those with a preference for right handed working can be categorized in terms of the elbow joint angle $\theta 1$ and the wrist joint angle $\theta 2$, as illustrated in Figure 54.

- $\theta 1$: The flexion of the forearm;
- $\theta 2$: The flexion of the wrist;

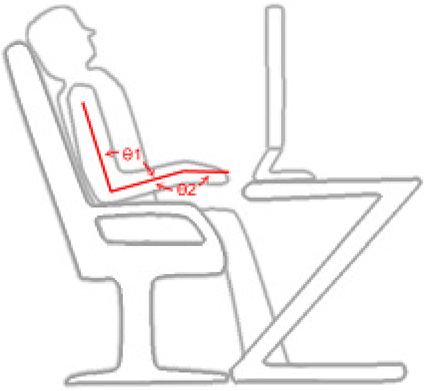

Figure.54 The elbow joint angle $\theta 1$ and the wrist joint angle $\theta 2$

Based on the observation, there were four operational postures being defined, shown as follows:

- Type I: It is the neutral position where $\theta 1$ and $\theta 2$ are approaching to 0^{o}, shown in Figure 70.
- Type II: Where $\theta 1 \fallingdotseq \theta 2 > 10^{o}$ AND $< 30^{o}$, shown in Figure 71.
- Type III: Where $\theta 1 \fallingdotseq \theta 2 > 30^{o}$, shown in Figure 72.
- Type IV: IF subjects swing the pointing device, then the posture is defined as “Type IV”. Not like the working model V.1 in the previous session, no Type IV posture occurred with the working model V.2.

Figure.70 Posture Type I with the working model V2

Figure.71 Posture Type II with the working model V2

Figure.72 Posture Type III with the working model V2

Subjects were informed that they should have a neutral posture (Type I) to operate the working model V.2 since it is the planned working area and the planned ROMs. During the experiment, a digital video recorder (DV) was used to record the posture of the right arm of each participant. The post-video analysis is undertaken after the experiment: if any posture changes at each learning block, a steady photo is then taken from the video. Although the number of subjects invited was n = 43, 13 cases were excluded owing to the technical problems where there was insufficient memory to record the video. In total, there were n = 3 learning blocks × 30 subjects = 90 cases found.

As can be seen in Table 50, 77.8% of postures were identified as the type I, following by the type III (16.7%) and the type II (5.6%). It was obvious that subjects preferred to use the postures in which the angle $\theta 1$ and the angle $\theta 2$ were zero to avoid the arm and wrist fatigue.

Table.50 Operational Postures with the working model V2 (n = 90 cases) (Chapter 6)

Learning Block	#1	#2	#3	Sum	%
Posture Type 1	26	26	26	78	77.8%
Posture Type 2	1	1	1	3	5.6%
Posture Type 3	3	3	3	9	16.7%
	Sum			108	100%

Furthermore, participants who attended the studies with the working model V1 were invited randomly for the study with the V2. As can been seen in Table 51, 29 cases were found to have posture photos with both the V1 and V2. As a result, 26 cases out of these 29 cases were found to have the neutral posture (posture Type 1). In other words, nearly 90% of these cases are at a neutral posture. In total, among these 26 cases, 10 cases were found to have their joint ROMs reduced from the posture Type II or III with the working model V1, to the neutral posture (posture Type 1) with the V2.

To sum up, it is validated that the working model V2 is better than the V1 because it can allow users to maintain the elbow and wrist joint angles in a neutral posture according to the planned working area. Moreover, by comparison with the one having continuous cursor movement (i.e. V2), the result suggests that the tilt-base gesture interfaces having discrete cursor movement (i.e. V1) can increase both elbow and wrist joint ROMs which apart from the neutral posture.

Table.51 The posture change between using the working model V1 and V2 (Chapter 6)

Case NO	Participants' information				Result of the posture change	
	Original ID(V1)*	New ID (V2)*	Gender	Age	Using V.1 **	Using V.2 **
1	70	120	Female	20	1	3 ↑
2	53	121	Female	18	2	3 ↑
3	34	122	Male	22	1	1
4	43	124	Female	21	1	1
5	89	125	Female	20	1	1
6	32	126	Female	21	1	1
7	79	129	Female	25	1	1
8	96	130	Female	23	1	1
9	20	131	Female	20	1	1
20	23	132	Female	23	1	1
11	91	134	Female	23	2	1 ↓
12	40	137	Male	19	3	2 ↓
13	24	139	Female	18	3	1 ↓
14	17	141	Female	21	1	1
15	94	142	Male	21	1	1
16	93	143	Male	19	2	1 ↓
17	85	144	Female	20	1	1
18	87	145	Female	19	1	1
19	88	146	Female	19	2	1 ↓
20	86	147	Female	20	1	1
21	62	149	Male	18	3	1 ↓
22	63	150	Male	19	1	1
23	67	151	Female	18	2	1 ↓
24	82	152	Female	19	4	1 ↓
25	83	153	Male	23	3	3
26	13	154	Female	22	2	1 ↓
27	64	155	Female	20	1	1
28	49	156	Male	19	1	1
29	44	157	Male	19	2	1 ↓

** Since the participants often changed the posture with the V.1, if there is more than one posture found, the posture having the highest joint angles is used for the comparison.

*** Blue arrow ↓ means that the joint angles are decreased, and red arrow ↑ means that the joint angles are increased.

6.5. Discussion

This session has achieved its aims:

Firstly, the working model V2 (1,349 ms ± 569) is 31% faster than with the working model V1 (1,963 ms ± 1,401). Furthermore, The hypothesis test *H2* indicated that the human performance with the working model V2 is better than with the V1 in terms of significantly lower *error rate* (p<0.01), lower target re-entry *TRE* (p<0.01), shorter cursor movement distance D_e (p<0.01), shorter approaching time *AT* (p<0.01), shorter pointing time *PT* (p<0.01) and shorter total movement time *MT* (p<0.01). The subjective assessment also highlights that the participants like the V2 more than the V1 in terms of the significant enhancement of the subjective feelings about the design, the discomfort and user experience.

With respect to the Peak Noise Compensation Unit (i.e. *Formula (3)* in Chapter 2), it replaces the original manual error compensation with the working model V1. By integration of the Peak Noise Compensation Unit with the original decoding unit and the noise filter unit, the working model V2 produces nearly the same amount of continuous cursor movement as the mouse because the result analysis indicted that the adjusted R^2 = 0.15 is achieved for the prediction of the total movement time *MT* across *ID* and ID_{e2}, in comparison to the adjusted $R^2 \fallingdotseq 0$ obtained with the working model V1 having the discrete cursor movement. Furthermore, the huge *S.D.* is caused by the gesture interfaces. For instance, a smaller *S.D.* is produced with the ordinary mouse by the same sample population. Similar results are also obtained by the current study with a novel remote pointing device (Hsu *et al.*, 1999c). It is one of the reasons which causes the absence of a linear relation between the movement time *MT* and three models with the P5 Glove and the working model V1 related to the usability problems, i.e. discrete cursor movement (Chen *et al.*, 2007a, 2007b, 2009a; Wu *et al.*, 2008i).

Secondly, the hypothesis *H3* test is accepted. Thus the gender effect on the human performance exists with the working model V2. However, the working model V2 requires participants to grasp the mouse in the palm and the belt needs to be used to tighten the Zstar sensor pack on the hand. Both requirements have produced a force on the muscle groups and the tendons in the hand. Therefore, this session cannot conclude that the females have a disadvantage using the tilt-based gesture interface as compared to the males.

Fourthly, the hypothesis *H4* test is accepted and reveals that the effect of the mouse experience can influence the human performance with the working model V2. It is likely that the motor skill and the work-related injury came together, which can contribute to the discomfort development in particular body regions (i.e. in particular of the wrist) and impacts on the human performance with the working model V2.

Finally, it is validated that the working model V2 is better than the V1 because it can allow users to maintain the elbow and wrist joint angles in a neutral posture according to the planned working area. Moreover, by comparison with the one having continuous cursor movement (i.e. V2), the result suggests that the tilt-base gesture interfaces having discrete cursor movement (i.e. V1) can increase both elbow and wrist joint ROMs which depart from the neutral posture.

As for the future work, the result of the open-end comment suggest that both *P13: Fatigue* (-6) and *P2: Button actuation (-1) (14%)* are the most critical design factors with the most negative critical margins. Therefore, both design factors should be tackled for better quality-in-use in the future. Furthermore, *P5: Cursor emulation* (7) gets the highest positive margin, which highlight that the working model V2 has produced continuous cursor movement that is acceptable to the participants.

Chapter 7: General discussion

7.1. Introduction[25]

This chapter aims to discuss the following three issues:

(1) The intra-discussion: It aims to discuss the intra-relation of the methods in order to prove the validity of this research;

(2) The inter-discussion: It aims to discuss the inter-relation among the independent design factors and dependent factors in order to prove that there is a relation between the cursor movement behaviour, the specific body movement and the design factors of the gesture interfaces;

(3) Advantages of the tilt-based gesture interface V2: Since this version of the working model produces a nearly continuous cursor movement, the advantage of such a device are summarised as a reference for future work.

Note that button actuation and the cursor movement are both reported as the most critical design factors and improved through the iterative design process (Chapter 5 and 6), thus the other design factors, such as the shape of the device and the forearm posture, were unable to be discussed by this research.

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[25] The findings described in this chapter is going to be published in the following conference:

Chen, C. C., Wu, F. G., Chen, T. K. and Fang, H. L. (2009a) Extension of Fitts' Law for the design of the gesture pointing interaction: The effect of the phenomenon of discrete cursor movement on the usability of gesture-based pointing devices. *in Proceedings of 3rd IASDR 2009 on Design, Rigor & Relevance*, Kyunggi-do, Korea, Korea Design Center (paper accepted).

