UNIVERSITAS INDONESIA

FACTORS AFFECTING PERFORMANCE OF TARGET ACQUISITION TASK IN TOUCHPAD

TESIS

Diajukan sebagai salah satu syarat untuk memperoleh gelar Magister Teknik

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Telah berhasil dipertahankan di hadapan Dewan Penguji dan diterima sebagai bagian persyaratan yang diperlukan untuk memperoleh gelar Magister Teknik pada Program Studi Teknik Industri, Fakultas Teknik, Universitas Indonesia

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ABSTRACT

The performance and usability of the input device play an important role in providing better experience for the user. The touchpad is commonly known as a pointing device and is a predominant pointing technology for notebook computers. However, comparative evaluations have established that touchpad performance is poor in comparison with a mouse. The best setting of touchpad is also remaining unknown. Furthermore, there is no research that study about the velocity pattern in touchpad. To solve this drawback, this research attempts to implement Fitts' Law method, merely focused on touchpad. In the design of experiment, touchpad size and position filter are added as new independent variables, along with Control Display Gain, Distance, Width, and Angle, as the well-known variables in Fitts' Law researches. Two sizes of touchpad are prepared which consist of large (100*60) and small (65*36) sizes. In addition, position filter is set at 2 different levels: 30 and 50, moreover gain setting is set at 3 different levels of fixed gain: 0.5, 1, and 2. For the Fitts' Law Program, 3 different levels of distance (100, 300, and 500 pixel), 3 different levels of target width (10, 40, and 70 pixel), and 8 directions (0, 45, 90, 135, 180, 225, 270, and 315) are applied. Moreover, the dependent variables that are being studied are movement time, error count, movement count, target re-entry count, and peak velocity. In this experiment, 20 participants are recruited and ANOVA Split Plot is used as the method. In total, each participant performed 2592 trial movements (2 touchpad size × 3 position filter × 3 control display gain x 3 distance × 3 target size × 8 moving direction × 3 repetitions). As for the results, touchpad size significantly affects movement time, error count, movement count, and re-entry count. Position filter also significantly affects the re-entry count. The best setting acquired from result shows that filter 50 and gain 2 are better implemented for primary movement, and filter 30 and gain 0.5 are better applied in secondary movement. The result also shows that there is difference in angle for touchpad performance and mouse. The different behavior for touchpad user also differs in touchpad performance indicator. Moreover, clutching behavior on touchpad user makes touchpad velocity graph to be modeled into several primary movement. Furthermore, strong interaction between distance and gain influences Fitts' Law equation to be modified.

Keyword: Fitts' Law, Touchpad, Position Filter, Control Display Gain, Finger Velocity

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CHAPTER 1

INTRODUCTION

1.1 Research Background and Motivation

Nowadays, pointing device plays an important role in providing better experience for computer users. If user could control a pointing device to execute the task on the computer very well, they will undergo and enjoy a good experience; if not, they would believe that the device is not a reliable, controllable, and pleasurable tool. Thus, fast and accurate pointing devices are of considerable importance to users' overall task performance and to their subjective experience of a system (Hertzum and Hornbaek, 2005).

Pointing is a fundamental and the most frequent task in Graphical User Interface (GUI). The most common pointing device in computer is mouse, although others are also available, such as joystick, trackball, and touchpad. However, the strong existence of portable computer nowadays creates a different story. Due to constrained operating space in portable computer, a mouse is generally not practical, and so alternative pointing device is used. In this case, touchpad is found as a common alternative pointing device in portable computer. However, comparative evaluations have established that touchpad pointing performance is poor in comparison with a mouse (Douglas et al., 1999; MacKenzie et al., 2001; MacKenzie and Oniszczak, 1998).

On the other hand, nowadays it is quite difficult to find an easy-to-use touchpad. When somebody has a notebook, usually they buy a portable mouse as a replacement for the touchpad. The definition of easy to use for touchpad consist of several criteria, some of them are related to the velocity of the device. Generally, user wants the velocity of touchpad fast enough to reach the target, but also slow enough to click the target accurately. They also want the cursor is stable enough to click the target.

Furthermore, touchpad generally consists of several machines (position filter and control display gain) that are responsible for setting its sensitivity, velocity, and other functions. Position filter affects the smoothness of movement, and control display gain influences the velocity of cursor. Moreover, the best setting of touchpad is remaining unknown, and there is still no research that focuses on optimizing touchpad setting, besides CD gain, to achieve better performance.

Some previous studies have attempted to improve touchpad performance by (1) making the touchpad hardware more sophisticated (MacKenzie and Oniszczak, 1998; Hertzum and Hornbaek, 2005; Casiez et al, 2007; McCallum and Irani, 2009); (2) optimizing the control display gain (C:D gain), which produced various results such as CD gain has appreciable effect (Graham and MacKenzie 1995), negligible (Jellinek and Card, 1990), and still other is critical of gain concept (Accot and Zhai, 2001); and (3) devising new interaction techniques such as Drag-and-Pop and Drag-and-Pick which use the direction of the initial cursor movement to determine a set of likely candidate targets, and temporarily move these targets to the vicinity of the cursor (Baudisch et al., 2003). However, there is no research that focuses on improving touchpad setting and only for studying touchpad in Fitts' Law methodology.

On the other hand, there is also no research that study about the velocity pattern in touchpad. The previous study already examine velocity pattern for mouse, which has only one primary and one secondary movement (Thompson et al, 2007) and also velocity pattern in 3D movement, which affected by the depth and position (Lee and Wu, 2010).

For touchpad, no researchers focus their attention on its velocity graph. Some studies already point out about clutching (MacKenzie and Oniszczak, 1998; Hertzum and Hornbaek, 2005; Casiez et al, 2007; McCallum and Irani, 2009), therefore no research indicates the connection between clutching behavior and velocity graph in touchpad.

For that reason, this research concentrates on factors related to touchpad performance as the pointing device, which are position filter, CD gain, and also touchpad size. These three factors will be studied along with factors which are already well-known in Fitts' Law (distance, target size/width, and angle/direction). Moreover, the behavior of touchpad user is also observed, with purpose to examine the effect of different behaviors into user performance. The velocity graph in touchpad also is studied and compared to velocity graph in mouse to see the difference.

1.2 Research Objective

The purposes of this study are as below:

(1) To study about effect of touchpad size, position filter, control display gain, and their interaction to performance measurements.

(2) Examine the finger velocity of touchpad to determine gain setting

(3) Observe the behavior of touchpad user and compare the performance based on different behaviors

(4) Modify the formula of ID (Index of Difficulty) in Fitts' Law based on independent variables.

1.3 Research Limitations

There are certain limitations regarding the proposed approaches. In this study, the research constraints are:

- This research has 20 participants from Taiwanese race and different hand, assumed to represent all population generally.
- All of the participants are right-handed, therefore this research is not able to consider left-handed person.
- The control display gain being tested has only 3 levels: 0.5, 1, 2. Therefore, higher gain and lower gain are not tested.
- The position filter being tested has only 2 levels: 30 and 50. Therefore, higher or lower filter are not tested in this experiment.
- The design of this experiment follows Split Plot ANOVA because of hard-to-change factors such as touchpad size, position filter, and CD gain.

1.4 Research Framework

The framework of this research is organized as follows. First, background and purpose of this research are defined. Second, some previous literatures about Fitts' Law, movement and velocity curve, control display gain, and speed-accuracy tradeoff are reviewed. Third, the design of experiment is created, while independent and dependent variables of the experiment are defined at the same time. Fourth, the pilot test is conducted, and the result is evaluated as feedback to the design of experiment. The participants are recruited, and the experiment is conducted. The data is then analyzed by ANOVA Split Plot, Post-Hoc Test, and Regression Analysis, and the result is compared to previous researches. Finally, the conclusion and future research is drawned. The framework of this study is illustrated in Figure 1.1.

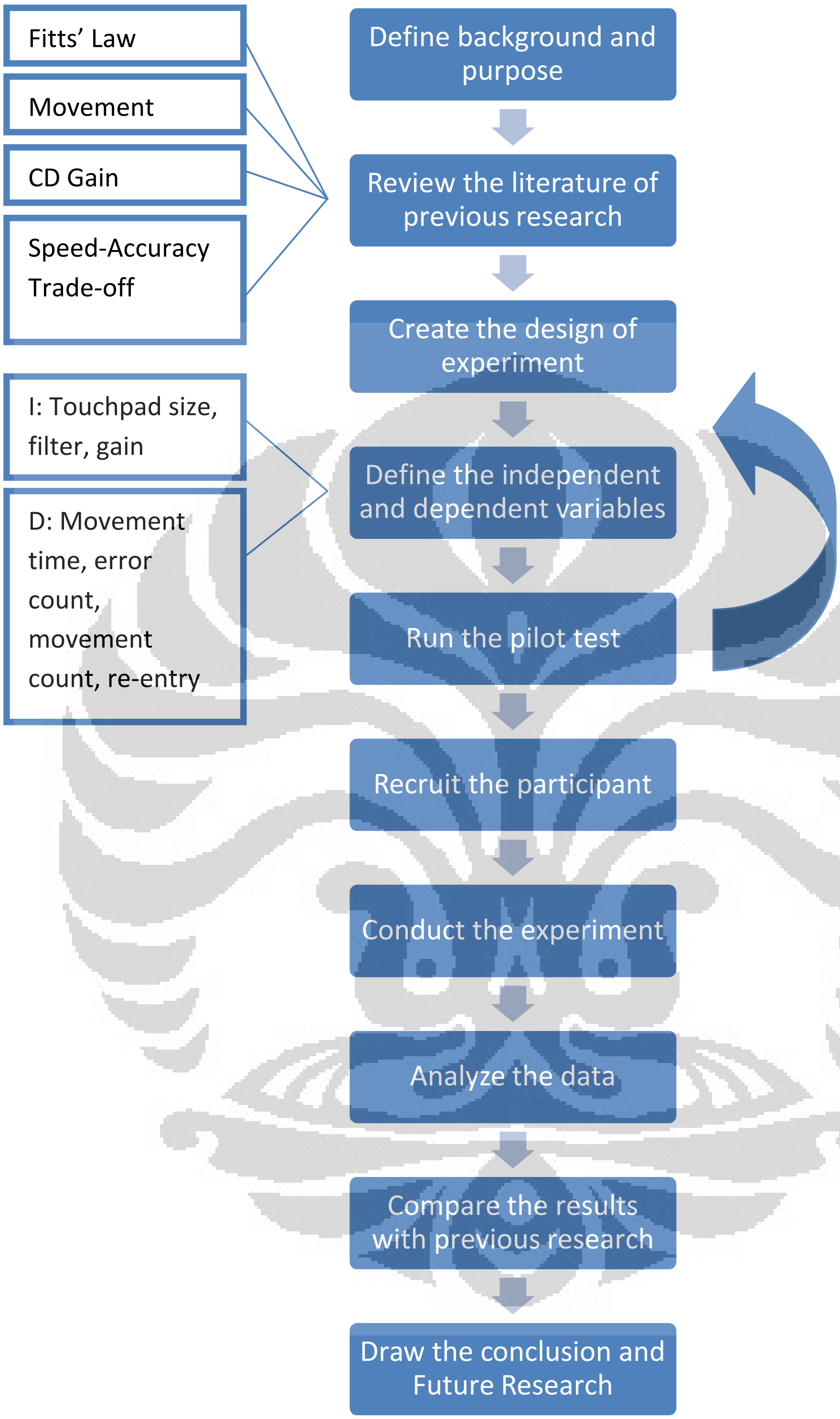


Figure 1.1 Research Framework

CHAPTER 2

LITERATURE STUDY

2.1 Touchpad

Touchpad is one of a pointing device featuring a tactile sensor, a specialized surface that can translate the motion and position of a user's fingers to a relative position on the screen. Nowadays touchpad is commonly found in notebook as a default pointing devices. However, in early years of portable computers, joystick and trackball are both used as pointing device. This changed in 1994 when Apple Computer, Inc. (Cupertino, CA) introduced the PowerBook 500 series of notebook computers, the first commercial computer with a built-in touchpad as a pointing device (MacNeill and Blickenstorfer, 1996). Since then, numerous notebook computer manufacturers have also adopted this technology. Today, the trackball is all but extinct in notebook computers. Joystick usage is also down, with IBM and Toshiba remaining as the key players (MacKenzie and Oniszczak, 1998). The touchpad is now the predominant pointing technology for notebook computers. Among the touchpad's important factors are price and size. It is very inexpensive to manufacture in large quantities, and it is very thin and is easily installed within the tight confines of a notebook computer (Akamatsu and MacKenzie, 2002).

Figure 2.1 Various Types of Touchpad

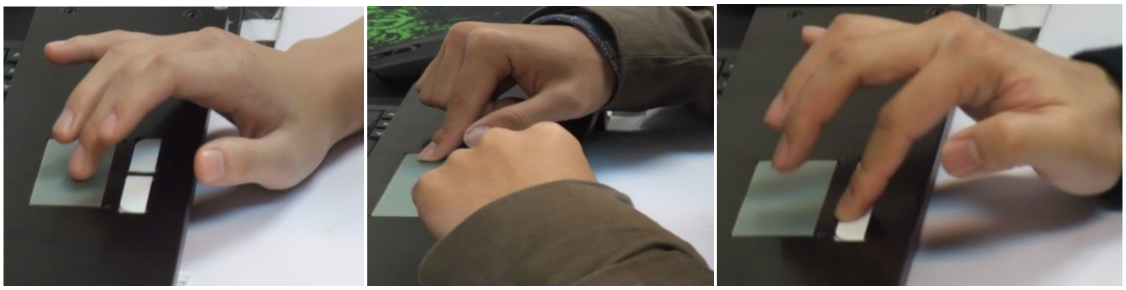


Figure 2.2 Three ways of using touchpad

Most touchpad include physical buttons that are typically operated with the index finger or thumb. Nowadays, people tend to use touchpad in three different ways. The first one is using one finger and tap in touchpad surface (as can be seen in left side of figure 2.2), the second way is using two hands with two fingers and tap in touchpad button (as can be seen in center side of figure 2.2), and the third way is using one hand and tap in touchpad button (as can be seen in right side of figure 2.2). For right hand users which usually use touchpad with two hands, they always use right finger to move the cursor, and left finger to click the button.

There are some previous studies related to improve touchpad performance by modifying its hardware. One of them study about tactile touchpad, and compare it to two conventional ways of selecting target (lift-and tap and button). They produced result that tactile touchpad performance is 20% faster than lift-and-tap and 46% faster than button (MacKenzie and Oniszczak, 1998). Furthermore, there is also a research from Akamatsu and MacKenzie (2002), who study about force applied to a touchpad during pointing task for large and small target and compare the touchpad performance with mouse. The result is pressure applied for touchpad is lower than mouse, therefore the finger force should be a variable in the touchpad's transfer function to afford a better blend of coarse and fine positioning strategies. Another research studies about TouchGrid, a different version of cell cursor. It replaces the behavior of moving the cursor through dragging the finger on a touchpad with tapping in different regions of the touchpad. TouchGrid is claimed significantly faster for small target and for tasks requiring one tap, and marginally faster for two-tap tasks (Hertzum and Hornbaek, 2005). Furthermore, Casiez et al (2007) studies about RubberEdge, which is purposed to reduced clutching behavior. RubberEdge is a 2D hybrid position-and-rate control technique using elastic feedback. RubberEdge can reduce clutching significantly, because it combines the ordinary touchpad with pressure-based pointing. Moreover, a research accomplished by McCallum and Irani (2009) introduce ARC-pad, a novel technique for interacting with large displays using a mobile phone's touch screen. The result shows that ARC-Pad is faster than with cursor accelerating technique, and ARC-Pad reduces clutching by half.

2.2 Fitts' Law

Acclaimed as one of the most successful human performance models, Fitts' Law has served as one of the few quantitative foundations for human-computer interaction (HCI) research. Fitts' Law is a robust human performance model that predicts target acquisition times in rapid aimed movements (Fitts, 1954). Fitts' Law establishes that the time required to perform basic aiming movements is a function of distance (D) between starting point to target and the target size (W). The original Fitts' formulation is written as below:

$$MT = a + b \log_2 (—) \qquad (1)$$

In this formula, MT is movement time, D is distance from home to target, W is target size, "a" represents the start/stop time of the device, and "b" represents the inherent speed of the device. Both are remained constant.

The continuous modification of new formula is executed by several researchers. Moreover, the most well-known formula modification is Shannon Formulation (MacKenzie, 1989, 1991, 1992a). The superiority of the Shannon formulation over the two other popular formulations, those of Fitts (1954) and Welford (1960), is well documented (MacKenzie, 1989, 1991, 1992a). The Shannon formulation is preferred because: (i) it provides a better fit with observations (a higher correlation-coefficient is typically achieved), (ii) it exactly mimics the information theorem that Fitts' law is based on (Shannon and Weaver, 1949, Theorem 17), and, (iii) with this formulation negative ID values are not possible. By using exact adaptation of Shannon's theorem, one can obtain even better fit of empirical data and always get a positive ID using a further modification as below:

$$ID = \log_2 (- + 1) \quad (2)$$

Accot and Zhai (2003) examined different scale dependencies, limit tasks, dominance effects, dualities, and continuities of the factors of target width, target height, and target distance with respect to pointing time. They demonstrated that of these factors, the interpretation of target width was most critical for the accuracy of the model. Reformulations of Fitts' law involve targets moving at constant velocity (Hoffmann, 1991). Models incorporate the target's velocity into a new index of difficulty for targeting tasks, where higher velocities imply more difficulty in targeting.