7.2. Intra-Discussion

7.2.1. Validity of the graphical measurement platform

In this research, Fitts' Law is expanded into a two-dimensional description using a polar coordinate system for the study of the complex body-based interaction. The objective measures of the human performance are summarised in Table 52.

Table.52 Objective measures of human performance

Independent Variable	Description
error (%)	A error attempt is recorded
Target Re-Entry *TRE* (%)	When the cursor enters the target, it will be counted.
Cursor movement distance D_e (mm)	The cursor movement distance is calculated for each trial.
Approaching time *AT* (ms)	The time length between the start point and the time the cursor enters the target is measured.
Pointing Time *PT* (ms)	The time length between the time the cursor enters the target and the time a attempt is success is measured.
Movement time *MT* (ms)	$MT = AT + PT$

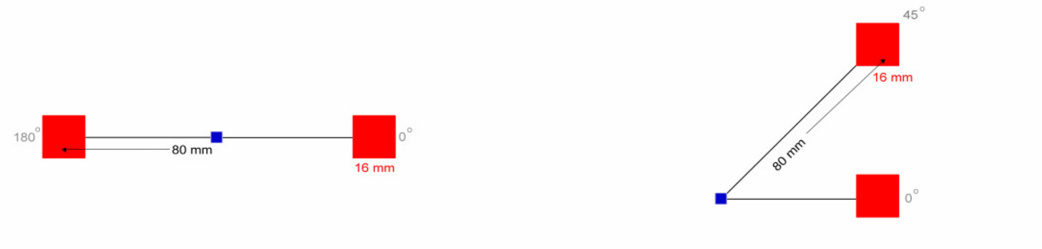
Since the cursor movement is the only outcome of the gesture interfaces, a "poorly designed" gesture interface might reflect the device that generates the discrete cursor movement on the screen and that might impact on the subjective feelings about the device design and discomfort in particular body regions. Therefore, a new accuracy measure of the cursor movement distance D_e is proposed to provide an explanation of the cursor movement behaviour, as shown in Eq. (6). D_e is the cursor movement distance calculated by the sum of the micro-distances between the coordinates of the start point of and those of the end point. Unlike movement time or standard deviation of the endpoint, D_e is based on a single measurement per trial.

Furthermore, a new model ID_{e2} is proposed by the replacement of the ordinary target distance D with the new accuracy measure D_e, shown in Eq. (6). Thus, ID_{e2} could be used to explain *why* some devices, tasks or people, are more efficient than others and is vital for expanding the theoretical knowledge base on the measurement of the performance of neutral human body motion.

In order to collect the objective measures of human performance and the new accuracy measure of D_e, a graphical measurement platform was developed, namely the Fitts' Law Generator (FLG). Based on the use of the FLG software, the result discussed in Chapter 4 has highlighted that the adjusted $R^2 = 0.638$ is achieved for the prediction of the movement time *MT* across ID_{e2} with the ordinary mouse, which is better than that found in the current studies. The result highlights the validity of the FLG measurement platform and the associated new model $ID_{e2.}$ With reference to the target conditions, the analysis of variance shows significant effects on the movement time of the target angle ($F = 3.95$, $p<0.01$), the target weight ($F = 4496.96$, $p<0.01$) and the target distance ($F = 4361.26$, $p<0.01$). The result is consistent with current studies (Whisenand and Emurian, 1999f; Thompson *et al.*, 2004e). Hence, the effects of the target condition on the movement time MT are significant ($p<0.01$).

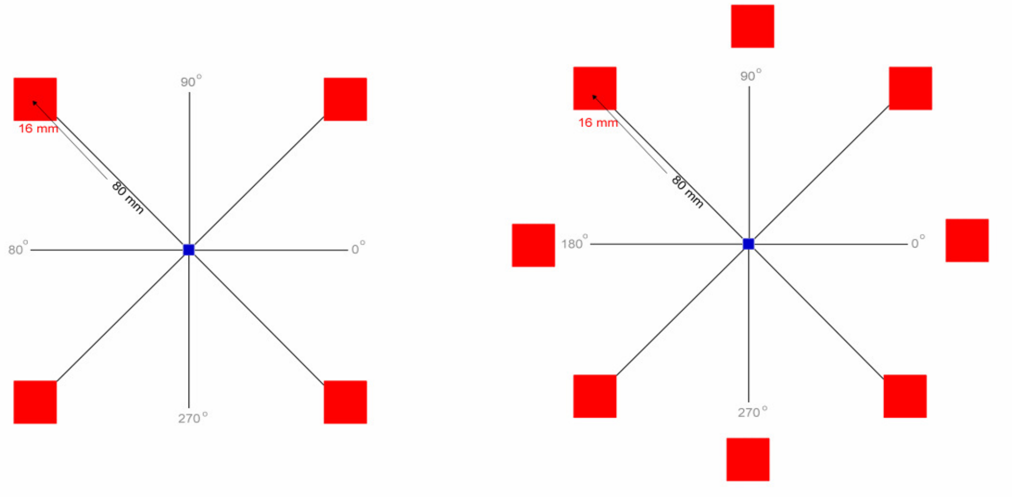
Furthermore, the advantages of using the FLG include the following (Chen and Chen, 2008a):

- Multi-directional human-centred performance can be measured, based on various Non-Keyboard Input Devices (NKIDs) used in WindowsXP/Linux/Mac operation environments.
- Allowing researchers to configure various target conditions to make control of the experiment efficient; for instance, the FLG software allows at least four types of angle of approach as proposed in the current studies (MacKenzie and Buxton, 1992; Whisenand and Emurian, 1999f; Thompson *et al.*, 2004e; Gleeson, *et al.*, 2004a) as demonstrated in Figure 73.
- The x and y coordinates of the cursor movement are captured in about 50 Hz, i.e. 50 times per sec. This allows D_e to be automatically calculated at the end of each trial. Other associated data of each trial, i.e. the x and y coordinates of the start point and end point, MT, AT, PT, $Error$ and TRE are recorded at about 170 Hz, i.e. 170 times per sec.
- Break time between blocks will be recorded.
- Access from the Internet is easy.



(a) Angle of Approach: 0 and 180 degree.

(b) Angle of Approach: 0 and 45 degree.



(c) Angle of Approach: 45,135, 215 and 315 degree.

(d) Angle of Approach: 0,45,90,135,180,215,270 and 315 degree.

Figure.73 At least four types of angle of approach can be represented by the FLG software

Moreover, the result of the trials that form part of this research indicate that the FLG measurement platform is very sensitive and able to detect the differences among different participants in terms of the micro-structure of the human performance with the gesture interfaces. Therefore, the FLG software is recommended for the study of human performance with various types of Non-Keyboard Input Devices (NKIDs). However, it should be noted that one of the disadvantages of using the FLG is that the result analysis, such as adjusted R^2, $S.D.$, W_e, etc, must be produced by the researcher himself/herself.

7.2.2. Subject selection criteria

In this research, the primary studies employ the same subject selection criteria, which help to reduce the variance caused by the effects of the individual difference. For instance, all participants used their preferred right hand to perform the tasks and reported over 6 years' experience with PCs. None of the participants reported uncorrected visual problems or physical limitations that would inhibit their use of the mouse as an input device. The age range is within the same category 17 to 32 approximately. The numbers in each gender group are nearly equal within each trial, as shown in Table 53.

Table.53 Summary of the participants selected for the user test with various gesture-based interfaces

Trial	Age range	Remark
Sweep-based gesture interface (P5 Glove)	●Females (n=5): 23 to 30 years. ●Males (n=5): 24 to 28 years	Chapter 4
Tilt-based gesture interface (V1)	●Females (n=52): 17 to 32 years ●Males (n=48): 18 to 32 years	Chapter 5
Tilt-based gesture interface (V2)	●Females (n=27): 18 to 25 years ●Males (n=16): 18 to 23 years	Chapter 6

7.2.3. Experiment design

Since the users differ in their physical condition[26], these individual differences can vary the result of the human performance measurement. In order to deal with the variance caused by the individual difference, the within-repeated measurement has been widely adopted by current Fitts' Law studies. It is a user test by repeating the same test with the same target condition for participants, thus a better estimate of the performance can be gained.

In this research, the within-repeated measurements based on the same target condition (see Table 54) was adopted in the trials with the working models V1 and V2, thus it is believed that the v caused by the individual difference has been reduced.

Table.54 Target Condition used with working model V1 and V2

Factors/Parameters	Levels
Width/Height (mm)	30, 45
Target distance (mm)	45, 90
Angle of Approach (degree)	0,45,90,135,180,225,270,315

Further meta-analysis was undertaken in order to validate that the device differences exerted a significant interactive effect (V1 (n=8,614) and V2 (n=3,879)) on the human performance when achieving the target condition. As a result, the analysis of variance revealed that the target distance *D* has the most influence on the total movement time *MT* with both working models (F=353, p<0.01), followed by target width *W* (F=170, p<0.01) and angle of approach (F=16, p<0.01). The result might be useful for the graphical user interface (GUI) design with the tilt- and gesture-based pointing devices. Furthermore, it is also revealed that the device differences are the main effect on the total movement time *MT* by the target width (F=713, p<0.01), the target distance *D* (F=718, p<0.01) and by the angles of approach (F=705, p<0.01). Therefore, the total movement time *MT* with the working model V2 is significantly faster than with the V1 based on the same target condition.

---

26. The cognitive aspect of the human being is not the focus of this research, since improvement of the cognition might not be an effective way to enhance the human performance for a point-and-click task; however, it will be discussed in the future.