2.2 Movement and Velocity Graph

The movement in Fitts' Law studies is divided into two phase: the primary and secondary phase. The primary phase occurs when user move the cursor to the target for the first time that will highly increase the velocity. The secondary movement occurs when user already in the target area and adjusts cursor's position to correctly press the target. A reaction phase (initiation time) was determined as the time from the target appearing on the screen and the velocity of the hand exceeding 8% of peak velocity, and a verification phase was established as the last time when the velocity dropped below 2% and the mouse button was depressed inside the target (Thompson, McConnell, Slocum, and Bohan, 2007).

The "primary submovement time" followed the design of Jagacinski et al. (1980), Walker et al. (1993), and Thompson et al. (2007). For all pointing task, there are cases with and/or without a "secondary submovement." Identification of a "secondary submovement" is based on the size of the global peak velocity of the primary submovement and the subsequent local peak velocity. Following Thompson, et., al. (2007), the secondary submovement should fulfill criteria of : (1) the subsequent local peak velocity must have been at least 15% of the global peak; (2) local minimum velocities surrounding the local peak must have been at most 15% of the global peak and at most 50% of the local peak; and (3) a local minimum occurred not only when the graph turned back upward, but also when it leveled out to a near-horizontal slope. In the study, the slope was 0.5% of the global peak, per sample.

For tasks without a secondary submovement, the primary submovement started with the reach of hand velocity exceeding 8% of the peak velocity and ended with the dropped of hand velocity below 2% of the peak velocity. In this case, total movement time equal to primary submovement time.

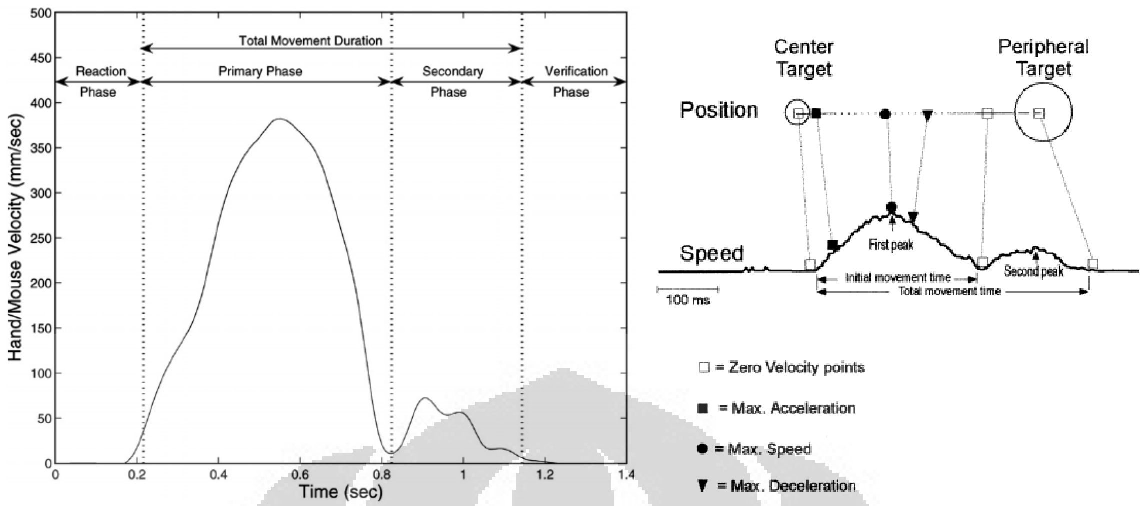


Figure 2.3 A sample velocity profile

2.3 Control Display Gain

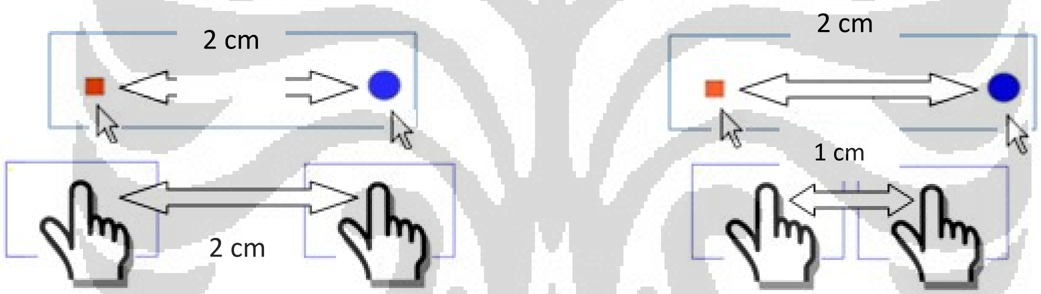


Figure 2.4 Illustration of gain 1 (left) and gain 2 (right)

Gain is defined as the amount of cursor movement on the display in response to a unit amount of movement of the control (Arnaut and Greenstein, 1986). For example, if the pointing device is moved one inch and the cursor moved two inches, the CD gain is 2. Where the relationship is a simple linear one, the term CD gain is used (Akamatsu and MacKenzie, 2002). CD gain is an important factor in touchpad, because touchpad has a very small size compared to user's primary display and require clutching (lifting the finger from touchpad surface and repositioning it) to move the cursor. Clutching degrades performance (Casiez et al, 2007), particularly when the display size is large. Therefore, a simple solution to minimize clutching is increasing the CD gain. However, increase CD gain reduces accuracy, making smaller objects more difficult to target (Casiez et al, 2008).

Jellinek and Card (1990) found that plotting mean selection times against CD gain resulted in a U-shape, with the best performance when CD gain was near 2 (no error rates were reported). They attributed the effect to increased clutching at low CD gain and to quantization at high gain. They tested CD gain levels of 1, 2, 4, 8, 16, 32, and their IDs ranged from 1.6 to 5.0, with a maximum target distance of 223 mm and a minimum target width of 7 mm.

Johnsgard (1994) found that higher CD gains decreased selection time when using a mouse and a virtual reality glove with mean error rates of 6.5% for the mouse. However, this experiment used low IDs (1 to 4) and low CD gain levels (1, 2, and 3) so any conclusion should be taken within this context (Casiez et al, 2008). He proposed an equation to model the result and demonstrated that it explained 81% of the variance of his data, as below:

$$MT = a + b \log_2 (\text{— —} + 1) \qquad (3)$$

The equation reduces to Fitts' law when CD gain equals 1 (G = 1). However, changing the CD gain divides both the distance and width of the target in motor space and thus should not change the motor space ID. This equation predicts that movement time decreases as CD gain is increased.

Fernandez and Bootsma (2004) manipulated the difficulty of the movement using target size, the orientation of the movement in the horizontal plane, and the CD gain. They found that an increasing gain caused a proportionate decrease in movement distance and target size when the difficulty of the task remained constant. Sandfeld and Jensen (2005) examined mouse gains of 2, 4, and 8, found a reduced working speed (an increased movement time of 1 sec), and hit rate at the highest mousing gain (8) when the target size was small. Higher gain enables faster cursor movements and the ability to make smaller micro-adjustments, and is preferred by users who employ higher risk-taking strategies (Hsu, et al., 1999). Gain can be a constant, a function of mouse acceleration, a function of cursor position (Blanch, et al., 2004; Keyson, 1997), or a logistic transformation of the displacement in the effector space (Fernandez and Bootsma, 2008). A change in CD gain highlights the roles of biomechanical and information processing factors in the tradeoff between speed and accuracy (Thompson, et al., 2007).

2.4 Speed-Accuracy Trade-off

The movement time and Index of Difficulty relationship in Fitts' Law had been briefly described by some formulations, as can be seen in table 2.1. From table 2.1, it seems clear that all researchers believe that target distance is negatively affect target size. It is shown in those equations, that A (target distance) is always divided by W (target size). The target distance is inversely related with target size, it stated the term "speed-accuracy trade-off" begins. Target distance is related to "speed", because to achieve the target faster, the speed must be as fast as possible, however, target size is associated with the accuracy, because to click the target in shortest time, the speed must be very accommodate to click the target as accurate as possible. In other words, the fastest speed may be useful to reach the target in shortest time, but would need longer time to click the target, especially if the target become smaller and smaller. Other models constructed to explain the speed-accuracy trade-off resulted in reformulations of Fitts' law to fit certain sets of experimental data (Crossman and Goodeve 1983; Jagacinski et al. 1980; Hoffman 1991; MacKenzie 1989; Meyer et al. 1988).

Table 2.1 Previous Research of Fitts' Law Reformulation

Authors	Equation	Remarks
Crossman (1956)	$MT = a + b \log_2 (—)$	The constant of "a" had a value of 0.05 sec
Welford (1968)	$MT = k \log_2 (— + 0.5)$	*k* is an experimentally determined constant
Welford et al (1969) Jagacinski et al (1980b)	$MT = a + b_A \log2 (A) + b_W \log2 (—)$ $MT = c + dA + e(V+1) (— - 1)$	V is the mean velocity of target movement, and c, d, e are fitting constant
Jagacinski et al (1980b)	$MT = p + q \log_2\{2[A + — (MT + T)]\}$ $MT = x + y \log_2 (—) + z \log_2 [\frac{}{/} + 1]$	T is constant; p, q, x, y, z are fitting variables
Hoffmann (1991a)	$MT = a+b \log_2 (A + —) – c \log_2 (— - —)$	K, a, b, and c are fitting parameters
Hoffmann (1992)	$MT = a + b (c + D) \log_2 (—)$	D is delay; a, b, and c are regression coefficient
MacKenzie (1989; 1992)	$MT = a + b (— + 1)$	
Gan & Hoffmann (1988)	$MT = a + b \sqrt{A}$	
Johnsgard (1994)	$MT = a + b \log2 (\frac{/}{} + 1)$	
Kvalseth (1980)	$MT = a (—)^b$	

2.5 State of The Art

This research strives to bring something "new" that other researchers have never pointed out before. Basically, this research is developed based on a few studies that have been conducted by previous researchers. Several studies that have previously developed can be seen in the following table (table 2.2).

Table 2.2 Relevant research that has been developed previously

Year	Jurnal Title (Author)	Contribution
1998	A Comparison of Three Selection Techniques for Touchpad (MacKenzie and Oniszczak)	Develop Tactile Touchpad and compare it to two ways of selecting target
2002	Changes in Applied Force to a Touchpad during Pointing Task (Akamatsu and MacKenzie)	The applied force for touchpad is lower than in mouse, the detected finger should be a variable in the touchpad's transfer function to make touchpad performance more inline with mouse
2005	TouchGrid: Touchpad Pointing by Recursively Mapping Taps to Smaller Display Regions (Hertzum and Hornbaek)	Replaces the behavior of moving the cursor through dragging the finger on a touchpad with tapping in different regions of the touchpad. TouchGrid is faster for small target and for tasks requiring one tap, and marginally faster for two-tap tasks
2007	RubberEdge: reducing clutching by combining position and rate control with elastic feedback (Casiez et al)	Introduce RubberEdge, which is a 2D hybrid position-and-rate control technique using elastic feedback. RubberEdge can reduce clutching significantly, because it combines the ordinary touchpad with pressure-based pointing.
2009	ARC-Pad: Absolute + Relative Cursor Positioning for Large Displays with a Mobile Touchscreen (McCallum and Irani)	Introduce ARC-pad, a novel technique for interacting with large displays using a mobile phone's touch screen. The result is ARC-Pad is faster than with cursor accelerating technique, and ARC-Pad reduces clutching by half.

The first one is this research focus on touchpad, while other researches mainly focused on mouse. Of course, there are some researchers that use touchpad in their study, but mainly use touchpad to compare it with another pointing device (MacKenzie, et al), or examine about the force applied in touchpad and compare it with mouse (Akamatsu and MacKenzie, 2002), or observe the tactile touchpad and compare it with lift-and-tap and button behavior (MacKenzie and Oniszczak, 1998). Still, no research concentrates in merely touchpad, to observe to its relationship with factors affecting its performance, to obtain the best setting, so that user can use the touchpad more comfortably. This research is attempted by that background. The second one, this research brings in some factors that will affect performance in touchpad, which is never studied by other researchers before. The factors are touchpad size and position filter. Thirdly, this research also attempts to examine the behavior of touchpad user and compare their performance, which never pointed out by other researcher before. Furthermore, this research also observes the finger velocity in touchpad to focus on the difference with the finger velocity in mouse, and also determine non-linear gain setting.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Design of Experiment

3.1.1 Participant

20 participants that consist of 10 male and 10 female, aged 21–29 years (23.4±1.9 years old), self-declared right-handed, participated in this study. They participated voluntarily and were paid for the study. All had normal or corrected-to-normal vision and no color blindness. They have been using computer for 10.7±2.7 year, their weekly computer use time is 45.50±13.7 hours, and their weekly touchpad use time is 6.5±5.8 hours. Signed informed consent is provided for participants before experiment begins.

3.1.2 Apparatus

3.1.2.1 Hardware

Figure 3.1 Hardware in Experiment

This experiment uses one notebook with 14 inch screen HP Notebook and two sizes of touchpad. The touchpad used in this experiment is not the default touchpad in the notebook, but the portable touchpad which is connected to the notebook using a small white wire.

3.1.2.2 Software

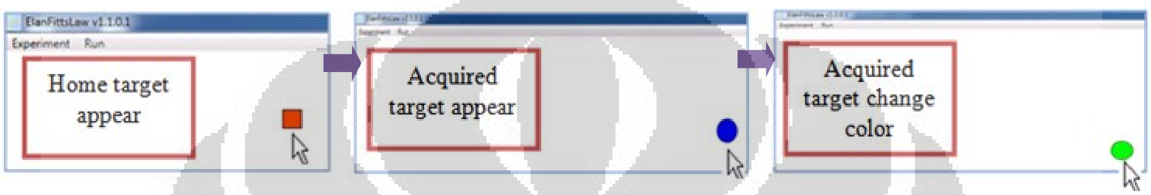


Figure 3.2 Illustration of the Fitts' Law Program

The Fitts' Law program applied in this experiment is a multidirectional tapping task. The home target is designed square-shaped, and the target is designed round-shaped. The reason why this study apply circular target is because square target may pose a problem. The problem is the dependent width upon the angle of approach. When approaching a square target from vertical or horizontal angle and from diagonal angle, the width is not the same. If the width is approached from diagonal angle, there is a greater effective width resulting in lower ID (Thompson et al, 2004; MacKenzie, 1995). Furthermore, the home has red color; the target has dark blue color. Color of target is changed into bright green if the cursor enters target boundary. It follows the reality task in Windows 7, where the color of icon or folder is changed when cursor enters target boundary. Target is settled to appear in random position in the screen.

3.1.3 Independent Variables

The independent variables of this experiment are touchpad size, position filter, gain, distance, width, and angle. Two sizes of touchpad are prepared which consist of large (100*60 mm) and small (65*36 mm). In addition, position filter is set at 2 different levels: 30 and 50, moreover gain setting is set at 3 different levels of fixed gain: 0.5, 1, and 2. For the Fitts' Law Program, we use 3 different levels of distance (100, 300, and 500 pixel), 3 different levels of target width (10, 40, and 70 pixel), and 8 directions (0, 45, 90, 135, 180, 225, 270, and 315).

3.1.3.1 Touchpad Size

The touchpad sizes applied in this experiment are 2 sizes: large and small. The large one represents large notebook (14" and 15" screen size) and the small one represents netbook which has screen size around 10".

3.1.3.2 Position Filter

The position filter in touchpad technology has a function for receiving a sensing signal captured by sensing pen, filtering and outputting the sensing signal utilized. It has function to filter the noise of finger signal. Position filter in this experiment consists of 2 types: 30 and 50. The 30 filter is heavier than filter 50. It means movement with filter 50 is smoother than moving with filter 30. However, filter 50 is more likely to have cursor noise and cursor jumping, because it is filtering less noise than filter 30.

3.1.3.3 Control Display Gain

The Control Display Gain used in this experiment is fixed gain, which consists of 0.5, 1, and 2. The series of fixed gain purposed for measuring the best gain for slow and high speed.

3.1.3.4 Index of Difficulty

In this experiment, ID range of 1.28-5.6 is being used. The ID varies from distance and width of the target, which follows Shannon Formulation.

3.1.3.5 Angle (Direction)

The direction applied in the experiment consists of 8 angles. The purpose of 8 angles is to see the difference between 8 directions in touchpad target acquisition task.

3.1.4 Dependent Variables

The dependent variables from this experiment are performance measurement from several variables: movement time, number of errors, number of movement count, and number of re-entry count.

3.1.4.1 Movement Time

Movement time is defined as the time between when the home target disappeared (the cursor moved away from the home target) and the acquired target is clicked.

3.1.4.2 Error count

Error is defined as the number of failures to click the target. If the participants fail to click the target, they have to redo the same combination.

3.1.4.3 Movement Count

Movement count is defined as number of finger movement participants executes to acquire the target in the touchpad. We are interested to study about this dependent variable because in touchpad target acquisition, the participants often doing clutching, which move several times to reach the target, especially in long distance target. It is because the limited size of the touchpad. However, mouse target acquisition does not need movement count as dependent variable, because when participants use mouse, they can move their arms freely in one movement.

3.1.4.4 Target Re-entry count

Target re-entry count is a variable which count how many times cursor enter target boundary before click the target. This variable is related to accuracy, and important to measure the difficulty to click the target.

3.2 Research Model

The means and standard deviations of all measurements are calculated using standard methods. This study uses split-plot analysis of variance (ANOVA) method to determine the effects of inter-subject variability, touchpad size, position filter, gain, target size, target distance, target width, and angle on the results. The Tukey HSD test is used to do post-hoc comparison. Regression is also used to modify the new Fitts' Law formula. An alpha value of 0.05 was selected as the minimum level of significance; data are presented as means or standard deviations (SD).

The split-plot ANOVA model consists of 6 independent variables: touchpad size, position filter, control display gain, distance, target width, and angle. The touchpad size, position filter, and control display gain serve as whole plot of this experiment, because they are categorized as hard-to-change factors. The whole plot consists of 12 combinations of touchpad size, position filter, and gain. Moreover, distance, target width, and angle are addressed as subplot, because they are classified as easy-to-change factors. The subplot consists of 72 combinations of distance, target width, and angle. The whole plot and subplot are counterbalanced to avoid learning curve effect. The block for this experiment is 20, comes from 20 participants. The 3 replications for each combination are averaged to get one single data. The model of split plot design can be viewed in figure 3.3 and table 3.1.

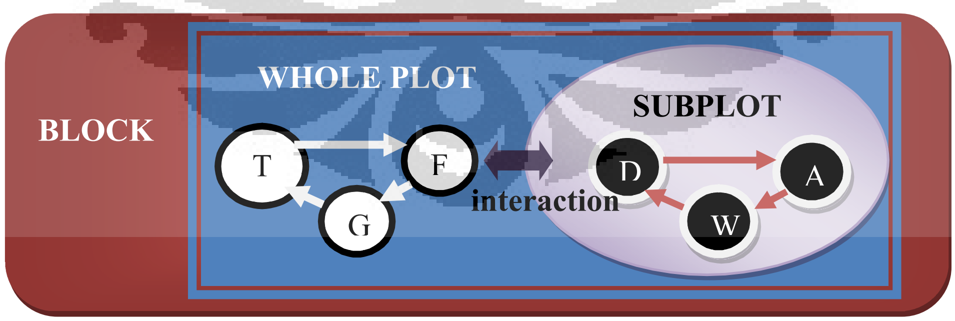


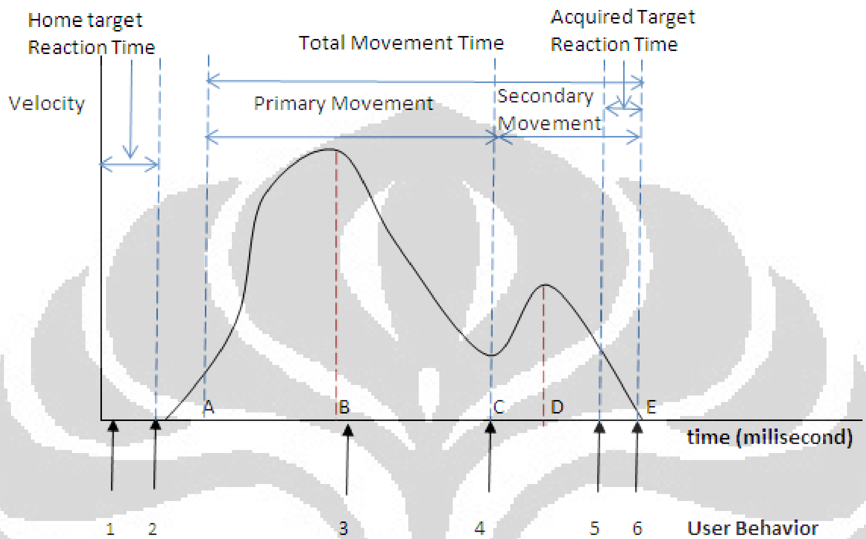
Figure 3.3 ANOVA Split Plot Model

Table 3.1 ANOVA Split Plot Illustration

Block	Whole Plot	Touchpad Size	Filter	Gain	Distance	Width	Angle
1	1	Large	30	0.5	Combination of Distance,Width,Angle (72 combinations)		
1	2	Large	30	1	combination of Distance,Width,Angle (72 combinations)		
1	3	Large	30	2	combination of Distance,Width,Angle (72 combinations)		
1	4	Large	50	0.5	combination of Distance,Width,Angle (72 combinations)		
1	5	Large	50	1	combination of Distance,Width,Angle (72 combinations)		
1	6	Large	50	2	combination of Distance,Width,Angle (72 combinations)		
1	7	Small	30	0.5	combination of Distance,Width,Angle (72 combinations)		
1	8	Small	30	1	combination of Distance,Width,Angle (72 combinations)		
1	9	Small	30	2	combination of Distance,Width,Angle (72 combinations)		
1	10	Small	50	0.5	combination of Distance,Width,Angle (72 combinations)		
1	11	Small	50	1	combination of Distance,Width,Angle (72 combinations)		
1	12	Small	50	2	combination of Distance,Width,Angle (72 combinations)		
continue ~ 20							

3.3 Target Acquisition Task

The target, cursor, and visual database are computer-generated. All participants performed target acquisition tasks to test the usability of the touchpad. In each task, participants will be instructed to click the home position first. The disappearance of the home signaled the start of the target acquisition task. After that, participants move cursor to reach the target, adjust the cursor to enter target boundary, and finally click the target. The processes are described in figure 3.4.



Note:

Point	Activity	Parameter
A	Beginning of primary movement	8% of peak velocity
B	Peak velocity of primary movement	
C	Beginning of secondary movement	
D	Peak velocity of secondary movement	At least 15% of peak velocity
E	End of the movement	2% of peak velocity

User Behavior	Activity	Parameter
1	Home target appeared	Home target color is Red
2	Click home target	Success: Home target disappear
		Not Success: Sound prompt, Home target not disappear
		Acquired target appear (color = dark blue)
		Finger down
3	Move to acquired target	
4	Adjust cursor to acquired target	
5	Cursor is in the acquired target area	The color of acquired target changed into green
6	Acquired target clicked	Success: Acquired target disappear
		Not Success: Sound prompt, acquired target disappear
		Finger down

Figure 3.4 Cursor and User Behavior

In total, each participant performed 2592 trial movements (2 touchpad size × 3 position filter × 3 control display gain x 3 target distance × 3 target size × 8 moving direction × 3 repetitions). Participants will be encouraged to complete the tests as quickly as possible. There will be only one target on the screen at a time. Successful pointing will be defined as click the target at its boundary. At this time, the target disappears, and it is marked as the end of a successful target acquisition task. If the participant failed to click the target, the feedback sound will be provided and the target will be disappear. Furthermore, participant is required to redo the failed combination.

3.4 Experiment Procedure

The workstation is consisted of a desk and an adjustable chair. Participants will be required to adjust the height of the seat, the location of the notebook, and the angle of the screen before the experiment began. Practice trials with the touchpad will be conducted before the actual experiment and continued until the participants reported that they felt comfortable and ready for the experiment.

To minimize the difficulties of touchpad replacement between trials, this study adopts a split plot design where each setting of design variable (touchpad, filter and gain) will be randomly assigned to each combination. In each setting, distance, width, and angle will be randomly assigned to each setting of design variables (touchpad, filter and gain). Each session lasted about 120 minutes. A rest period of 3 min between settings will be provided to prevent cumulative local muscle fatigue. Each participant completed all experimental tasks in 2 sessions, for approximately four hours.

Figure 3.5 Illustration of Experiment Running

CHAPTER 4

ANALYSIS

4.1 Finger Velocity

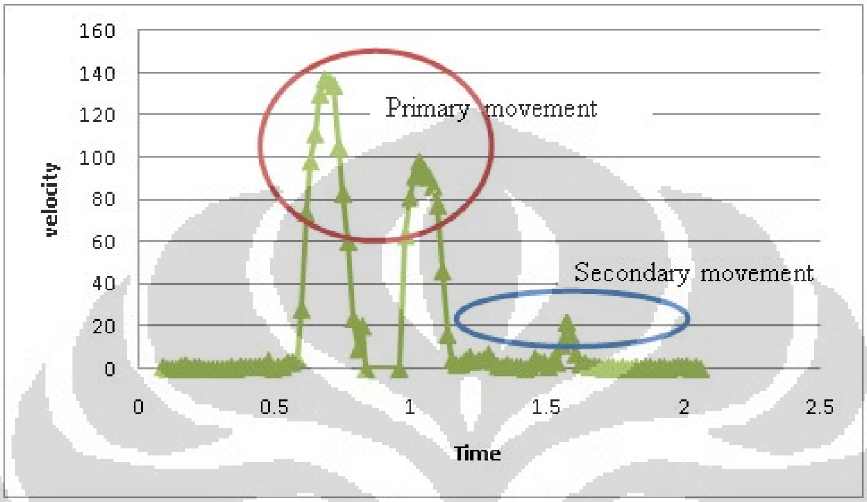


Figure 4.1 Finger Velocity of Touchpad

Target acquisition task using touchpad is different than using mouse, mainly because of the operation area differences. When using mouse, users can move their arm freely without boundary, while using touchpad, they only can move their finger in limited area, depends on the touchpad size. This difference will create a different velocity graph. From the observation and finger velocity data, we figure out that finger velocity in the touchpad consists of several primary movements and one or several secondary movement, depends on the target size, as viewed in figure 4.1.

The sample of velocity graph taken from gain 0.5, 1, and 2 shows that the peak velocity of primary movement differs from each other. In gain 0.5, the number of peak is 4 peaks; in gain 1, it has 3 peaks; and in gain 2, it has 2 peaks. The peak velocity is decreased when the gain value is higher.

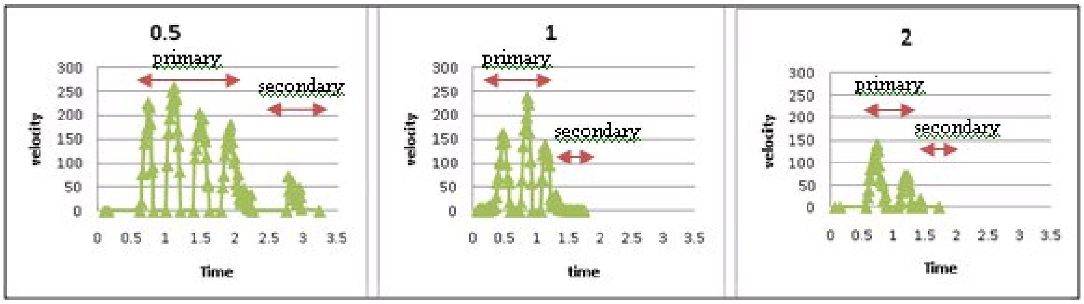


Figure 4.2 A sample of velocity graph in gain 0.5, gain 1, and gain 2

For examining the velocity graph in the touchpad, we take 192 samples from all velocity data. From 192 graphs, the duration of primary and secondary velocity is being studied, along with number of primary movement count. The result will be categorized in three main factors: touchpad size, position filter, and control display gain. It is because we want to see the difference of velocity graph only based on those three variables, in order to obtain the best setting of touchpad.

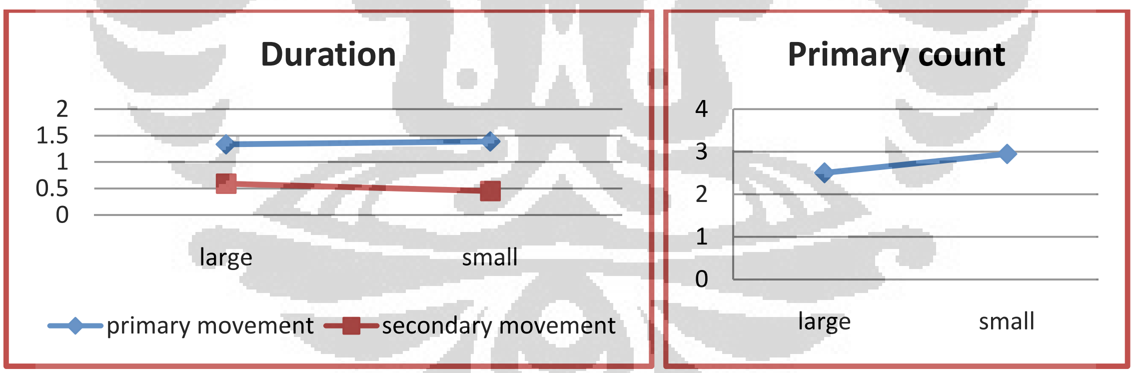


Figure 4.3 Touchpad Effect of Velocity Graph

As the result, in touchpad size, the large touchpad has lower movement time than small touchpad in primary movement, while in the secondary movement, the small touchpad spend lower movement time than large touchpad. For the primary movement count, small touchpad has higher value than large touchpad.

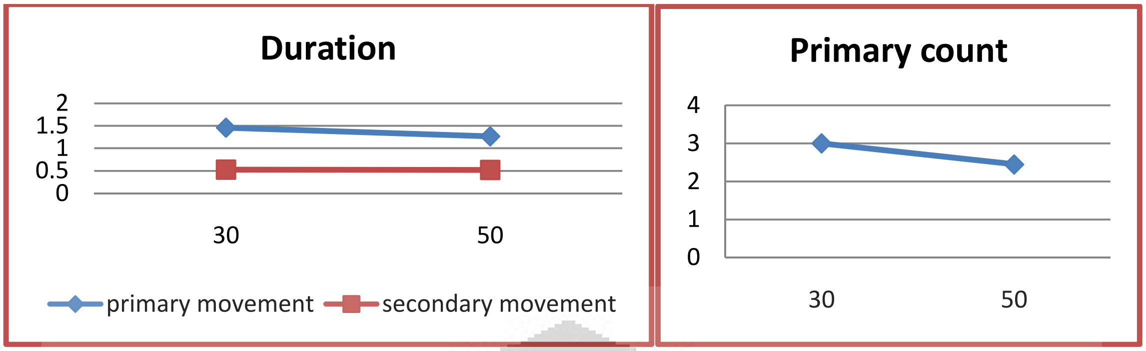


Figure 4.4 Filter Effect of Velocity Graph

From figure 34, filter 50 is better than filter 30 in primary movement. However, in secondary movement, filter 30 and filter 50 are not differed significantly. For primary movement count, filter 50 has lower value than filter 30.

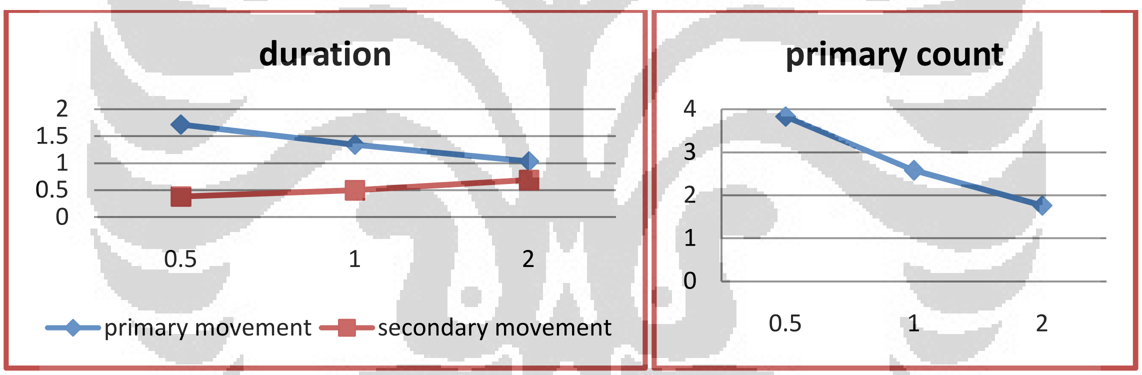


Figure 4.5 Gain Effect of Velocity Graph

In primary movement, the gain 2 has the lowest movement time, but in secondary movement, gain 2 has the highest movement time. Gain 2 is the best for primary movement, but gain 0.5 is better for secondary movement. For primary movement count, gain 2 has the lowest value than gain 1 and gain 0.5. Moreover, the primary count average for gain 2 (as the highest speed) is still above 1. It shows that gain 2 is not enough for high-speed movement.