7.2.4. Standard operation procedure (SOP)

In this study, four trials (Chapter 3, 4, 5 and 6) were all based on the same standard operation procedure (SOP), thus the difference caused by the process bias could be reduced. For instance, all participants invited by these trials were allowed to practise for a learning block. After the practice, participants were instructed to perform each task “as accurately as possible and as fast as possible” before the experiment. During the experiment, the FLG software randomly generated red target stimuli; a diagrammatic representation of several red square targets, displayed at different amplitudes from the measurement page of the FLG. Participants made a simple point-and-click between a permanent blue square target and a red square target in varying target conditions. A beep sounded if the button was clicked while the cursor was outside the target. The FLG recorded the angle of approach, target width, amplitude, the x and y coordinates of the start point and the end point, *MT*, *AT*, *PT*, *Error*, *TRE* in about 170 Hz and D_e in about 50 Hz. At the end of the experiment, each subject was asked to complete a five-point scale subjective questionnaire.

With regards to research limitations, since the experiment requested participants to operate pointing devices repetitively during a short period of time, the degree of tiredness depended on an individual’s physical condition, although a one-minute break between testing blocks was introduced.

7.2.5. Fitness-of-models

According to Whisenand and Emurian (1999f), an error occurred when a participant registered a target acquisition while the cursor was outside the target. However, the FLG software continued to measure variables, i.e. movement time, cursor movement distance and it stopped only upon successful acquisition of the target. Therefore, error cases are analyzed separately for all trials in this research.

In both Chapter 4 and 5, two mice were employed to centre the studies. The result indicates that there is a linear regression relation of the movement time *MT* across models with the mouse, as shown in Table 55.

Table.55 The prediction of the total movement time (*MT*) (ms) across models (ID, ID_e, ID_{e2}) with the mouse in Chapter 4 and 5

Device	N*	Models' prediction rate (adjusted R^2) **				Remark
		ID	ID_e	ID_{e2}	Predictable?	
Mouse A	3,652	0.31	0.31	0.31	Yes	Chapter 4
Mouse B	3,689	0.48	0.49	0.49	Yes	Chapter 5

* The error trials were excluded from the analysis.

** The linear regression analysis was applied on the adjusted data for the prediction of the movement time *MT* across models (ID, ID_e, ID_{e2}). The adjusted R^2 value was used since the sample size was different for each of the studies.

7.2.6. Subjective assessment

In Chapter 4, studying the P5 Glove, the inter-reliability test was applied on the subjective raw data and gave Cronbach's Alpha = 0.74 for design and Cronbach's Alpha = -0.6 for the discomfort in the particular body regions. Since the numbers of participants were few (participant n=10). The result is only considered to be a reference for future work.

As for the subjective assessment with the working models V1 (Chapter 5) and V2 (Chapter 6), the inter-reliability test discovered that inter-reliability about the design is very high with both the working models V1 and V2, thus the comparison can be made for both devices in terms of the design, the discomfort and the user experience, as summarised in Table 56.

Table.56 Inter Reliability Statistics with the working model V1 and V2

Subjective feeling	Cronbach's Alpha	
	V1	V2
Design	0.82	0.89
Discomfort	0.79	0.90
User Experience	0.89	0.85

7.3. Inter-discussion

7.3.1. Cursor movement behaviours and the Fitts' Law models

This research concludes that there is a relation between the cursor movement behaviour and the adjusted R^2 for the prediction of the movement time, MT, across models.

There were five pointing devices tested in this research, i.e. two mice, the sweep-based gesture interface P5 Glove and two tilt-based working models (V1 and V2). As can be seen in Figure 74, each device obtained a range of the adjusted R^2 values for the prediction of the total movement time across ID_e. As a result, the pointing devices within the blue block exhibit continuous cursor movement (adjusted $R^2 > 0.3$), followed by the devices with nearly continuous cursor movement within the green block (adjusted $R^2 > 1$ and < 0.3) and the pointing devices with the discrete cursor movement within the orange block (adjusted $R^2 < 1$ and ≒ 0).

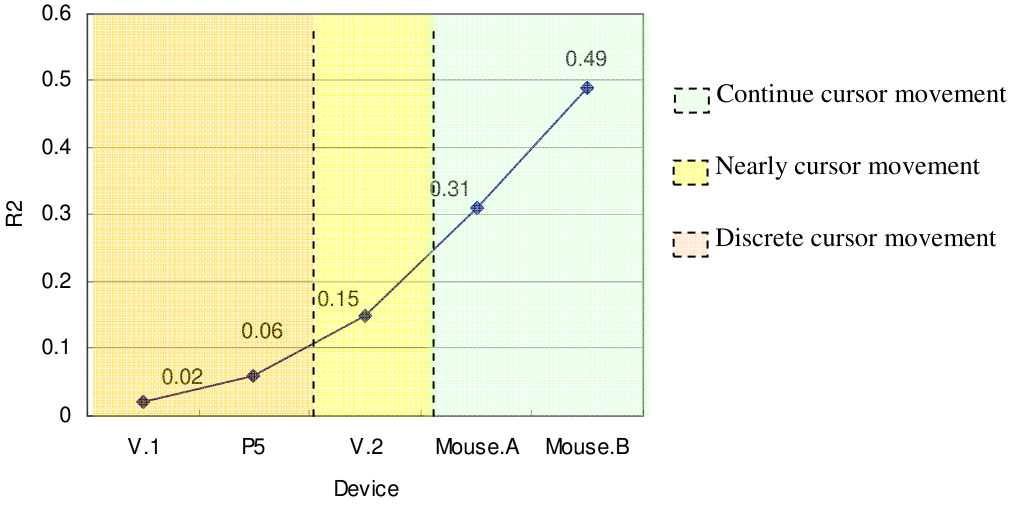


Figure.74 The prediction of the total movement time MT (ms) across ID_e with the various pointing devices tested in this research

(1) Pointing device with continuous cursor movement

Since the cursor movements were generated by the Operating System (OS) for the mouse, thus the continuous cursor movement is very smooth. As can be seen, there is a linear relation between the movement time MT and the three models, the adjusted R^2 =0.31 with the mouse A and the adjusted R^2 =0.48 with the mouse B across ID_{e2}. Hence, it is likely that pointing devices having the continuous cursor movement will have an adjusted $R^2 > 0.31$ for the prediction of the movement time MT across models.

(2) Pointing device with discrete cursor movement

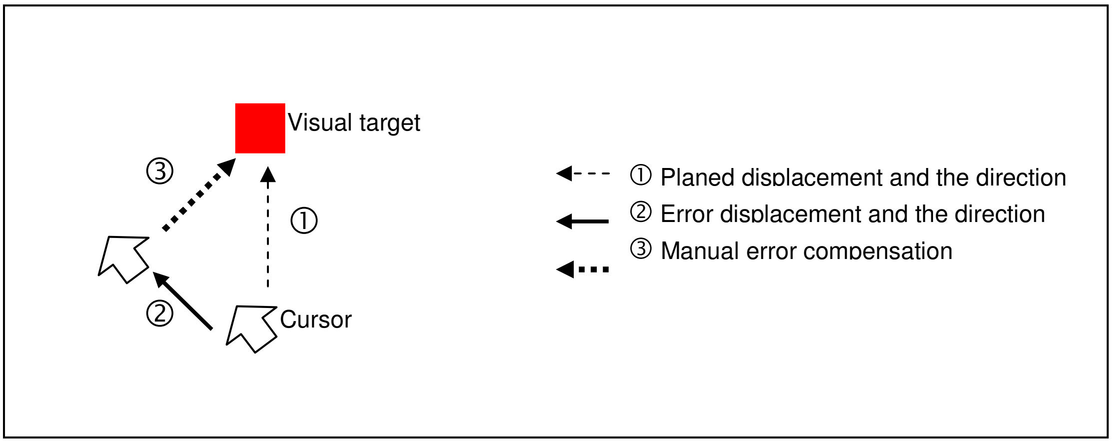
There is no linear relation of the movement time MT across the three models with the P5 Glove (adjusted R^2 =0.06) and with the working model V1 (adjusted R^2 <= 0.02). Both devices were reported by participants to have discrete cursor movement. Thus, it is logical to say that pointing devices having discrete cursor movement have an adjusted $R^2 < 1$ and $R^2 \risingdotseq 0$ for the prediction of the movement time MT across models.

(3) Pointing device with the nearly continuous cursor movement

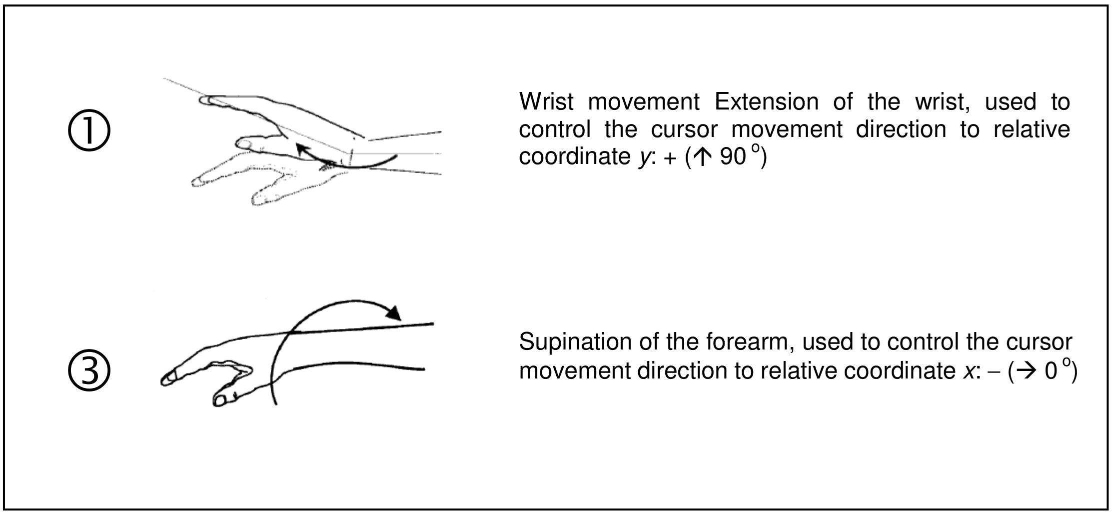
There is a linear relation of the movement time MT across ID_{e2} with the working model V2 (adjusted R^2 =0.15). The V2 employs the Peak Noise Compensation Unit, which removes the peak noise that was the major cause of the discrete cursor movement with the working model V1. However, the adjusted R^2 is lower than for the mouse. Therefore, it is likely that pointing devices having the nearly continuous cursor movement will have an adjusted $R^2 > 1$ and $R^2 < 0.3$ for the prediction of the movement time MT across models.