4.2 ANOVA Analysis

After finger velocity is observed, the next step is to conduct ANOVA analysis. The purpose of this analysis is to determine the effect of touchpad size, filter, and gain to performance measurements. In this experiment, SPSS 18 is used to produce the results. Before run the data with ANOVA Split Plot analysis, outlier data is checked by Anderson-Darling Normality Test. Moreover, the descriptive statistic of performance measurement is presented in table 4.1.

Table 4.1 Descriptive Statistics of Performance Measurements

Constraint	Movement time	Error count	Movement count	Re-entry count
Touchpad size (mm)				
Large	2.069 (0.894)	0.24 (0.695)	3.033 (2.012)	1.184 (0.574)
Small	2.180 (1.007)	0.178 (0.56)	4.086 (2.872)	1.129 (0.39)
Filter				
30	2.151 (0.985)	0.201 (0.614)	3.581 (2.636)	1.145 (0.459)
50	2.098 (0.921)	0.217 (0.65)	3.538 (2.429)	1.168 (0.522)
Control Display Gain				
1:0.5	2.553 (1.101)	0.131 (0.411)	5.207 (3.134)	1.051 (0.233)
1:1	1.982 (0.778)	0.175 (0.522)	3.261 (1.85)	1.125 (0.379)
1:2	1.840 (0.792)	0.321 (0.859)	2.209 (1.185)	1.295 (0.704)
Distance (pixel)				
100	1.476 (0.567)	0.195 (0.607)	1.669 (0.844)	1.151 (0.473)
300	2.143 (0.751)	0.211 (0.659)	3.626 (1.839)	1.156 (0.5)
500	2.756 (1.011)	0.221 (0.629)	5.385 (2.875)	1.162 (0.5)
Width (pixel)				
10	2.665 (0.984)	0.45 (0.957)	3.918 (2.621)	1.353 (0.739)
40	1.944 (0.814)	0.101 (0.336)	3.501 (2.512)	1.089 (0.299)
70	1.766 (0.803)	0.075 (0.286)	3.260 (2.424)	1.028 (0.171)
Angle (deg)				
0	2.024 (0.841)	0.208 (0.608)	2.971 (1.948)	1.179 (0.532)
45	1.973 (0.811)	0.187 (0.592)	3.192 (2.139)	1.169 (0.473)
90	2.280 (1.085)	0.204 (0.612)	4.248 (3.112)	1.14 (0.5)
135	2.254 (1.045)	0.223 (0.722)	3.975 (2.747)	1.146 (0.46)
180	2.058 (0.887)	0.217 (0.656)	3.242 (2.102)	1.156 (0.483)
225	1.963 (0.835)	0.202 (0.598)	3.143 (2.090)	1.149 (0.448)
270	2.243 (1.026)	0.21 (0.617)	4.074 (3.012)	1.152 (0.494)
315	2.204 (0.991)	0.221 (0.642)	3.632 (2.504)	1.16 (0.534)

4.2.1 Movement time

Table 4.2 The summary of ANOVA table for movement time

Source	SS	DF	MS	F	Sig.
TP	158.449	1	158.449	14.114	.000
Filter	35.502	1	35.502	3.162	.077
Gain	4913.895	2	2456.948	218.848	.000
D	14184.404	2	7092.202	35504.649	.000
W	7819.143	2	3909.572	19571.914	.000
A	810.061	7	115.723	579.327	.000

Consistent with Fitts' Law, movement time increased with the Index of Difficulty (range from 1.28 to 5.6). With regard to the variables that compose this index, MT significantly increased as a function of distance (F=35504.649, p=0.000), and decreased as a function of target width (F=19571.914, p=0.000). As for the main plot, touchpad size affects MT (F=14.114, p=0.000) when small touchpad has higher movement time than large touchpad. MT also significantly increased as a function of gain (F=218.848, p=0.000), with high gain has lower MT than low gain. Angle of approach also has significance to MT (F=579.327, p=0.000), which angle 45 and 225 has the lowest movement time. However, filter effect is not significant in movement time, but the descriptive statistics shows that filter 50 (mean=2.098) has lower MT than filter 30 (mean=2.151). The interaction of all 6 factors also can be studied from the analysis. For interaction of the whole plot, Touchpad size*gain has significant interaction effect to movement time (F=14.676, p=0.000) and filter*gain also has slightly significant interaction effect to movement time (F=4.459, p=0.031). For interaction of whole plot and subplot, interaction of gain and distance generates a very significant value

(F=2969.919, p=0.000), followed by touchpad size*distance (F=368.362, p=0.000), gain*width (F=241.658, p=0.000), touchpad size*width (F=135.701, p=0.000), distance*angle (F=113.137, p=0.000), touchpad size*gain*distance (F=105.677, p=0.000), and gain*angle (F=103.35, p=0.000).

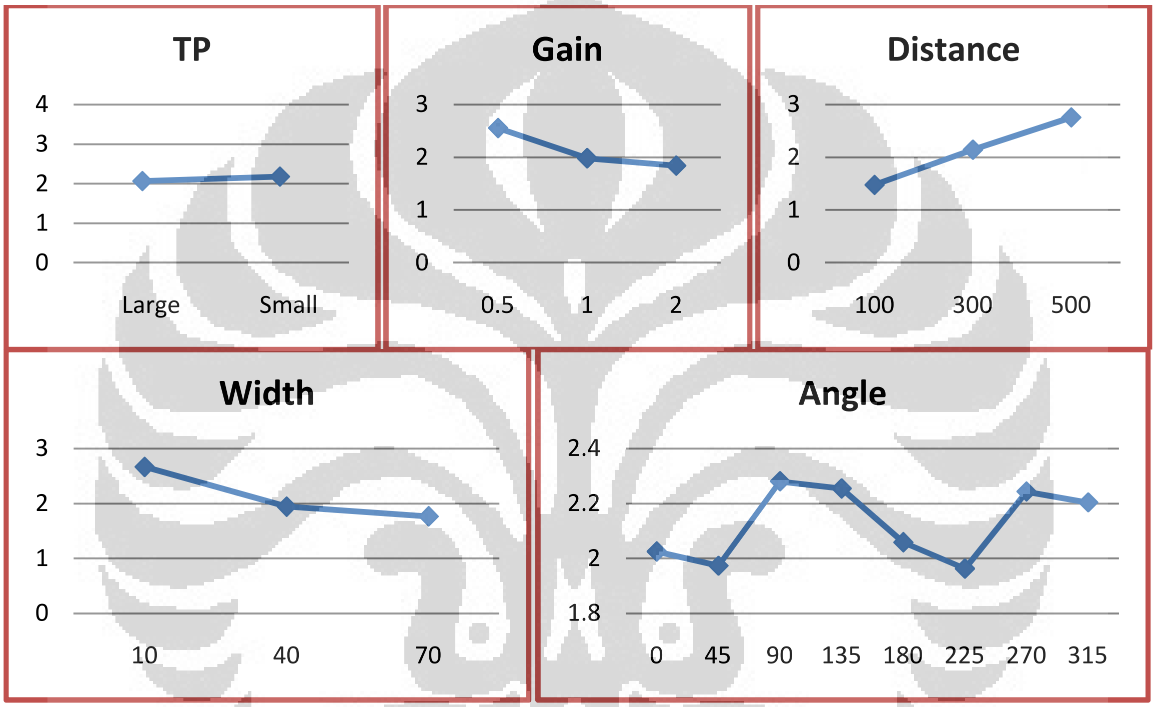


Figure 4.6 Main Factor Effect for Movement Time

For the whole plot interaction (figure 4.7), we can conclude that in the low gain (0.5), the large touchpad has longer movement time than small touchpad. However, in the higher gain (1 and 2), the large and small touchpad have relatively the same movement time. On Filter and Gain interaction, in lower gain (0.5) the filter 30 has higher movement time than filter 50, but in higher gain (1 and 2), the movement time has no difference.

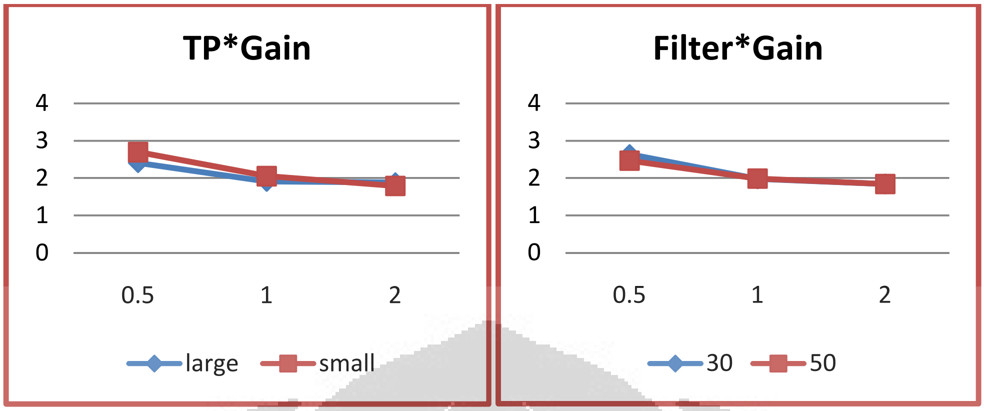


Figure 4.7 Whole Plot Interaction for Movement Time

From figure 4.8, in distance*angle and gain*angle interaction, we can conclude that in lower distance (100), the effect of angle is not significant, but getting higher along with the growth of distance. Angle has the biggest effect on distance 500. As for gain, the highest gain (2) does not have significant interaction with angle, and the lower gain receive bigger effect from angle. In touchpad size*distance and touchpad size*width interaction, longer distance and bigger target size have interaction with touchpad size. Distance 300 and 500 with small touchpad has higher movement time than large touchpad. Furthermore, target size 40 and 70 with small touchpad has higher movement time than large touchpad. For gain*distance and gain*width interaction, in short distance (100), the gain almost does not give any effect. However, in longer distance (300 and 500), the higher gain generates lower movement time. As for width (target size), the bigger width (40 and 70) has negative interaction with gain, when gain is higher, the movement time will be lower. For width 10, the gain 1 and 2 produce the same movement time, and gain 0.5 has higher movement time. For touchpad size*gain*distance interaction, the touchpad size and gain interaction does not give any effect for lowest distance (100), because the value of movement time is remaining the same for each combination. However, in distance 300 and 500, the combination of touchpad size and gain generates a significant interaction, where combination of small touchpad and gain 0.5 has the highest movement time.

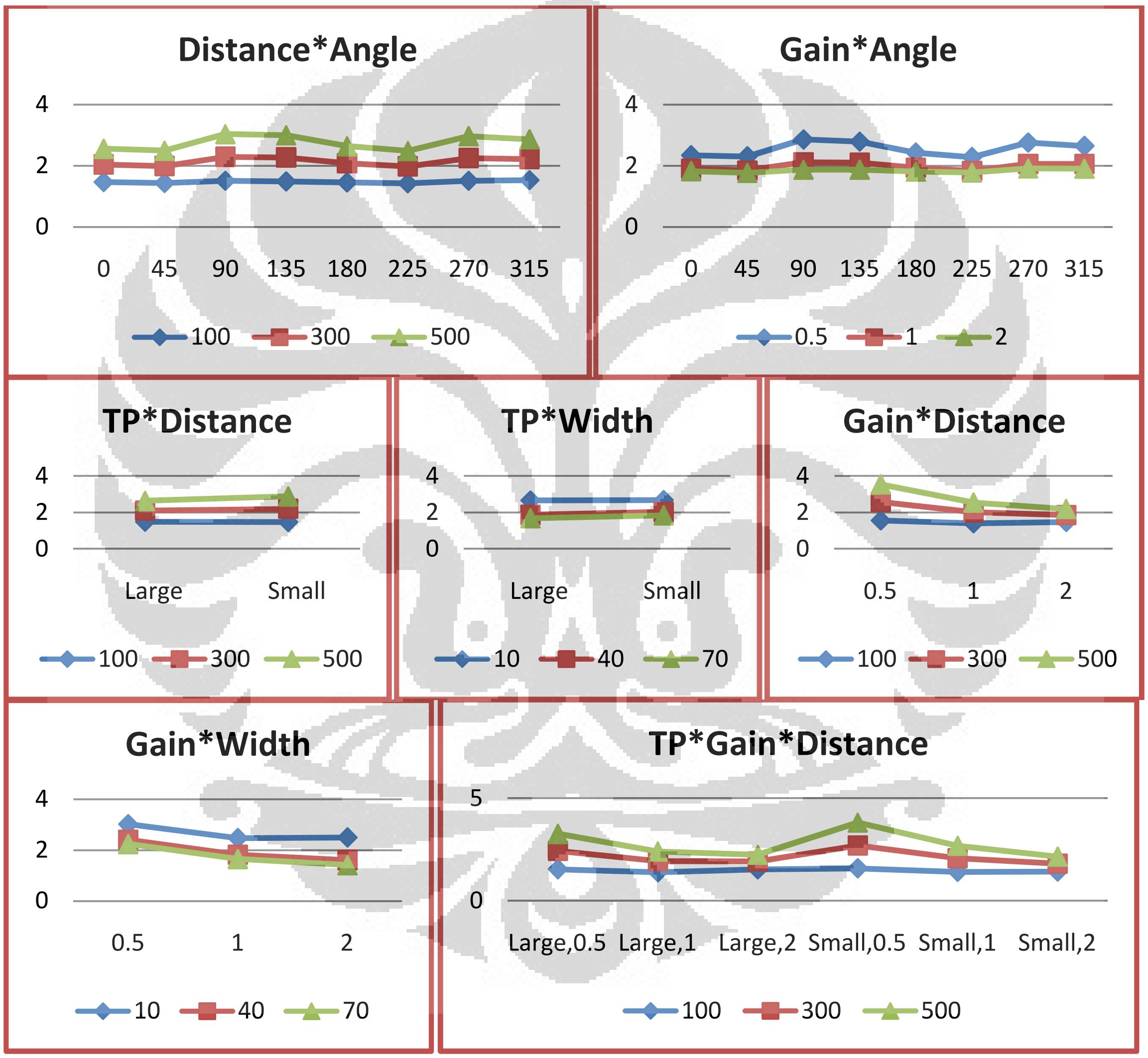


Figure 4.8 Interaction of Whole Plot and Sub Plot of Movement Time

4.2.2 Number of error (error count)

Table 4.3 The summary of ANOVA table for error count

Source	SS	DF	MS	F	Sig.
TP	16.564	1	16.564	9.899	.002
Filter	.993	1	.993	.594	.442
Gain	114.413	2	57.206	34.189	.000
Distance	2.056	2	1.028	3.299	.037
Width	505.692	2	252.846	811.360	.000
Angle	2.180	7	.311	.999	.430

From result of ANOVA Split Plot, the main factors affecting error count significantly are touchpad size (F=9.899, p=0.002), with large touchpad has higher error count than small touchpad, gain (F=34.189, p=0.000), as error increased by higher gain, distance (F=3.299, p=0.037), with error increased as distance getting longer, and width (F=811.360, p=0.000), as smaller width caused higher error. Despite of not significantly affected error, we can see that filter 30 (mean=0.201) has lower error than filter 50 (mean=0.217). For interaction of the whole plot, Touchpad size*gain has significant interaction effect to movement time (F=8.825, p=0.000). For interaction of whole plot and subplot, interaction of gain and width generates a significant value (F=157.541, p=0.000), followed by touchpad size*width (F=49.307, p=0.000), touchpad size*gain*width (F=47.759, p=0.000), touchpad size*gain (F=8.825, p=0.000), and touchpad size*filter*width (F=7.977, p=0.000).

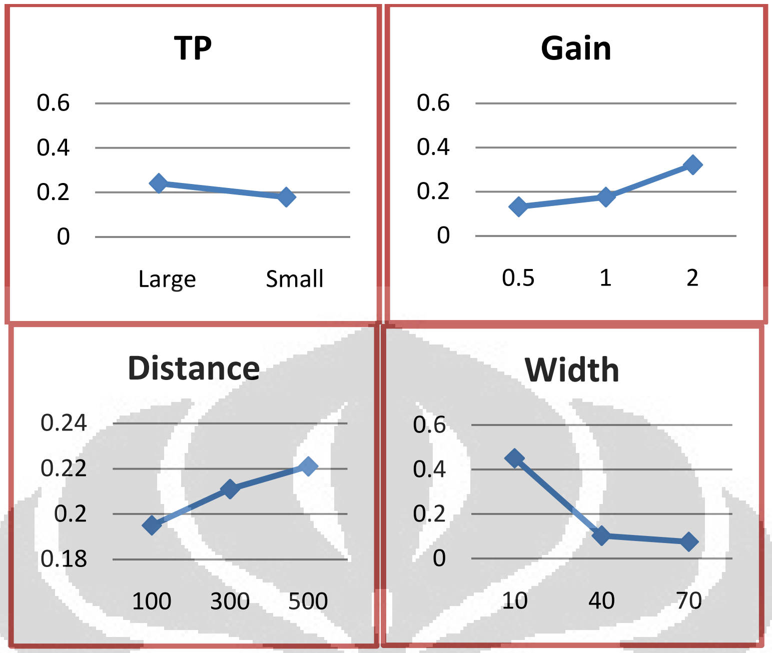


Figure 4.9 Main Factor Effect for Error Count

In the whole plot interaction, the touchpad size and gain has significant interaction effect to error count. In lower gain (0.5 and 1), the error count has the same value for both large and small touchpad. However, in high gain (2), the large touchpad has higher error than small touchpad.