7.3.2. Cursor movement behaviours and the body movement

It has been identified that the peak noise is the major cause of the discrete cursor movement with the working model V1. Because there was no error compensation function to eliminate the peak noise, it caused the error displacement and direction, which generates the discrete cursor movement on the screen and which leads to the development of discomfort in the wrist by requiring extra types of wrist movements to be performed.



Cursor movement



Hand movement

Figure.75 The relation among the cursor movement and hand movement

As can be seen in Figure 75, if there is no peak noise, only one type of wrist movement (marked ①) is performed for the given target acquisition task. However, if there is peak noise, it causes the error displacement and direction (marked ②), which need to be manually compensated for by participants performing an extra type of wrist movement (marked ③).

Since the variance of the signal produced by both the decoding unit and the noise filter units have been verified by Freescale Co as being all within the default values stated in the data sheet, therefore, it is likely that the peak noise is produced by the mechanism sensor.

In the working model V2 (Chapter 6), by using the Peak Noise Compensation Unit in *Formula (3)* to replace the *Formula (2)*, it produces the nearly continuous cursor movement. Because of the nearly continuous cursor movement with the V2, 26 out of the 29 participants who attended both studies with the V1 and the V2 were found to have their joint ROMs reduced from a posture Type II or III with the working model V1, to the neutral posture (posture Type 1) with the V2.

7.3.3. Cursor movement behaviours and the subjective feelings

In terms of the design, participants gave a significantly higher score for all seven indicators (i.e. smoothness, effort, accuracy, speed, comfort and overall performance) with the working model V2 than with the V1. With regard to the discomfort, participants gave lower values for all body regions with the working model V2 than with the V1 and all of the discomfort levels among body regions are lower than the average (2.5). With respect to the user experience, the participants also felt more relaxed and experienced greater ease-of-use and usefulness with the V2 than with the V1.

7.3.4. Manners of button actuation and human performance

There were two button actuation manners tested within the same position and the same target condition, these were the flex sensor buttons used in the working model V1 (Chapter 5) and the mouse button used in the working model V2 (Chapter 6). The only human performance measure associated with the usability of the button actuation is the pointing time, *PT*. The differences between the two models are summarized in Table 57.

Table.57 The difference of the pointing time *PT* between the working model V1 and V2

Human Performance	Working model ***		*P value*
	V1 with flex sensor button (n=8,614)	V2 with mouse button (n=3,879)	
Pointing time *PT* (ms)*	258 ± 279	165 ± 113↓	<0.01**

* The error trials were excluded for the analysis.
** The difference between the devices is statistically significant.
*** The blue arrow ↓ means the improvement was made

Although the difference is significant but small, i.e. 93ms, the pointing time *PT* might have been influenced by the cursor movement behaviour shown on the screen because of the fact that the V1 exhibits discrete cursor movement on the screen whilst the V2's cursor movement is nearly continuous.

Since these button actuation manners were only the temporary replacement for each other, this research cannot conclude which one is the better. Nevertheless, it appears highly likely that both button manners can lead to discomfort in the wrist and have a different individual effect on it, owing to the fact that an individual's hand shape and the length and width of the fingers are different. Thus, the button actuation manners with gesture interfaces need to be further studied in the future.

7.3.5. Gender effect and gesture interfaces

As for the sweep-based gesture interface, it is likely that there are no gender effects on human performance with the sweep-based gesture interface, except for the error rate since the females tends to make significantly more error attempts than the males ($p<0.05$). However, since the P5 Glove produces a discrete cursor movement on the screen, the result might have been influenced by this effect. Therefore, this research cannot conclude that the females are at a disadvantage compared to males when using the sweep-based gesture interface.

In respect to the tilt-based gesture interface, there is a significant gender effect on the human performance with both the working models V1 and V2. Since the V1 produced the discrete cursor movement on the screen and both devices had poorly designed button actuation manners, this research cannot conclude that the females have a disadvantage when using the tilt-based gesture interface compared to males.

7.3.6. Mouse experience and gesture interfaces

As for the sweep-based gesture interface, no significant effect of the mouse experience on the human performance was found with the sweep-based gesture interfaces. Again, the P5 Glove produces the discrete cursor movement on the screen, which might have influenced the result. Therefore, this research cannot conclude that the mouse experience has no influence on the human performance with the sweep-based gesture interface.

As for the tilt-based gesture interface, the result indicated that there is a significant positive effect of the mouse experience on the human performance with the working model V1 and a significant negative effect of the mouse experience on the human performance with the working model V2. It might be concluded that the mouse experience might influence human performance with the tilt-based gesture interaction because these devices use the wrist movement frequently, thus the motor skill as well as the injury to the wrist might be transferable between these devices. However, the V1 produced a discrete cursor movement on the screen and both devices had poorly designed button actuation manners, these extra forces might have already influenced the result of the human performance. Hence, this research cannot conclude that the number of years using the mouse (i.e. mouse experience) could impact on, or contribute to, the human performance with the tilt-based gesture interfaces.

7.4. The advantages of the tilt-based gesture interface V2

By adopting the *Formula (3)* instead of *Formula (2)*, the research can conclude that the working model V2 produces the nearly continuous cursor movement like the ordinary mouse and that it also has the following advantages:

(1) The nearly continuous cursor movement

Chapter 6 validates that by using *Formula (3)* with the Zstar sensor pack, the difference between the planned working area and the actual working area can be reduced by maintaining the wrist and the hand in a nearly neutral posture. Based on the subjective assessment about the feelings of discomfort in the wrist, it also validates that there was a significant decrease in the wrist discomfort level when using the working model V2 in comparison with of the V1.

(2) Reduce the opportunity for manual error compensation

In the study with the working model V1, the participants need to perform a variety of manual error compensation strategies by the implementation of more complex wrist movements to deal with both the positive and negative error direction of the cursor movement for the target acquisition task randomly generated by the FLG testing platform. By using *Formula (3)*, the peak noise is removed and that also reduces the chance to perform extra wrist movements. However, the cursor movement is nearly continuous, thus it requires further improvement in the future.

(3) Similar cursor movement behaviour to the ordinary mouse

Figure 76 illustrates the design development of the working model from V1 to V2 in terms of the cursor movement behaviour. It is based on the matrix analysis of the cursor movement distance D_e and the target-Re-Entry *TRE*. In comparison with the ordinary mouse, the result highlights that there might be a potential market opportunity to introduce the tilt-based gesture interface into the desktop computer market dominated by the ordinary mouse. This is because the working model V2 resembles the ordinary mouse in terms of their similar movement behaviours. It is further suggested that a market survey and more user studies need to be done in the future in order to specify the detailed requirements of the future gesture interface for the point-and-click task, in particular for the development of a novel button actuation method for a hands-free interactive gesture system.

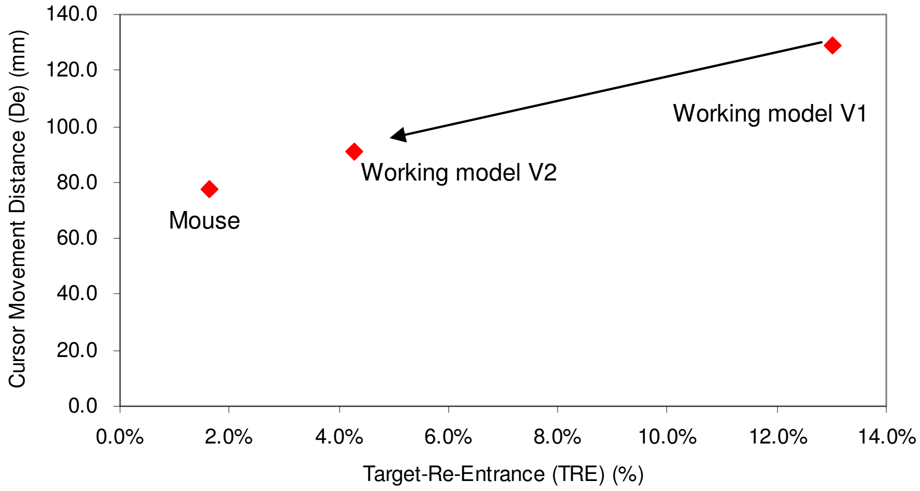


Figure.76 The change of the movement behaviour during the development of the working model in comparison with of the ordinary mouse. The data is found in Chapter 5 and 6. (The arrow means the improvement)

Chapter 8: Summary and strategy for future work

8.1. Summary of findings of the research

The research has achieved its aim to investigate the design factors of gesture interfaces for the point-and-click task in the desktop computer environment. The main finding of this research has been that there is a relation between the cursor movement behaviour and the adjusted R^2 for the prediction of the movement time across models expanded from Fitts' Law. It was also discovered that the malfunctions of the hardware and software of gesture interfaces can produce the discrete cursor movement. In such a situation, the actual working area and the joint ranges are lengthy and away from those that had been planned. Moreover, the research has contributed new knowledge through design improvements to tilt-based gesture interfaces and the improvement of the discrete cursor movement by elimination of the manual error compensation. The methods and the models are therefore recommended for the study of human performance with various types of NKIDs.