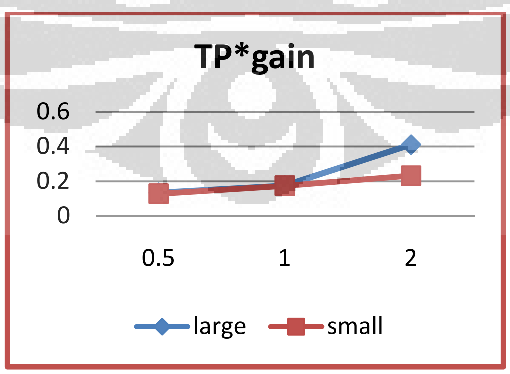


Figure 4.10 Whole Plot Interaction in Error Count

In whole plot and subplot interaction, we can see the effect of target width and its interaction with touchpad size and gain. For medium and big target width (40 and 70 pixel), size of the touchpad and the difference of gain do not significantly affect error count. However, for small target width (10 pixel), size of touchpad and gain significantly affect the error count. The largest error count for target width 10 pixel occurs in combination large touchpad with gain 2, and the smallest error count occurs in combination large touchpad with gain 0.5.

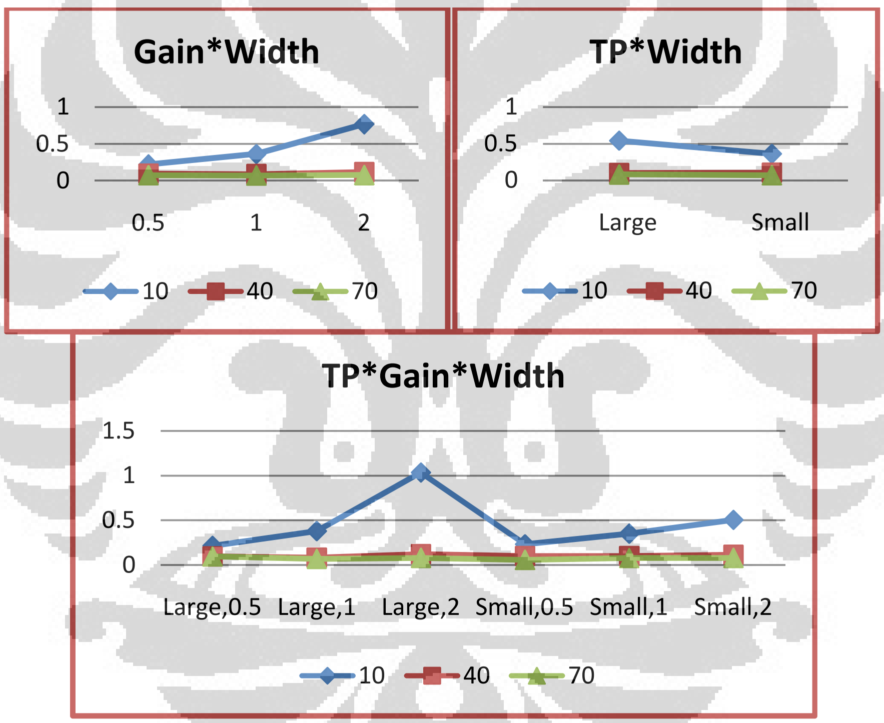


Figure 4.11 Interaction of Whole Plot and Subplot in Error Count

4.2.3 Post-Hoc Test

After main effect and interactions are already calculated with ANOVA, the next step is Post-Hoc test. This study is using Tukey HSD as the tool for running Post-Hoc test. The touchpad size and position filter factor cannot be analyzed in Post-Hoc test, because their number of level is below 3 levels. For movement time, we can see that 3 categories of gain, 3 category of distance, and 3 category of width are divided into 3 different groups, which confirmed that result generated from those 3 categories differs from each other. It means that the 3 gains generate different and significant result, and so do distance and width. However, Post-Hoc analysis in angle effect is quite different. There are 2 angles that remain in the same group: group A (45 and 225), and the group E (angle 270 and 315). It indicates that movement time produced from angle 45 and 225 is not differed from each other, and neither does angle 270 and 315. However, in other angles, the movement time is significantly differed from each other. Furthermore, in error count, despite touchpad size, the significant main effect only gain, width, and distance, therefore only those 3 main effects that can be analyzed. From the Post-Hoc test, we can see that 3 categories of gain and 3 category of width are divided into 3 different groups, which confirmed that result generated from those 3 categories differs from each other. It indicates that the 3 gains generate different and significant result, and so does the width. However, for the distance, it indicates that distance 300 is not differed significantly with distance 100 and 500, because it is placed in group AB. Therefore, only distance 100 and 500 that differ significantly.

Table 4.4 Post-Hoc Test in Movement Time and Error Count

Post-Hoc	Movement time	Error count	Rank
Control Display Gain			
1:0.5	C	A	
1:1	B	B	A<B<C
1:2	A	C	
Distance (pixel)			
100	A	A	
300	B	AB	A<B<C
500	C	B	
Width (pixel)			
10	C	C	
40	B	B	A<B<C
70	A	A	
Angle (deg)			
0	B		
45	A		
90	F		
135	E		A<B<C<D<E<F
180	C		
225	A		
270	E		
315	D		

4.2.4 Movement Count

Table 4.5 The summary of ANOVA table for Movement Count

Source	SS	DF	MS	F	Sig.
TP	14359.889	1	14359.889	195.003	.000
Filter	23.256	1	23.256	.316	.575
Gain	79965.138	2	39982.569	542.952	.000
D	119472.838	2	59736.419	81733.470	.000
W	3833.619	2	1916.809	2622.646	.000
A	10844.747	7	1549.250	2119.738	.000

For the movement count, which is related with movement time, touchpad size (F=195.003, p=0.000) affects it significantly, with small touchpad has higher movement count than large touchpad. Gain affects movement count significantly (F=542.952, p=0.000), with lower gain generates higher movement count. Distance (F=81733.47, p=0.000) and width (F=2622.646, p=0.000) also has influence, which longer distance and smaller target width derives higher movement count. Angle (F=2119.738, p=0.000) also affects movement count significantly, which angle 0 and 225 has the lowest movement count. Position filter is not significantly affected movement count, however, filter 50 (mean=3.538) has lower movement count than filter 30 (mean=3.581). For whole plot interaction, touchpad size and gain interact significantly (F=34.389, p=0.000). For whole plot and subplot interaction, interaction of gain and distance generates a very significant value (F=8164.255, p=0.000), followed by touchpad size*distance (F=3101.255, p=0.000), touchpad size*gain*distance (F=593.348, p=0.000), distance*angle (F=353.504, p=0.000), gain*angle (F=294.624, p=0.000), and touchpad size*angle (F=202.826, p=0.000).

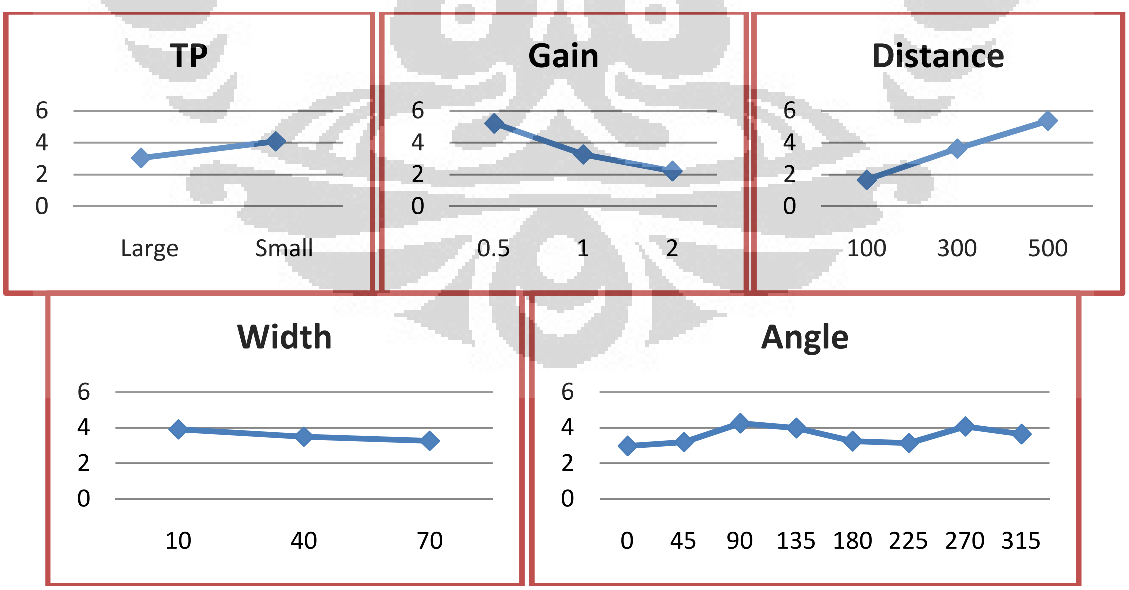


Figure 4.12 Main Factor Effect for Movement Count

For whole plot interaction, the interaction of touchpad size and gain generates significant effect for movement count. In gain 0.5 and 1, the small touchpad generates higher movement count than large touchpad. However, for the gain 2, the large and small touchpad generates no difference movement count.

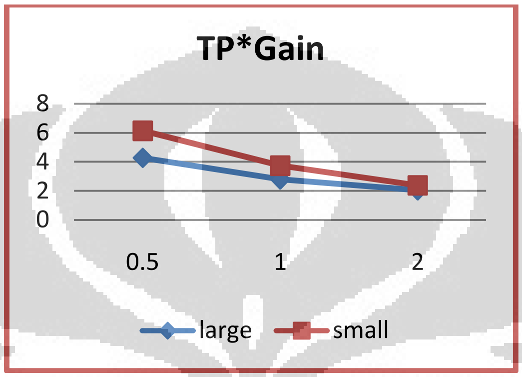


Figure 4.13 Whole Plot Interaction in movement count

From interaction of touchpad size, gain, distance, and angle, we can conclude that touchpad size interact with angle significantly, as small touchpad produce the lowest movement count in angle 0 and highest movement count in angle 90. However, for large touchpad, the lowest movement count occurs in angle 225 and highest movement count in angle 90. The interaction between distance and angle also plainly distinguishable, as the effect of angle do not affect shorter distance (100), though in longer distance (300 and 500), effect of angle has more significant outcome for movement count. The lowest movement count occurred in angle 0 and the highest occurred in angle 90. The same thing happened with interaction of gain and angle. The highest gain (2) do not receive significant effect from angle, though gain 1 and gain 0.5 is interact significantly with the angle (as highest movement count occurs in angle 90 and lowest movement count occurred in angle 225). From interaction of touchpad size, gain, and distance, we can conclude that the effect of touchpad size and gain interact with distance is only occurred in longer distance (300 and 500 pixel). For short distance (100 pixel), the difference of touchpad size and gain combination is not noticeable. However, when the distance is getting longer, the effect of touchpad size and gain can clearly distinguished, as the higher gain will produce lower movement count and small touchpad generates higher movement count.

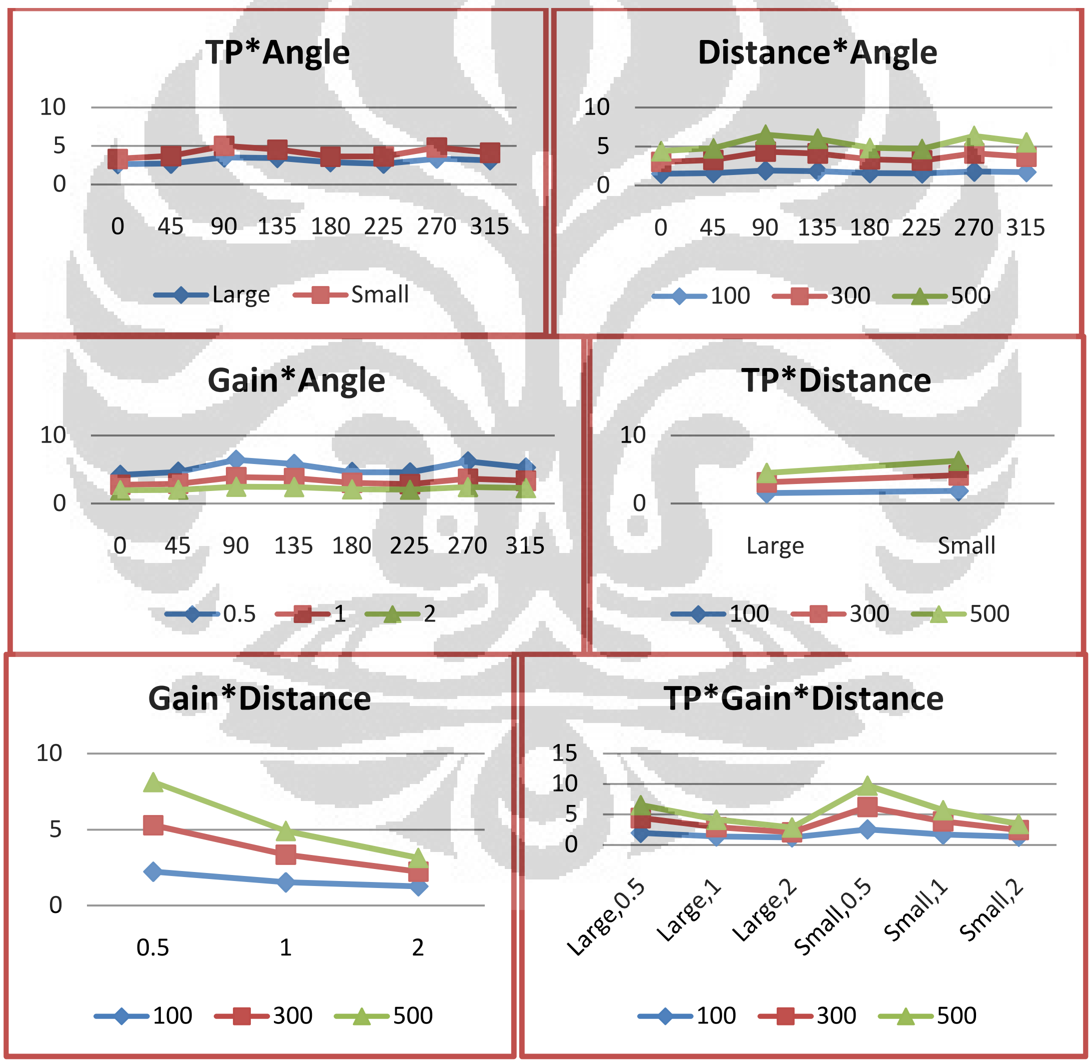


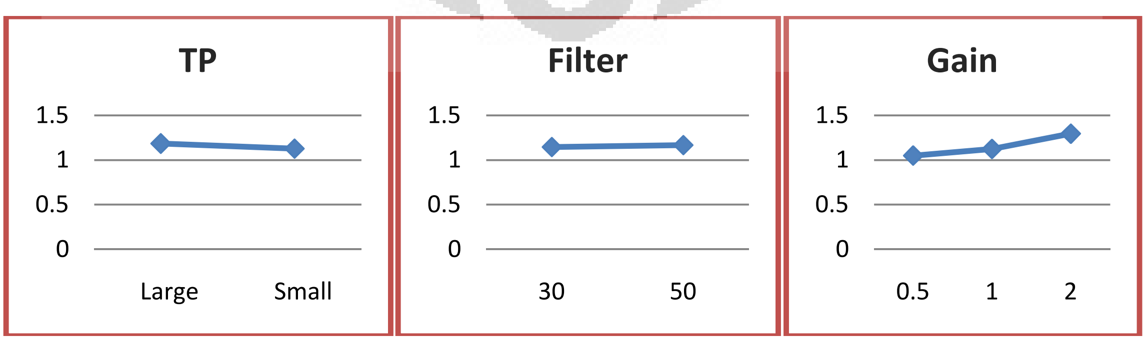
Figure 4.14 Interaction of Whole Plot and Subplot in Error Count

4.2.5 Re-entry count

Table 4.6 The summary of ANOVA Table for Re-entry Count

Source	SS	DF	MS	F	Sig.
TP	39.061	1	39.061	39.752	.000
Filter	6.602	1	6.602	6.718	.010
Gain	542.440	2	271.220	276.020	.000
D	1.101	2	.550	2.828	.059
W	1030.308	2	515.154	2648.009	.000
A	7.588	7	1.084	5.572	.000

As for re-entry count, the touchpad size (F=39.752, p=0.000), filter (F=6.718,p=0.010), gain (F=276.020, p=0.000), width (F=2648.009, p=0.000), and angle (F=5.572, p=0.000) have significant effect. Large touchpad has higher re-entry count than small touchpad, and filter 50 has higher re-entry count than filter 30. Higher gain and smaller target width caused higher re-entry count value. Moreover, different angle produced different re-entry count. The interaction of all 6 factors also can be studied from the analysis. For whole plot interaction, touchpad size and gain interact significantly (F=15.512, p=0.000). For interaction of whole plot and subplot, interaction of gain and width generates a significant value (F=477.110, p=0.000), followed by touchpad size*width (F=143.649, p=0.000), and touchpad size*gain*width (F=86.776, p=0.000).



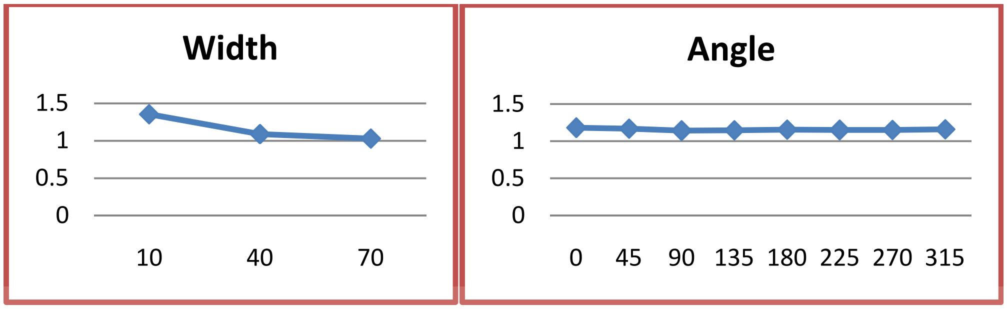


Figure 4.15 Main Factor Effect for Re-entry Count

In whole plot interaction of touchpad size and gain, the difference between large and small touchpad is distinguishable in higher gain than in lower gain. In lower gain, the re-entry count for large and small touchpad are the same, while in higher gain, the re-entry count for large touchpad is higher than small touchpad.

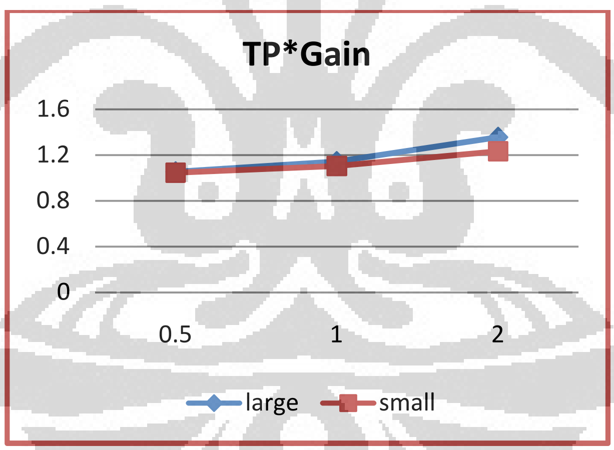


Figure 4.16 Whole Plot Interaction in Re-entry count

As portrayed in figure 4.17, Interaction of whole plot and subplot describes the same thing that width 40 and 70 are not affected by touchpad size and gain, because they give the same results for re-entry count. However, the target width 10 is significantly affected by touchpad size and gain. For target width 10, small touchpad produces lower re-entry count, while higher gain generates higher re-entry count. The largest re-entry count comes from combination of large touchpad and gain 2, and the lowest one derived from combination of small touchpad and gain 0.5.

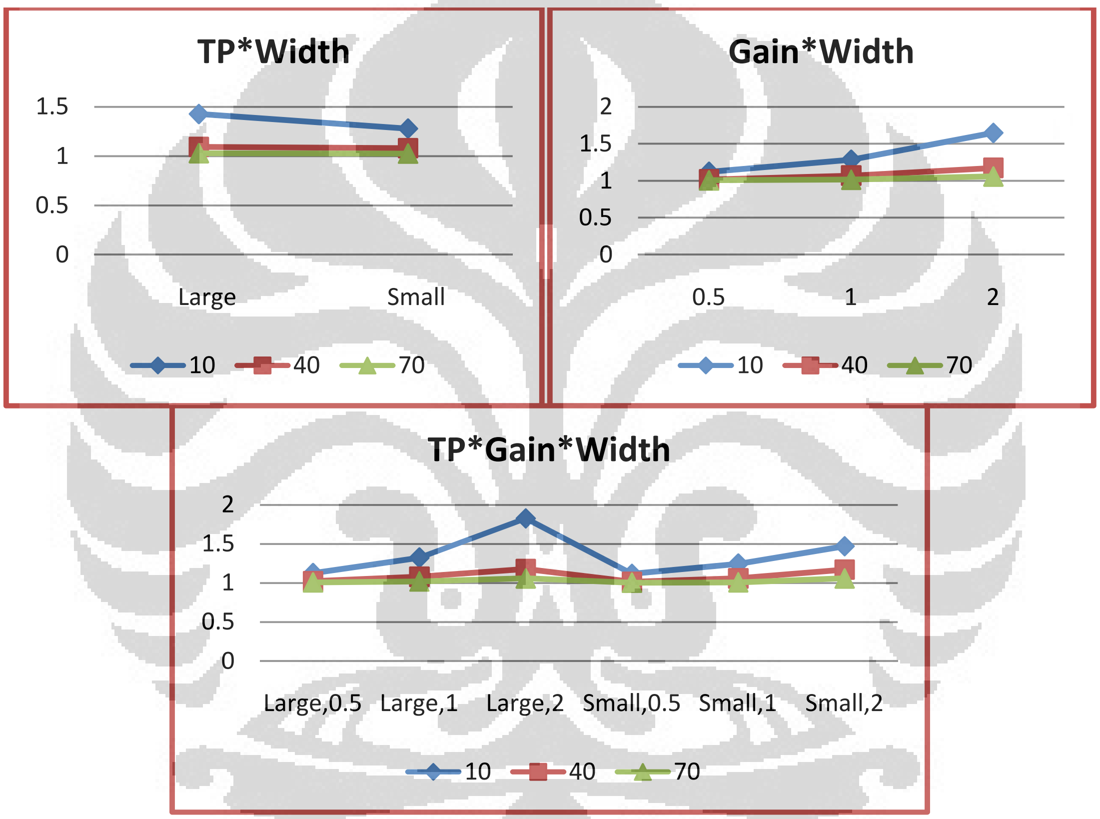


Figure 4.17 Interaction of Whole Plot and Subplot of Re-entry count

4.2.6 Index of Difficulty (ID)

Table 4.7 The list of ID

Distance	Width	ID
100	70	1.28
100	40	1.807
300	70	2.402
500	70	3.026
300	40	3.087
100	10	3.459
500	40	3.755
300	10	4.954
500	10	5.672

The index of difficulty effect in movement time is quite fluctuating. In overall, the movement time is not constantly increase as ID increase, as it should be in Fitts' Law formula. Furthermore, in ID 3.087 and 3.459, the movement time is lower than smaller ID. It is possibly because of the distance effect. ID 3.026 has longer distance than ID 3.087 and 3.459. On the other hand, the ID effect on error count is also not stable. In ID 3.459, the error swiftly increased, and in ID 3.755 the error rapidly decreased. It is because of the width of target. In ID 3.459, the width changed into the smallest one (10 pixel), and in ID 3.755, the width change into larger width (40 pixel).

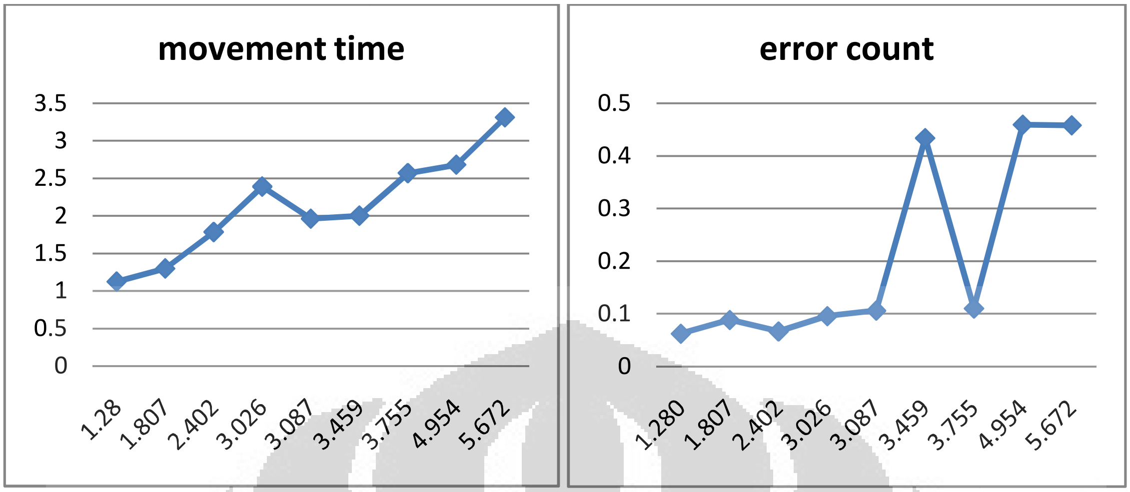
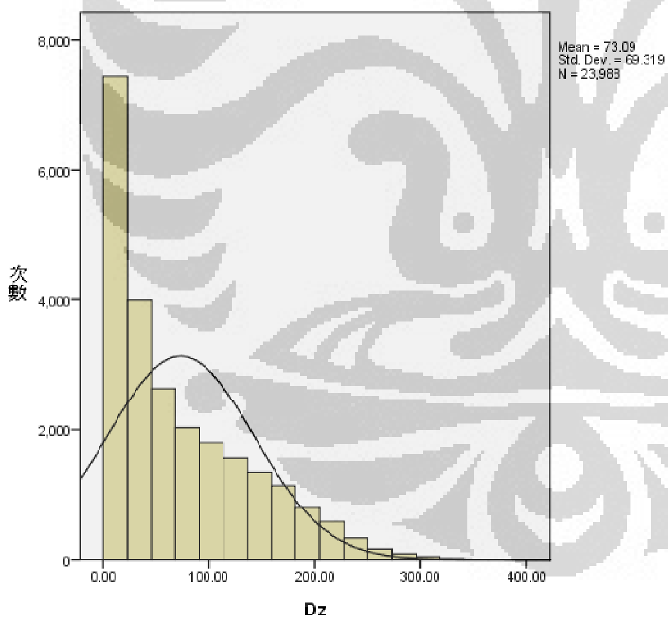


Figure 4.18 Index of Difficulty of movement time and error count

4.3 Distribution of Velocity



Percentile

5	6.080
25	17.03
50	50.01
60	71.31
65	85
70	99.02
75	115.11
95	205.56

Figure 4.19 Distribution and percentile of finger velocity

In accordance with subchapter 4.1, the finger velocity is one of the most crucial part in touchpad, because from finger velocity, touchpad company can design the non-linear gain, a real gain, to be implemented in their product. Non-linear gain is the gain setting that adjusted automatically to finger velocity. The advantage of non-linear gain is that users can control their own velocity to successfully click the target. In the primary movement, they can fasten their velocity to get high gain, and in secondary, they can slow down to get lower gain.

The figure below shows the histogram of finger velocity in the touchpad. It is taken from 192 samples data. The maximal velocity of this histogram is about 300 Dz. From the histogram, we can see that 75% of the data belongs to velocity 115 Dz. The result indicates that most of the velocity still below 115, and there is only 25% velocity above 115 Dz. For the non-linear gain, the velocity is divided into 5 parts: 0%, 5%, 25%, 50%, and 75% to determine the gain for each velocity. Based on the result of histogram, the stepping point for each velocity are as below:

- Starting point: low velocity from 0 to 6 Db, implement the slow gain purposed to click the target accurately, especially for small target.
- Middle-down point: low-medium velocity from 6 to 17 Db, implement the low-medium gain to optimally reach the target in short distance.
- Middle-up point: medium to high velocity from 17 to 50 Db, implement medium-high gain to acquire target in medium distance.
- Upper point: high velocity from 50-115 Db, implement high gain to acquire target in long distance in a short time.
- More than upper point: still the same high velocity, implement the same high gain to acquire target in a very long distance and to ensure stability of the gain.

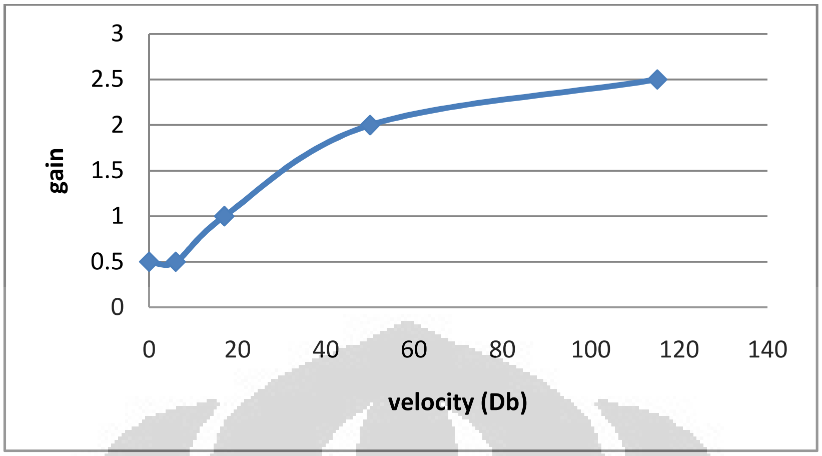


Figure 4.20 Example of non-linear gain

4.4 User Behavior Analysis

We observe some user behaviors in the experiment to examine the effect of different behavior into user performance. There are two strong behaviors that users do in using the touchpad. The first one is type of hand, which consist of:

1. Users that use one hand (right hand) and tap the surface of touchpad to acquire the target : 9 users
2. Users that use two hands and click the touchpad button to acquire the target (right hand to move the cursor and left hand to click the target) : 8 users
3. User that use one hand (right hand) and click the touchpad button to acquire the target (use middle finger to move the cursor and index finger to click the touchpad button) : 1 user
4. User that combines one hand (surface) and two hands (button) behavior in different combinations : 2 users

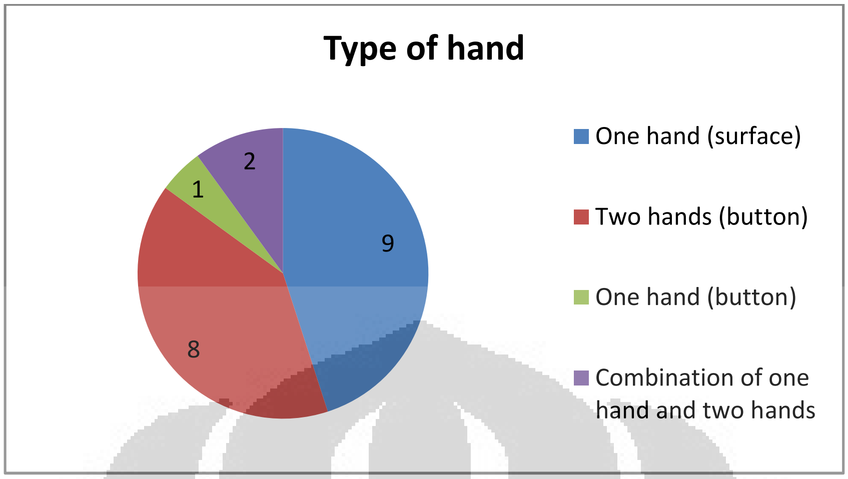


Figure 4.21 Pie Chart of Type of Hand

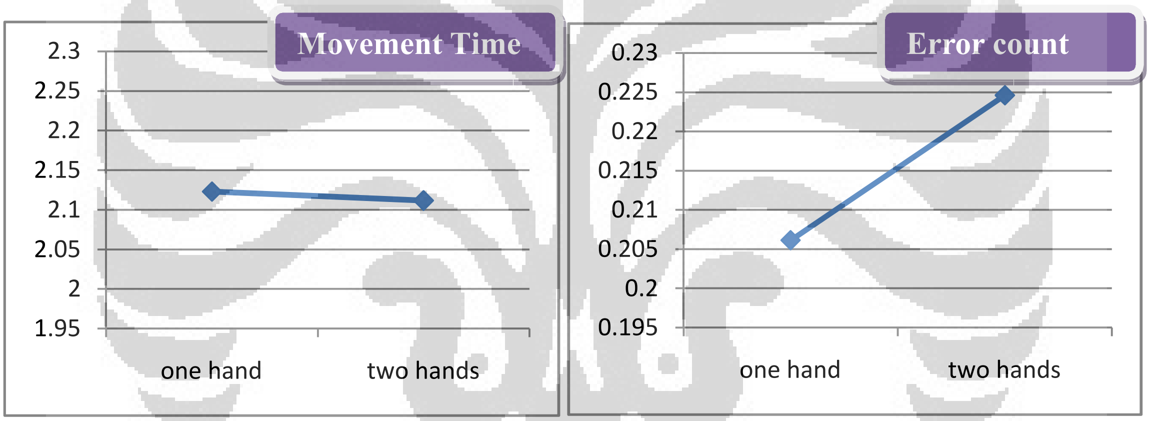


Figure 4.22 Comparisons of Movement Time and Error Count in Type of Hand

Furthermore, the type of hand users choose to accomplish the task are divided into 2 major criteria: one hand (tap in surface) and two hands (click with button). Since the one hand user that click touchpad button only 1 person, the data is excluded from analysis. From figures above, it can be observed that one hand user has higher movement time than two hands user. On the other hand, one hand user has lower error count than two hands user. Moreover, the movement time and error count are break down into 12 combinations, as shown in figure 4.23. The difference of one hand user and two hands user in movement time is not huge; however, the difference of one hand user and two hands user in error count is quite extreme, especially in gain 2, when one hand user has much higher error than two hands user.