In Chapter 1, this thesis begins with an introduction and overview intended to raise awareness of existing problems. Owing to the lack of usage of the gesture interfaces, as yet there neither an international standard for the testing procedure nor a guideline for the design and development of ergonomic gesture interfaces. Moreover, there is no tilt-based gesture interface on the market at the present time. Hence, the research area demands more design case studies on a practical basis.

Chapter 2 proposes a new accuracy measure of the cursor movement distance D_e (Eq.6) to provide an explanation for the cursor movement behaviour with the new model (Eq.7). The design guideline with detailed design requirements and specifications for the tilt-based gesture interfaces was provided, based on the information given in the literature on the recent development of gesture interfaces, the International Standard ISO 9241-9 (ISO, 2000c), and the technical datasheets supported by Freescale Semiconductor Co., U.S.

In Chapter 3, a graphical measurement platform, namely the Fitts' Law Generator (FLG) for the data gathering of human performance, was designed and validated. As a result, an adjusted $R^2 = 0.572$ has been achieved as a prediction of the movement time across ID_e and which is consistent with the study by Whisenand and Emurian (1999f) who reported an adjusted $R^2 = 0.44$.

In Chapter 4, the relationship between the design problems with one of the commercial sweep-based gesture interfaces, namely the P5 Glove, was studied and the causes and effect of the discrete cursor movement on the usability was investigated.

In Chapter 5, based on the proposed design guideline, a tilt-based gesture interface using inertial sensor technology was developed, namely the working model V1. The critical design factors and associated usability problems of the V1 were investigated. As a result, the study identified that the button actuation using the flex sensor needs to be improved and that the malfunction of the cursor emulation program is the major cause of the discrete cursor movement. Both usability problems were validated as the critical design factors that impacted on the usability of the tilt-based gesture interactive system.

In Chapter 6, the new button actuation using the mouse button mechanism was installed and the peak noise was identified as the cause of the discrete cursor movement. A Peak Noise Compensation Unit was developed and the new cursor emulation program was developed and evaluated, namely the working model V2. As a result, the V2 was found to be better than the V1 in terms of human performance and subjective feelings. Compared with the study of the working model V1 in the previous trial, it answered the research question that the discrete cursor movement can lengthen the elbow and wrist joint angles when a malfunction in the cursor emulation program occurs.

Most of the phenomena and results from the trials undertaken, which are inter-related, are analyzed and discussed in Chapter 7. In particular, the continuous cursor movement allows the user to maintain a more neutral posture with the tilt-based gesture interface.

8.2. Suggestions for future research

(1) This research reveals that there is a relation between the visual feedback and the body movement with the gesture interaction system. Therefore, the theory should be extended for the study of a gesture-based interactive system with a wide working area, which might be of benefit for health and rehabilitation purposes.

(2) The FLG measurement platform is very sensitive and can detect the differences between different participants in terms of the micro-structure of the human performance. Therefore, the FLG software is recommended for the study of human performance with various types of NKIDs.

(3) The proposed triangular design approach has also been proved useful in helping to improve the design of the tilt-based gesture interface. In order to collect more qualitative data in terms of the cognition of the users, the interview and think-aloud methods are suggested for use with the proposed triangular design approach, which might be helpful in exploring the hidden design factors that influence the usability of complex, body-based interactions.

(4) These trials proved that the proposed observation method using the digital camera and digital video recorder (DV) are a very effective way to explore the relation between the cursor movement and the body movement with the gesture interfaces. This study suggests that advanced ergonomic techniques, such as 3D passive optical motion capture systems and the EMG, should be considered as an alternative approach, which offers an objective explanation.

(5) With respect to the sweep-based gesture interface, one of the critical design factors causing the discrete cursor movement on the screen is the fact that the markers on the hand can easily be out of the optical visual zone (OVZ) of the receiver of the P5 Glove on the desk. It requires further study to solve this problem and to validate whether the sweep-based gesture interface with the continuous cursor movement could prevent the development of discomfort in the arm and shoulder.

(6) Based on participants' suggestions, both *Fatigue* and *Button actuation* are the most critical design factors with the tilt-based gesture interfaces, which should be tackled in order to develop a better tilt-based gesture interface with better quality-in-use. In particular, the fact that the working model V2 requires participants to grasp the mouse in the palm and that a belt is needed to tighten the Zstar sensor pack on the hand, needs to be examined in detail. Further study needs to be done in order to develop a hands-free interactive gesture system for various tasks, such as point-and-click and typing in 3D space in a neutral posture.

8.3. Future of the input devices

Since this research pays particular attention to the design and development of the tilt-based gesture interfaces based on the implementation of the inertial sensors for a point-and-click task, there is a research opportunity for further study of the novel input devices in the following directions:

1. Feedback: In terms of the human-computer interaction, the human input depends on the tactile, auditory or visual senses of the user, which can be influenced by an action produced by the machine output. This can involve movement, touch or the actuation of an input device. Hence, the relation between the human inputs and machine outputs should be studied as part of the design process of novel input devices.
2. Freehand input in three-dimensional Visual Reality (VR): Haptic devices have been influencing the development of the input devices in virtual environments (Burdea, 2000a), thus their impact on the design of novel input devices requires more detailed investigation. In addition, except for the point-and-click tasks, the ISO 9241-9 (ISO, 2000c) recommends that various tasks for interactive office computer operation should also be investigated, such as dragging, typing, selecting, tracing and tracking.
3. Mobile/wearable computing: It was emphasized by Pagani (2004c) that the mobile multimedia services have created a new market opportunity for handheld devices. Therefore, the ergonomics of gesture interface design in this research should be expanded from desktop computer applications to mobile/wearable computing.
4. Body regions: This study focuses on the implementation of the forearm movement with gesture interfaces for ordinary people. Therefore, whether the novel input devices using the body movement of different regions could be of benefit to people with special needs for specific tasks could be deemed as future work of the first priority.

Appendix A:

C# code

(working model V2)

```
//**********************************************************************************************
//**********************************************************************************************
//      Zstar Decoding and Noise Filtering programme
//**********************************************************************************************
//**********************************************************************************************

// Start of the Zstar Decoding and Noise Filtering programme

        public void zstarRun()
        {
            Performance.Stopwatch timer = new Performance.Stopwatch();
            ArrayList resultArray = new ArrayList();
            ArrayList calibrationArray = new ArrayList();
            DataRecived data = new DataRecived();
            DataPositioning x = new DataPositioning();
            DataPositioning y = new DataPositioning();
            DataPositioning z = new DataPositioning();

            _serialPort = new SerialPort("COM3", 9600, Parity.None, 8, StopBits.One);
            _serialPort.NewLine = "\r\n";
            _serialPort.Encoding = System.Text.Encoding.ASCII;
            _serialPort.DataReceived += new
                SerialDataReceivedEventHandler(serialPort_DataReceived);
            _serialPort.Open();

            double gSelection = 1.5;

            double timeSpent = 0;
            double sampleingRate = 0;
            double timeInterval;

           // 1) send  "R" to reset ZSTAR …which means you will work in 8-bit mode.

            _serialPort.Write("R");
```

```
            for (int i = 0; i < calibrationCycle; i++)
            {
                _serialPort.Write("K");

           // 2) if first byte recieved for "K" comment is "X" (0x58) then process data

                if (KK[0] == 0x58)
                {
                    data.xG0 = KK[1];
                    data.xG1 = KK[2];
                    data.yG0 = KK[4];
                    data.yG1 = KK[5];
                    data.zG0 = KK[7];
                    data.zG1 = KK[8];
                }

                // 3) send  “V” to get 17byte RAW message ” x..y..z.. ”

                _serialPort.Write("V");

                // 4) if first byte recieved for "V" comment is "x" (0x78) then process data

                if (VV[0] == 0x78)
                {
                    data.xRaw = VV[1];
                    data.yRaw = VV[3];
                    data.zRaw = VV[5];
                }

                // 5) to cacluate G force for x,y,z

                data.xReal = ((data.xRaw - data.xG0) * gSelection) / (data.xG1 - data.xG0);
                data.yReal = ((data.yRaw - data.yG0) * gSelection) / (data.yG1 - data.yG0);
                data.zReal = ((data.zRaw - data.zG0) * gSelection) / (data.zG1 - data.zG0);

                xNew = data.xReal;
                yNew = data.yReal;
                zNew = data.zReal;
}

           updateDeadZoneBound();
```

```
for (int j = 0; j < samplingNumber; j++)
{
    // 1) send  “K” to get 9byte previous calibration message ” x..y..z.."

    _serialPort.Write("K");
    System.Threading.Thread.Sleep(emulationSensetivity);

    // 2) if first byte recieved for "K" comment is "X" (0x58) then process data,
         otherwise errorCountforK++

    if (KK[0] == 0x58)
    {
        data.xG0 = KK[1];
        data.xG1 = KK[2];
        data.yG0 = KK[4];
        data.yG1 = KK[5];
        data.zG0 = KK[7];
        data.zG1 = KK[8];
    }

    // 3) send  “V” to get 17byte RAW message ” x..y..z.. ”

    _serialPort.Write("V");
    System.Threading.Thread.Sleep(emulationSensetivity);

    // 4) if first byte recieved for "V" comment is "x" (0x78) then process data,
         otherwise errorCountforK++

    if (VV[0] == 0x78)
    {
        data.xRaw = VV[1];
        data.yRaw = VV[3];
        data.zRaw = VV[5];
    }

    // 5) to cacluate G force for x,y,z

    data.xReal = ((data.xRaw - data.xG0) * gSelection) / (data.xG1 - data.xG0);
    data.yReal = ((data.yRaw - data.yG0) * gSelection) / (data.yG1 - data.yG0);
    data.zReal = ((data.zRaw - data.zG0) * gSelection) / (data.zG1 - data.zG0);
```

```
                x.accelerationNew = data.xReal - xDeadZoneMean;
                y.accelerationNew = data.yReal - yDeadZoneMean;
                z.accelerationNew = data.zReal - zDeadZoneMean;

                if ((x.accelerationNew < xDeadZoneUpperBound) && (x.accelerationNew >
                xDeadZoneLowerBound))
                {
                    x.accelerationNew = 0;
                    x.accelerationOld = 0;
                }

                if ((y.accelerationNew < yDeadZoneUpperBound) && (y.accelerationNew >
                yDeadZoneLowerBound))
                {
                    y.accelerationNew = 0;
                    y.accelerationOld = 0;
                }

                if ((z.accelerationNew < zDeadZoneUpperBound) && (z.accelerationNew >
                zDeadZoneLowerBound))
                {
                    z.accelerationNew = 0;
                    z.accelerationOld = 0;
                }

// End of the Zstar Decoding and Noise Filtering programme
```

```
//*********************************************************************************
//*********************************************************************************
//     Cursor emulation
//*********************************************************************************
 //*********************************************************************************

// Start of the Cursor emulation

                //*************************************************************************
                //     Double Integration
                //*************************************************************************

                // Start of the Double Integration

                // 1) first integration

                x.velocityNew = x.velocityOld + x.accelerationOld + (x.accelerationNew –
                     x.accelerationOld) / 2;
                y.velocityNew = y.velocityOld + y.accelerationOld + (y.accelerationNew –
                     y.accelerationOld) / 2;
                z.velocityNew = z.velocityOld + z.accelerationOld + (z.accelerationNew –
                     z.accelerationOld) / 2;

                // 2) second integration

                x.positionNew = x.positionOld + x.velocityOld + (x.velocityNew - x.velocityOld)
                     / 2;
                y.positionNew = y.positionOld + y.velocityOld + (y.velocityNew - y.velocityOld)
                     / 2;
                z.positionNew = z.positionOld + z.velocityOld + (z.velocityNew - z.velocityOld)
                     / 2;

                x.accelerationOld = x.accelerationNew;
                y.accelerationOld = y.accelerationNew;
                z.accelerationOld = z.accelerationNew;

                x.velocityOld = x.velocityNew;
                y.velocityOld = y.velocityNew;
                z.velocityOld = z.velocityNew;

                if (x.positionNew > x.positionOld)
```

```
{
    xDirection = 1;
}
else if (x.positionNew < x.positionOld)
{
    xDirection = -1;
}
else
{
    xDirection = 0;
}

if (y.positionNew > y.positionOld)
{
    yDirection = 1;
}
else if (y.positionNew < y.positionOld)
{
    yDirection = -1;
}
else
{
    yDirection = 0;
}

stepXNew = Convert.ToInt32 (Math.Abs(x.positionNew * 10 - x.positionOld * 10));
stepYNew = Convert.ToInt32 (Math.Abs(y.positionNew * 10 - y.positionOld * 10));

// End of the Double Integration
```

```
//******************************************************************************************
//     Peak Filter Unit
//******************************************************************************************

// Start of the Peak Filter Unit

    if ((stepXNew - stepXOld) >= 50)
    {
        stepXNew = stepXOld;
    }

    if ((stepYNew - stepYOld) >= 50)
    {
        stepYNew = stepYOld;
    }

    xMagnitude = stepXNew - stepXOld;
    yMagnitude = stepYNew - stepYOld;

// End of the Peak Filter Unit

    xStepCumulated = xStepCumulated + (xMagnitude * xDirection);
    yStepCumulated = yStepCumulated + (yMagnitude * yDirection);

    if (xStepCumulated >= xScreenMax)
    {
        xStepCumulated = xScreenMax;
    }

    if (xStepCumulated <= 0)
    {
        xStepCumulated = 0;
    }

    if (yStepCumulated >= yScreenMax)
    {
        yStepCumulated = yScreenMax;
    }

    if (yStepCumulated <= 0)
    {
```

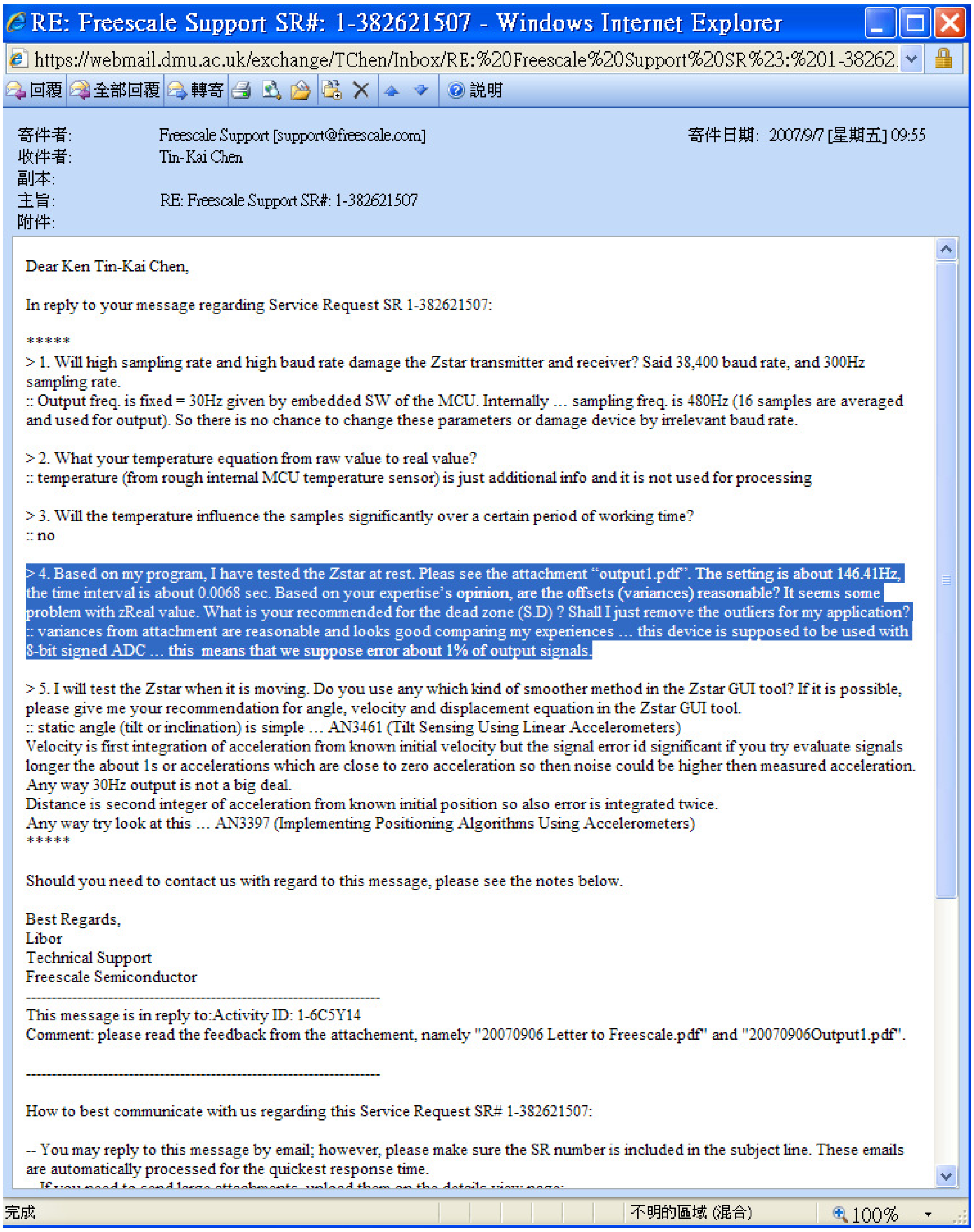
```
    yStepCumulated = 0;
}

mouse_event(MouseEventFlag.Move, (int)(xDirection * xMagnitude),
     (int)(yDirection * yMagnitude), 0, UIntPtr.Zero);

stepXOld = stepXNew;
stepYOld = stepYNew;

//movement_end_check

if (x.accelerationNew == 0)
{
    countX++;
}
else
{
    countX = 0;
}

if (y.accelerationNew == 0)
{
    countY++;

}
else
{
    countY = 0;
}

if (z.accelerationNew == 0)
{
    countZ++;
}
else
{
    countZ = 0;
}

x.positionOld = x.positionNew;
y.positionOld = y.positionNew;
```

```
                z.positionOld = z.positionNew;

            }
            _serialPort.Close();

}

// End of the Cursor emulation programme
```

Appendix B:

Verification via Freescale

(Dated 7-Sept-2007)



RE: Freescale Support SR#: 1-382621507 - Windows Internet Explorer

https://webmail.dmu.ac.uk/exchange/TChen/Inbox/RE:%20Freescale%20Support%20SR%23:%201-38262

寄件者: Freescale Support [support@freescale.com]
寄件日期: 2007/9/7 [星期五] 09:55
收件者: Tin-Kai Chen
副本:
主旨: RE: Freescale Support SR#: 1-382621507
附件:

Dear Ken Tin-Kai Chen,

In reply to your message regarding Service Request SR 1-382621507:

*****
> 1. Will high sampling rate and high baud rate damage the Zstar transmitter and receiver? Said 38,400 baud rate, and 300Hz sampling rate.
:: Output freq. is fixed = 30Hz given by embedded SW of the MCU. Internally … sampling freq. is 480Hz (16 samples are averaged and used for output). So there is no chance to change these parameters or damage device by irrelevant baud rate.