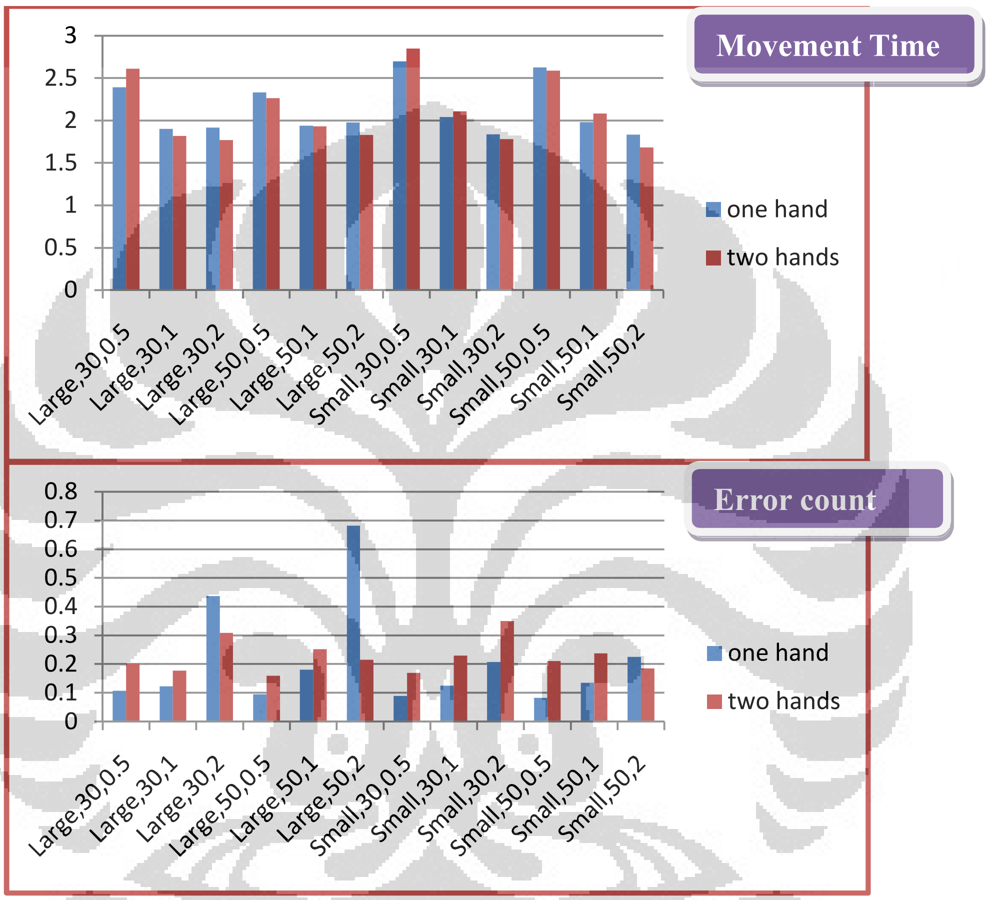


Figure 4.23 Comparisons of Movement Time and Error Count in Type of Hand in Every Combination

The second behavior in touchpad usage is type of finger user utilize in moving the cursor, which consists of:

1. Index finger: 10 users
2. Middle finger: 7 users
3. Combination of index and middle finger: 3 users

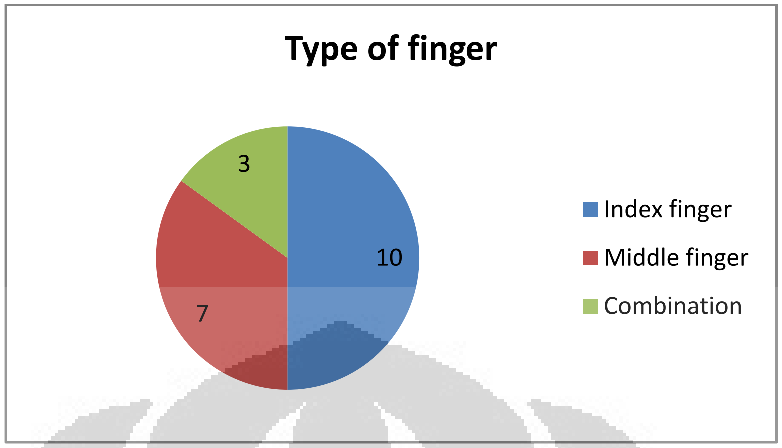


Figure 4.24 Pie Chart of Type of Finger

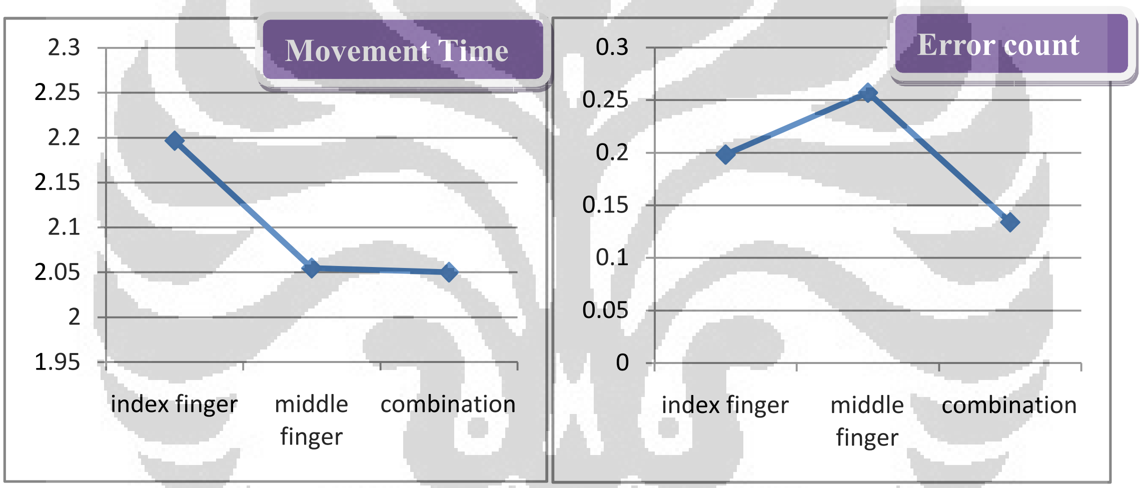


Figure 4.25 Comparisons of Movement Time and Error Count in Type of Finger

The type of finger user use to do the task is divided into 3 major criteria: moving target with index finger, middle finger, and combination of both. From figures above, it can be observed that index finger users have higher movement time than middle finger and combination of both users. On the other hand, index finger and combination user has lower error count than middle finger user. Moreover, the movement time and error count are break down into 12 combinations, as shown in figure 4.26. The difference of different type of finger in movement time is not huge, however, the difference of index finger user and middle finger user in error count is quite extreme, especially in gain 1 and 2.

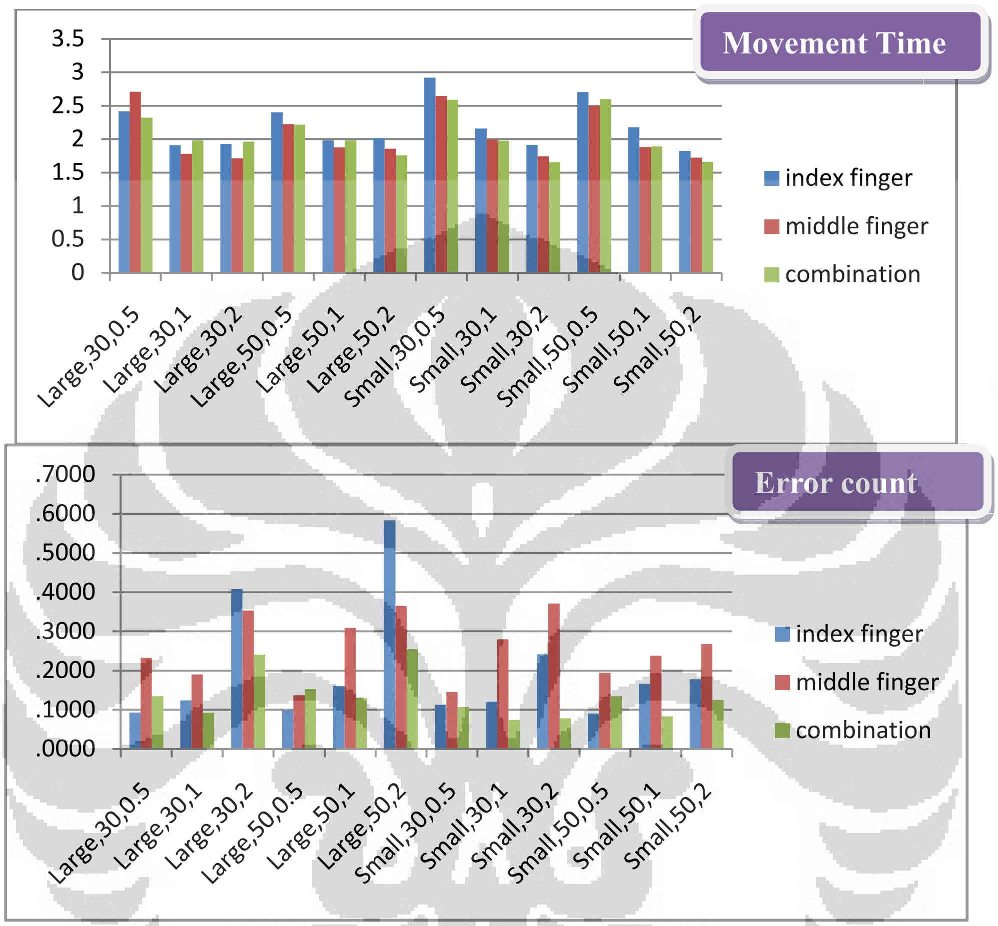


Figure 4.26 Comparisons of Movement Time and Error Count in Type of Finger in Every Combination

4.5 Fitts' Law Model

Increased target acquisition time with increasing movement distance and decreasing target size, indicating that data from this study conform to Fitts paradigm. Therefore, we are able to deduce Fitts' regression models based on moving distances (D) and target width (W). The calculation of the task difficulty index ($ID=\log_2((D/W)+1)$ of every combinations shows that the R square range from 0.6943 to 0.9853. Moreover, the regression model for overall combination is shown as below:

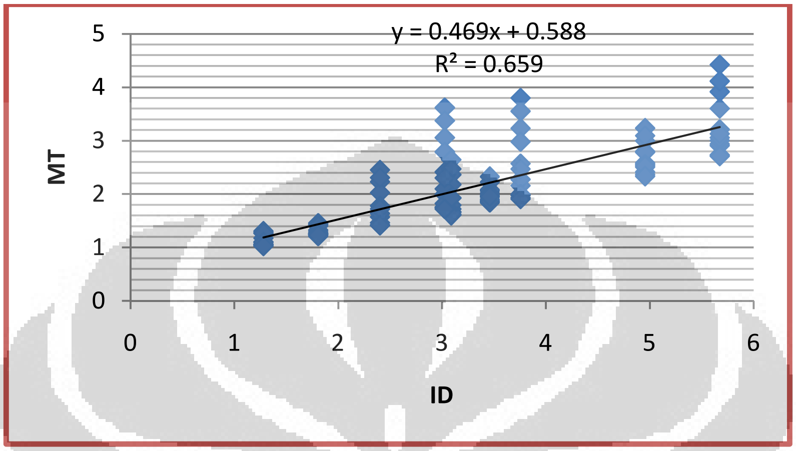


Figure 4.27 Regression of Fitts' Law Model

Based on the R^2 results (R^2=0.6593), it seems that every combination of these models is not explained well by the calculation of the task difficulty index. Moreover, the result on ANOVA table shows that the distance and gain interaction is pretty strong. From figure 4.28, we can see that in lower gain, the difference of movement time for different distance is higher than in higher gain (2). It indicates that the effect of gain towards distance is stronger in lower gain.

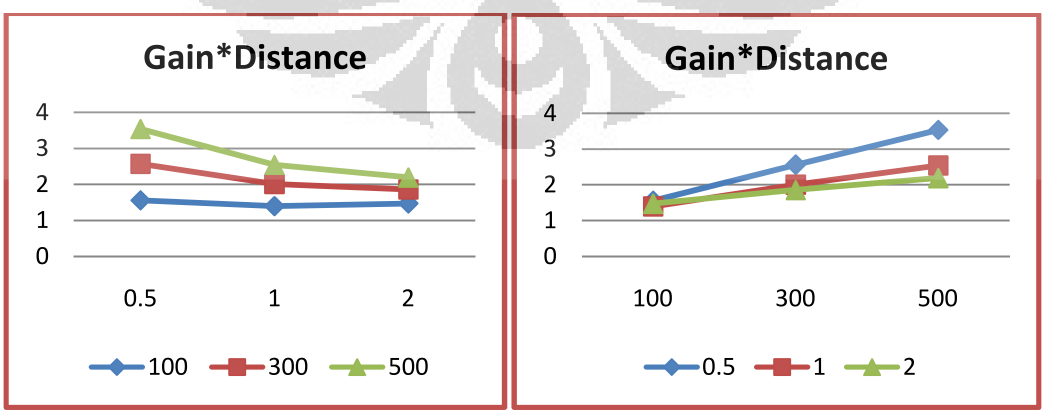


Figure 4.28 Effects of Gain towards distance (ID)

From right and left graph in figure 4.28, we can see that when gain decreased, the movement time is increased. The difference of increased movement time is obvious when the distance is also increased. Therefore, increased distance with decreased gain will produce increased movement time. For that reason, we can state that:

$$\frac{1}{\text{Gain}} \times \text{Distance} \propto \text{MT}$$

In accordance to our result, the approach of Fitts' Law formulation which was proposed by Johnsgard (1994) is being implemented in the Movement Time equation.

$$\text{MT} = a + b \log_2 \left(\frac{\ }{\ } + 1\right)$$

The regression line is shown as below:

From Shannon Formulation:

Gain 0.5: R^2= 0.7431

Gain 1: R^2= 0.9224

Gain 2: R^2= 0.9734

From Johnsgard ID modification:

Gain 0.5: R^2= 0.7503

Gain 1: R^2= 0.9224

Gain 2: R^2= 0.973

The regression line of Johnsgard equation for total movement time every combination is shown as below:

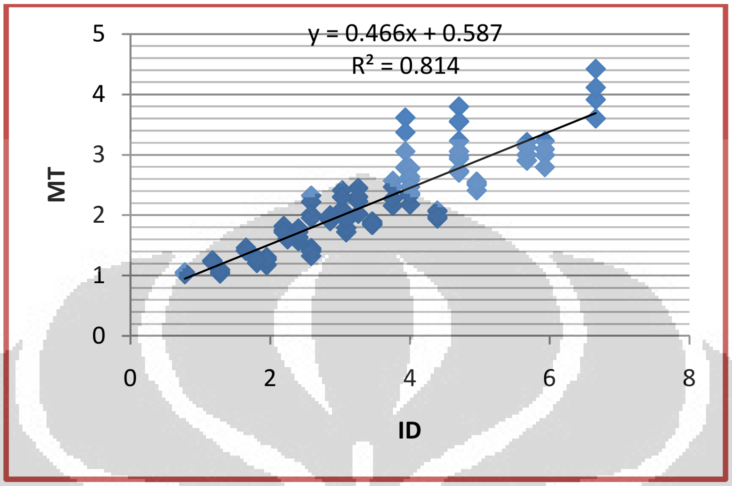


Figure 4.29 Regression Line of Johnsgard Formula (total)

Furthermore, the formula proposed by Johnsgard (1994) is better than Shannon formulation, because it has higher R^2 (Shannon Formulation=0.6593, Johnsgard=0.8147). The formula is better implemented especially in low gain, and it also explain more about distance and control display gain interaction.