> 2. What your temperature equation from raw value to real value?
:: temperature (from rough internal MCU temperature sensor) is just additional info and it is not used for processing

> 3. Will the temperature influence the samples significantly over a certain period of working time?
:: no

> 4. Based on my program, I have tested the Zstar at rest. Pleas see the attachment "output1.pdf". The setting is about 146.41Hz, the time interval is about 0.0068 sec. Based on your expertise's opinion, are the offsets (variances) reasonable? It seems some problem with zReal value. What is your recommended for the dead zone (S.D) ? Shall I just remove the outliers for my application?
:: variances from attachment are reasonable and looks good comparing my experiences … this device is supposed to be used with 8-bit signed ADC … this means that we suppose error about 1% of output signals.

> 5. I will test the Zstar when it is moving. Do you use any which kind of smoother method in the Zstar GUI tool? If it is possible, please give me your recommendation for angle, velocity and displacement equation in the Zstar GUI tool.
:: static angle (tilt or inclination) is simple … AN3461 (Tilt Sensing Using Linear Accelerometers)
Velocity is first integration of acceleration from known initial velocity but the signal error id significant if you try evaluate signals longer the about 1s or accelerations which are close to zero acceleration so then noise could be higher then measured acceleration.
Any way 30Hz output is not a big deal.
Distance is second integer of acceleration from known initial position so also error is integrated twice.
Any way try look at this … AN3397 (Implementing Positioning Algorithms Using Accelerometers)
*****

Should you need to contact us with regard to this message, please see the notes below.

Best Regards,
Libor
Technical Support
Freescale Semiconductor

This message is in reply to:Activity ID: 1-6C5Y14
Comment: please read the feedback from the attachement, namely "20070906 Letter to Freescale.pdf" and "20070906Output1.pdf".

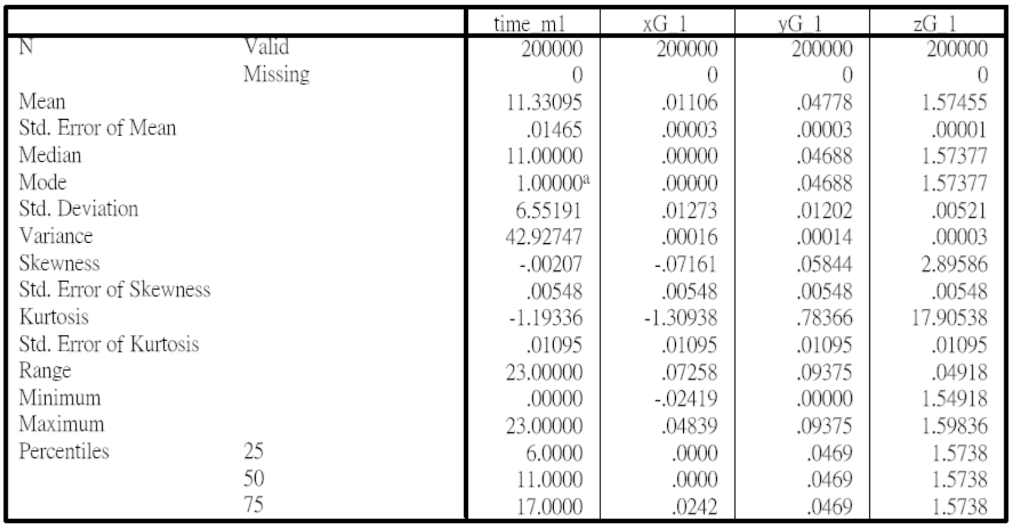
How to best communicate with us regarding this Service Request SR# 1-382621507:

-- You may reply to this message by email; however, please make sure the SR number is included in the subject line. These emails are automatically processed for the quickest response time.

Accordingly, the following analysis of variance analysis was sent to and verified by Freescale Co.

Frequencies

Statistics

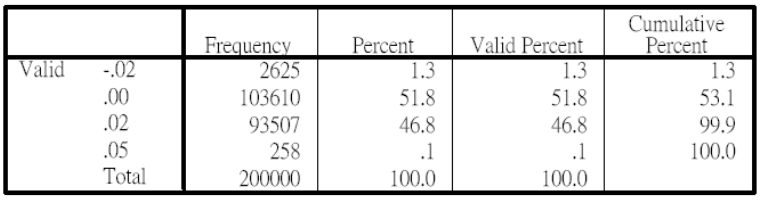


		time_m1	xG_1	yG_1	zG_1
N	Valid	200000	200000	200000	200000
	Missing	0	0	0	0
Mean		11.33095	.01106	.04778	1.57455
Std. Error of Mean		.01465	.00003	.00003	.00001
Median		11.00000	.00000	.04688	1.57377
Mode		1.00000[a]	.00000	.04688	1.57377
Std. Deviation		6.55191	.01273	.01202	.00521
Variance		42.92747	.00016	.00014	.00003
Skewness		-.00207	-.07161	.05844	2.89586
Std. Error of Skewness		.00548	.00548	.00548	.00548
Kurtosis		-1.19336	-1.30938	.78366	17.90538
Std. Error of Kurtosis		.01095	.01095	.01095	.01095
Range		23.00000	.07258	.09375	.04918
Minimum		.00000	-.02419	.00000	1.54918
Maximum		23.00000	.04839	.09375	1.59836
Percentiles	25	6.0000	.0000	.0469	1.5738
	50	11.0000	.0000	.0469	1.5738
	75	17.0000	.0242	.0469	1.5738

a. Multiple modes exist. The smallest value is shown

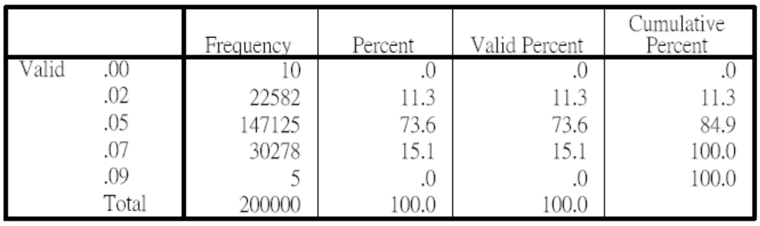
Frequency Table

xG_1



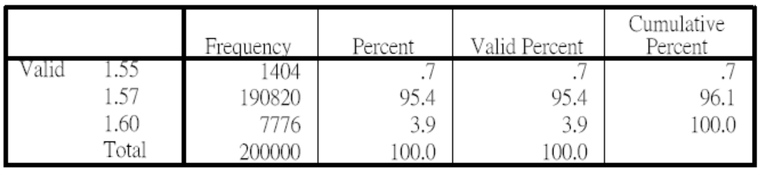
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	-.02	2625	1.3	1.3	1.3
	.00	103610	51.8	51.8	53.1
	.02	93507	46.8	46.8	99.9
	.05	258	.1	.1	100.0
	Total	200000	100.0	100.0	

yG_1

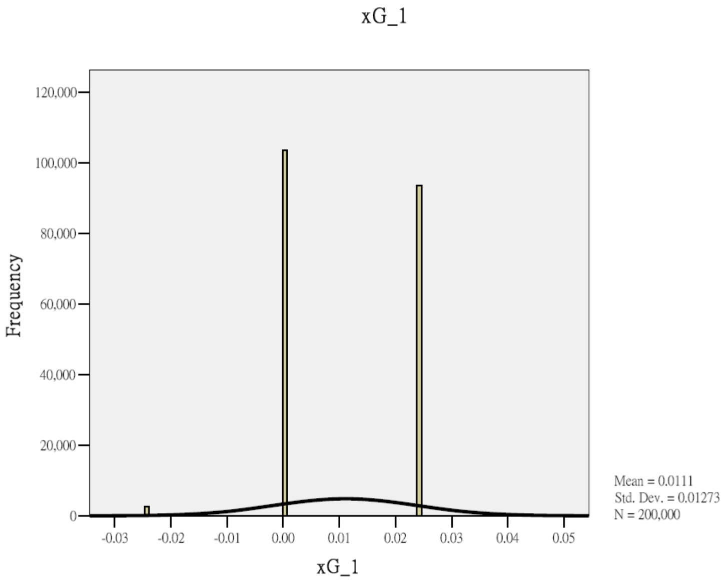


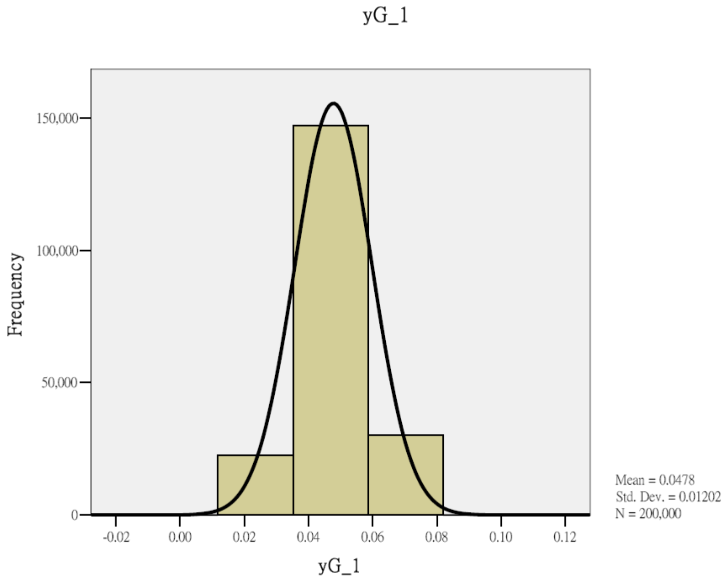
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	10	.0	.0	.0
	.02	22582	11.3	11.3	11.3
	.05	147125	73.6	73.6	84.9
	.07	30278	15.1	15.1	100.0
	.09	5	.0	.0	100.0
	Total	200000	100.0	100.0	

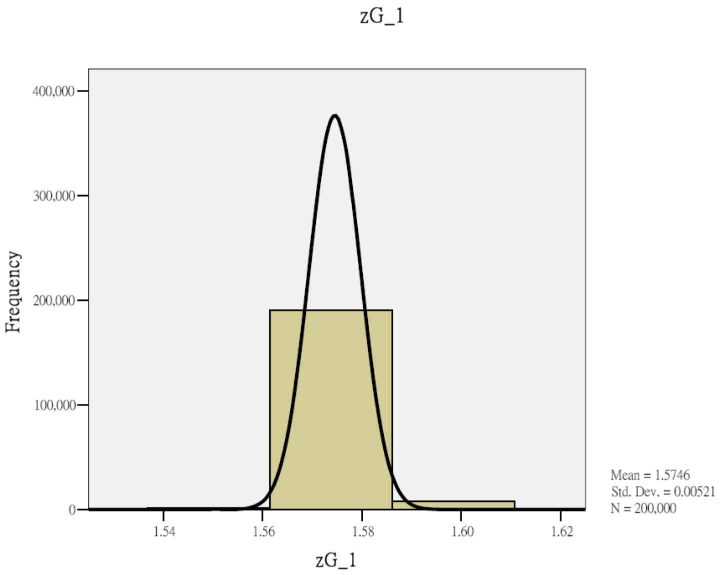
zG_1



		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1.55	1404	.7	.7	.7
	1.57	190820	95.4	95.4	96.1
	1.60	7776	3.9	3.9	100.0
	Total	200000	100.0	100.0	

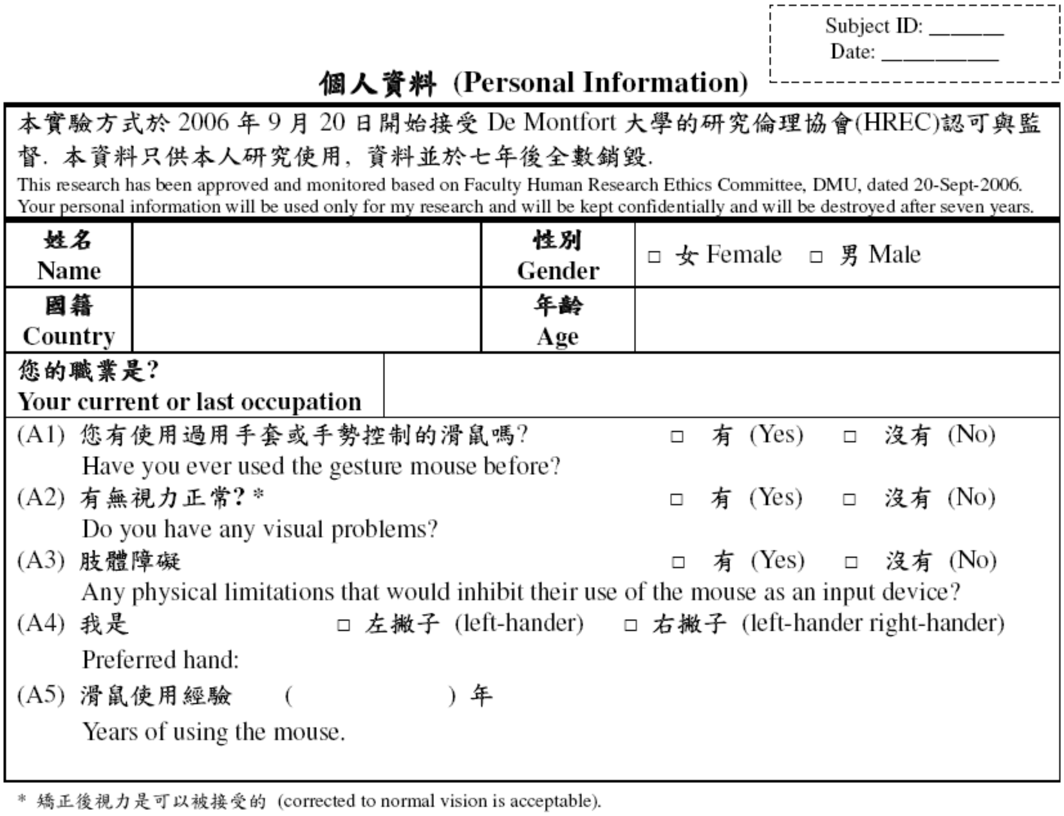

xG_1
Frequency
120,000
100,000
80,000
60,000
40,000
20,000
0
-0.03
-0.02
-0.01
0.00
0.01
0.02
0.03
0.04
0.05
xG_1
Mean = 0.0111
Std. Dev. = 0.01273
N = 200,000


yG_1
Frequency
150,000
100,000
50,000
0
-0.02
0.00
0.02
0.04
0.06
0.08
0.10
0.12
yG_1
Mean = 0.0478
Std. Dev. = 0.01202
N = 200,000


zG_1
Frequency
400,000
300,000
200,000
100,000
0
1.54
1.56
1.58
1.60
1.62
zG_1
Mean = 1.5746
Std. Dev. = 0.00521
N = 200,000

Appendix C:

Five-point Likert scale questionnaire



Subject ID: ______
Date: __________

個人資料 (Personal Information)

本實驗方式於 2006 年 9 月 20 日開始接受 De Montfort 大學的研究倫理協會(HREC)認可與監督. 本資料只供本人研究使用, 資料並於七年後全數銷毀.

This research has been approved and monitored based on Faculty Human Research Ethics Committee, DMU, dated 20-Sept-2006. Your personal information will be used only for my research and will be kept confidentially and will be destroyed after seven years.

姓名 **Name**		**性別** **Gender**	□ 女 Female □ 男 Male
國籍 **Country**		**年齡** **Age**	

您的職業是? **Your current or last occupation**	

(A1) 您有使用過用手套或手勢控制的滑鼠嗎? □ 有 (Yes) □ 沒有 (No)
Have you ever used the gesture mouse before?

(A2) 有無視力正常? * □ 有 (Yes) □ 沒有 (No)
Do you have any visual problems?

(A3) 肢體障礙 □ 有 (Yes) □ 沒有 (No)
Any physical limitations that would inhibit their use of the mouse as an input device?

(A4) 我是 □ 左撇子 (left-hander) □ 右撇子 (left-hander right-hander)
Preferred hand:

(A5) 滑鼠使用經驗 ( ) 年
Years of using the mouse.

* 矯正後視力是可以被接受的 (corrected to normal vision is acceptable).

主觀評比
(Subjective Assessment)

1. 裝置本身 Device	**非常不滿意 (Negative) ………………..**				**非常滿意(Positive)**
(C 1) 順暢 Operation smoothness	1	2	3	4	5
(C 2) 施力 Operation Effort	1	2	3	4	5
(C 3) 準確 Accuracy	1	2	3	4	5
(C 4) 快速 Operation speed	1	2	3	4	5
(C 5) 舒適 General Comfort	1	2	3	4	5
(C 6) 整體表現 Overall Operation	1	2	3	4	5
2. 身體本身 Comfort	**不會疲乏(Non) ………………………..**				**非常疲乏(Extreme)**
(C 7) 手指 Finger fatigue	1	2	3	4	5
(C 8) 手腕 Wrist fatigue	1	2	3	4	5
(C 9) 手臂 Arm fatigue	1	2	3	4	5
(C 10) 肩膀 Shoulder fatigue	1	2	3	4	5
(C 11) 脖子 Neck fatigue	1	2	3	4	5
(C 12) 背部 Back fatigue	1	2	3	4	5
(C 13) 眼酸 Eye Strain	1	2	3	4	5

(F) 互動經驗

(User experience)

3. 使用經驗 (User experience)	**反對(Disagree) ……….**				**贊同(Agree)**
(F 1) 好維護清潔 The device is easy to keep clean and maintain.	1	2	3	4	5
(F 2) 適合在桌面上使用 The device suitable for the layout of the desk.	1	2	3	4	5
(F 3) 不容易疲累 The device encourages a relaxed arm and a straight wrist.	1	2	3	4	5
(F 4) 讓我看起來很前衛 I feel tense or on edge because I am using the device	1	2	3	4	5
(F 5) 覺得與眾不同 Using the device makes me feel physically different.	1	2	3	4	5
(F 6) 有趣 It is fun to use the device	1	2	3	4	5
(F 7) 安全不受到傷害 I do feel secure and not harmful when using the device.	1	2	3	4	5
(F 8) 容易 (請留下您寶貴的意見) I find ease of using the device.	1	2	3	4	5
(F 9) 好用 (請留下您寶貴的意見) I find usefulness of using the device.	1	2	3	4	5
(F 10) 有發展潛力 (請留下您寶貴的意見) I find the potential of this device.	1	2	3	4	5

請留下您寶貴的意見，謝謝 (Comments):

Appendix D: Abbreviations

5^{th} $\%ile$	5^{th} percentilt = $Mean - (F\ value\ \times\ S.D.)$
50^{th} $\%ile$	$Mean$
95^{th} $\%ile$	95^{th} percentilt = $Mean + (F\ value\ \times\ S.D.)$
AT (ms)	Approaching time AT is the time length between the start point and the time the cursor enters the target is measured.
D_e (mm)	D_e is the cursor movement distance calculated for each trial.
FLG	Fitts' Law Generator
MT (ms)	Total movement time MT = Approaching time AT + Pointing time PT
NKIDs	Non Keyboard Input Devices
PT (ms)	Pointing time PT is the time length between the time the cursor enters the target and the time an attempt is success is measured.
QFD	Quality Function Development
$S.D.$	Standard deviation
TRE (%)	When the cursor enters the target, Target re-entry TRE will be counted.
W_e (mm)	Effective target width, which is standard deviation of endpoint.
ID	Index of Difficulty
ID_e	Effective Index of Difficulty

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