4.6 Discussion

4.6.1 Finger Velocity

The result in this experiment shows that the movement pattern in velocity graph of touchpad and mouse is not the same. In the mouse, the movement is divided into two sub-phases: the primary velocity peak followed by remaining movement until the onset of the verification phase (Thompson et al, 2007). On the other hand, in the touchpad, there is a behavior named "clutching". Clutching is a behavior that lifting the finger from touchpad surface and repositioning it (Hertzum and Hornbaek, 2005). According to their statement, they believe that clutching only occurred in small touchpad during medium and long distance. However, the result shows that clutching also occurs in large touchpad, with high gain, during long distance. The result also shows that clutching won't happen in short distance. It will affect the movement pattern in touchpad to remodel into 2 phases: several primary movement and secondary movement. However, we also agree with Casiez et al (2007) that Clutching degrades performance, particularly when the display size is large. Therefore, a simple solution to minimize clutching is increasing the CD gain. However, increase CD gain reduces accuracy, making smaller objects more difficult to target (Casiez et al, 2008). Furthermore, we strive to apply non-linear gain in touchpad to reduce clutching and increase accuracy.

4.6.2 Control Display Gain

Control display gain is a crucial factor for touchpad performance. A high gain setting can quickly maneuver the cursor to the vicinity of target, but has difficulty in final acquisition of the target. Low-gain setting, on the other hand, facilitate fine positioning of the cursor, but increase the time to advance the cursor over large distance (Akamatsu and MacKenzie, 2002). However, Jellinek and Card (1990) found no performance improvement using several higher order transfer functions with a mouse, and suggested that the only benefit is the smaller desktop footprint afforded by the higher-order relationship. Furthermore, previous study noted that user performance in target acquisition task on touch sensitive tablets is better with gain in range of 0.8-1 than with higher or lower gain (Greenstein and Arnaut, 1988). Moreover, the gain effect in pointing movement with hand is appreciable (Graham and MacKenzie, 1995). Based on our result, despite the different results shown by previous researches, gain has a large effect of target acquisition task in touchpad. Gain 2 is the best for obtaining high speed, but fails in accuracy. On the other hand, gain 0.5 is better for accuracy, as observed in its low error count and re-entry count value. In contrast, gain 1 served as medium gain, with medium speed and medium accuracy.

4.6.3 Velocity Distribution and Non-linear Gain

Since the input surface is small compared with the size of the output display, a higher gain combined with a non-linear relationship is often used (Akamatsu and MacKenzie, 2002). In this case, the relationship is expressed by the transfer function instead of a simple ratio. The transfer function gives the velocity of the cursor as function of the velocity, or the square of velocity, of the finger or mouse (MacKenzie, 1995). Furthermore, the gain is also a function of velocity for creating non-linear gain. For that reason, the distribution of velocity is computed and produce 4 points of stepping point:

low velocity (0 to 6 Db), low-medium velocity (6 to 17 Db), medium to high velocity (17 to 50 Db), and high velocity (50-115 Db). The result for secondary movement (low speed), it is better to implement gain 0.5; furthermore, in between primary and secondary movement (low to medium speed), gain 1 can be applied; and for primary movement, gain 2 can be implemented, though it is better to implement higher gain such as 2.5 or 3, because average of movement count for gain 2 is approximately 1.5, not fast enough to acquire the target. It is better to put gain 2 into medium-high speed and gain 2.5 or 3 in high speed.

4.6.4 Angle Effect

An interesting fact of angle (direction) for touchpad performance measurement is that angle 45 and 225 seems to have higher performance than other angle, based on movement time value and Post-Hoc test. In contrast, vertical angles like 90 and 270 tend to have lower performance than other angles. It is because the size of touchpad, which is rectangular-shaped, where the length is longer than the width, so that finger has longer space to move diagonally. A decline in performance for vertical angles is due to horizontal-vertical illusion (HVI) and biomechanical effect (Thompson et al, 2004). The result is different from previous study. Whisenand and Emurian (1996), MacKenzie and Buxton (1992), Thompson et al (2004), and Fernandez and Bootsma (2004) stated that performance in mouse was generally best along the lateral angles (0 and 180, to a lesser extent 315), longest along the vertical (90 and 270), and remaining diagonal falling in between. This reflects that the impact of angle for mouse and touchpad is not the same.

4.6.5 Fitts' Law Modification

For interactions of main effect, we also found same pattern. Control display gain and distance interaction has the highest value than other interaction in movement time and movement count. In accordance to our result, Johnsgard (1994), Thompson et al (2004), and Thompson et al (2007) also generates a significant interaction between control display gain and distance. On the other hand, in error count and re-entry count, interaction of target width and control display gain is the most significant. We can conclude that interaction of control display gain and distance is the most important factor in speed matters; however interaction of target width and gain is the most important thing in accuracy. A very significant interaction of distance and gain will affect the Fitts' Law model. This is in line with Johnsgard's previous research in 1994 that produce the new equation for ID. Therefore, the comparison between Shannon Formulation and Johnsgard produce the better fit for Johnsgard's equation, especially in low gain (0.5).

CHAPTER 5

CONCLUSION

5.1 Conclusion

The findings from this research are summarized as below:

- Touchpad size significantly affected movement time, error count, movement count, and re-entry count. Large touchpad is better for primary movement, because the movement time and movement count spent with large touchpad is overall lower than small touchpad. However, for secondary movement, small touchpad is practically better than large touchpad, because it has lower error count and re-entry count.
- Position filter is not a strong factor for measuring touchpad performance; however, it has a significant effect for re-entry count. For primary movement duration, filter 50 spends lower time than filter 30, yet for re-entry count, filter 30 has lower value than filter 50. Therefore, we can conclude that filter 50 is better to be implemented in primary movement, and filter 30 is better for accuracy, and can be implemented in secondary movement.
- The effect of CD gain is significant for movement time, error count, movement count, and re-entry count. The best CD gain for primary movement is 2, since it has higher movement time and movement count, however for the secondary movement, the best gain is 0.5, because it has lower error and re-entry count.
- Control display gain and distance interaction has the highest value than other interaction in movement time and movement count, however in error count and

re-entry count, interaction of target width and control display gain is the most significant.

- The finger velocity in the touchpad creates pattern of several primary movements in velocity graph because of clutching behavior
- One hand user has less error count and two hands user has less movement time. However, in higher gain (2), two hands user has less error count than one hand user. We can conclude that two hands user has more advantage in touchpad performance, especially in higher gain.
- Another behavior comes from type of finger generates result that user which combine index and middle finger in each combination tends to spend lower movement time and lower error than user who use index or middle finger all the time. This may be related to fatigue that user experienced with only use one finger all the time.
- Johnsgard's equation that included gain into Index of Difficulty formula produced better regression line than Shannon Formulation. Therefore, Johnsgard's equation of ID is better applied in target acquisition task in touchpad.

5.2 Future Research

The continuation of this research should be to develop and discover more about non-linear gain, since control display gain is the most affecting factor among those three (touchpad size, filter, and gain). Non-linear filter is also can be studied for future research, along with non-linear gain, to found the best filter setting for each non-linear gain.

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APPENDIX

1. Greeting Script for Laptop Touchpad Test

(請受測者簽到)

歡迎您前來參加筆記電腦觸控板評估測試,
我是負責執行這次測試的測試人員▪崇亮(介紹 MAYA~)

在實驗開始前請先確認您的手機已經關機或已經調整成靜音▪態，在測試中請不要將手機攜帶在身上，以免電話響起干擾測試進行。

測試的時間總共大約為五個小時左右，會切割成兩次的測試時間，各兩個小時至兩個半小時左右。您會在安排的時間前來受測兩次。

測試的主要目的在於評估兩款不同的筆記電腦觸控板，▪種觸控板會設定六種不同的設定。您所做出的任何評估結果對我們而言都可以提供▪品改善的寶貴資料。在測試中並沒有所謂的對錯，所以放鬆心情來進行測試就可以了。

接著這裡有份文件要麻煩您先花點時間完成，首先請您先填寫這份實驗同意書，這份同意書的目的是為了確保您是自願參加這項測試的。之後您的名字與個人資料將會完全保密，不會出現在測試報告或是任何其他的地方，請放心。此外，這項測試是一個自願性質的測試，您可以隨時中斷測試，我們便會讓您離開。

(簽實驗同意書)

接著，請填寫這份使用者問卷，這份問卷能幫助我們更了解您的背景資料、使用電腦及觸控板的相關經驗。

(發前測問卷)
(快速看過前測問卷以初▪確認受測者資格)

接著向您▪明有關測試的一些事項：
1. 您會參加此次測試是因為您符合我們的使用者條件。
2. 接下來您將會執行一連串指定的作業以幫助我們評估觸控板。
3. 在測試中您以筆記電腦與觸控板進行指定的作業。
4. 在測試中我們會鼓勵您盡量獨立的去完成作業，但是如果您有任何問題，也請隨時提出，以方便我們了解您的想法。
5. 有些測試項目比較難，並不是▪個人都可以完成，如果這個作業耗費您太多時間，我就會中斷這個測試項目，請您繼續進行下一個。
6. 當您完成所有作業的時候，我會與您做一個簡短的訪談，在訪談中您可以與我

們分享您在這項測試中的感覺或是對▪品的建議。

請問您到目前為止有無任何問題？沒有的話，接下來我們開始進行下一階段的講解
。

請問你有使用過觸控板嗎？
我來講解一下使用方式。
你可以藉由在平面上移動手指，來操控游標的位置。
想要點選左鍵功能時，你可以按壓下方按鍵，或是直接以手指敲擊觸控板。

請試一下。
你覺得哪一種方式比較順手？
接下來的測試請維持這樣的操作方式。

請問您到目前為止有無任何問題？如果沒有，讓我們開始測試。

（點選作業講解）
首先需進行的是點選作業。
如螢幕顯示，當點擊起始點之後，目標物會出現。
此時請儘速且正確的移動游標並點擊目標物。

我們來練習一下，並且熟悉一下這個touch pad 的手感。

直到你已經熟悉為止，我們就開始進行實驗。

2. Experimental Consent Document

實驗同意書

實驗受試人員務必詳讀本同意書▪容,
簽名同意遵循所有規範後，始可參加實驗受試

您所參加的實驗為「**觸控板的使用性分析與參數設定**」，目的在探討觸控板的各項使用性相關因素探討。研究計畫主持人為國立台灣科技大學工管系李永輝教授(TEL：27376339)。

參加資格：年齡範圍在20-
40▪之間，過去沒有手部外科手術之病史，半年▪無手指、手腕、手肘、肩膀等部位不適之就醫史。受試者必須有使用滑鼠一年以上的經驗。
實驗項目：觸控板使用情境測試，點擊時間、角度及點擊正確紀▪。
潛在問題：本研究可能會造成手指或手腕肌肉痠痛，因受試者肌力以及肌耐力不同而有差異。若有不適可依受試者▪況隨時中斷實驗。
受試費用：本研究提供受試人員新台幣900之受試費用以茲感謝。

本人在實驗單位人員對實驗流程以及▪容解▪後，願意參與該研究之實驗活動，並遵守上列條款，並了解實驗過程中可能造成的不適。本研究結果將提供學術參考，為保護受試者隱私，受試者基本資料以及實驗數據將被保密。

受試者同意並簽署：

實驗單位人員簽署：

計畫主持人：

簽署時間：中華民國______年______月______日

3. Pre-questionnaire

<u>受試者使用經驗問卷</u>

受試者編號：_______
姓　　名：_____________
性　　別：_____________
年　　齡：_____________
連 絡 電 話：___________________
地　　址：_______________________________________
教 育 程 度：□國中及以下 □高中、職 □大專 □碩士 □博士

先前使用電腦的經驗：

- □ 6個月以下 □ 6個月-3年 □ 3年-10年
- □ 10年以上 (實際經驗: ________年)

平均一週約使用電腦多少小時：
□少於21小時 □21-35 小時 □36-50 小時 □51-65 小時 □65 小時以上

平常較常使用的電腦類型： □筆記型 □桌上型

您是否擁有筆記型電腦？ □有 □無

您是否曾使用過觸控板： □總是使用 □經常使用 □偶爾使用 □幾乎不使用 □未曾使用

承上題，平均一週使用觸控板的時間
□少於4 小時 □5-9小時 □10-14小時 □ 14小時以上

4. Complete ANOVA Table

Table A.1 The complete ANOVA table for movement time

Source	SS	DF	MS	F	Sig.
TP	158.449	1	158.449	14.114	.000
Filter	35.502	1	35.502	3.162	.077
Gain	4913.895	2	2456.948	218.848	.000
TP * Filter * Gain * Participant	2346.382	209			
TP * Filter	13.202	1	13.202	1.176	.279
TP * Gain	329.530	2	164.765	14.676	.000
Filter * Gain	100.129	2	50.065	4.459	.013
TP * Filter * Gain	14.884	2	7.442	.663	.516
D	14184.404	2	7092.202	35504.649	.000
W	7819.143	2	3909.572	19571.914	.000
A	810.061	7	115.723	579.327	.000
D * W	3.077	4	.769	3.851	.004
D * A	316.393	14	22.600	113.137	.000
W * A	15.732	14	1.124	5.626	.000
D * W * A	3.605	28	.129	.645	.925
TP * D	147.164	2	73.582	368.362	.000
TP * W	54.214	2	27.107	135.701	.000
TP * A	45.189	7	6.456	32.318	.000
Filter * D	10.696	2	5.348	26.773	.000
Filter * W	1.009	2	.504	2.526	.080
Filter * A	4.047	7	.578	2.894	.005
Gain * D	2373.015	4	593.254	2969.919	.000
Gain * W	193.088	4	48.272	241.658	.000
Gain * A	289.025	14	20.645	103.350	.000
TP * Filter * D	3.882	2	1.941	9.716	.000
TP * Filter * W	.919	2	.460	2.300	.100
TP * Filter * A	5.744	7	.821	4.108	.000
TP * Gain * D	84.438	4	21.109	105.677	.000
TP * Gain * W	38.410	4	9.603	48.072	.000
TP * Gain * A	33.566	14	2.398	12.003	.000
Filter * Gain * D	15.554	4	3.889	19.466	.000
Filter * Gain * W	5.004	4	1.251	6.263	.000
Filter * Gain * A	6.951	14	.497	2.486	.002
TP * Filter * Gain * D	2.109	4	.527	2.640	.032
TP * Filter * Gain * W	2.000	4	.500	2.503	.040

TP * Filter * Gain * A	2.994	14	.214	1.071	.379
TP * D * W	.312	4	.078	.391	.815
TP * D * A	24.287	14	1.735	8.685	.000
TP * W * A	1.683	14	.120	.602	.866
TP * D * W * A	4.955	28	.177	.886	.638
Filter * D * W	.934	4	.234	1.169	.322
Filter * D * A	2.473	14	.177	.884	.576
Filter * W * A	2.720	14	.194	.973	.478
Filter * D * W * A	3.075	28	.110	.550	.974
Gain * D * W	2.120	8	.265	1.327	.225
Gain * D * A	103.236	28	3.687	18.458	.000
Gain * W * A	3.688	28	.132	.659	.914
Gain * D * W * A	10.627	56	.190	.950	.581
TP * Filter * D * W	.449	4	.112	.562	.690
TP * Filter * D * A	2.971	14	.212	1.062	.387
TP * Filter * W * A	4.048	14	.289	1.448	.122
TP * Filter * D * W * A	3.363	28	.120	.601	.952
TP * Gain * D * W	1.765	8	.221	1.104	.357
TP * Gain * D * A	19.174	28	.685	3.428	.000
TP * Gain * W * A	5.936	28	.212	1.061	.377
TP * Gain * D * W * A	12.530	56	.224	1.120	.250
Filter * Gain * D * W	.807	8	.101	.505	.853
Filter * Gain * D * A	6.914	28	.247	1.236	.181
Filter * Gain * W * A	2.918	28	.104	.522	.982
Filter * Gain * D * W * A	5.524	56	.099	.494	.999
TP * Filter * Gain * D * W	1.325	8	.166	.829	.577
TP * Filter * Gain * D * A	7.338	28	.262	1.312	.125
TP * Filter * Gain * W * A	4.046	28	.145	.723	.855
TP * Filter * Gain * D * W * A	11.615	56	.207	1.038	.396
Intercept	234073.374	1	234073.374	1863.815	.000
Participant	2386.178	19	125.588	11.187	.000
Error	10137.125	50748	.200		
Total	281230.920	51840			

Table A.2 The complete ANOVA table for error count

Source	SS	DF	MS	F	Sig.
TP	16.564	1	16.564	9.899	.002
Filter	.993	1	.993	.594	.442
Gain	114.413	2	57.206	34.189	.000
TP * Filter * Gain * Block	349.705	209	1.673	5.369	.000
TP * Filter	3.588	1	3.588	2.144	.145
TP * Gain	29.534	2	14.767	8.825	.000
Filter * Gain	1.562	2	.781	.467	.628
TP * Filter * Gain	6.710	2	3.355	2.005	.137
Distance	2.056	2	1.028	3.299	.037
Width	505.692	2	252.846	811.360	.000
Angle	2.180	7	.311	.999	.430
Distance * Width	.529	4	.132	.425	.791
Distance * Angle	4.214	14	.301	.966	.486
Width * Angle	1.120	14	.080	.257	.997
Distance * Width * Angle	4.911	28	.175	.563	.969
TP * Distance	.599	2	.299	.961	.383
TP * Width	30.731	2	15.366	49.307	.000
TP * Angle	1.077	7	.154	.494	.840
Filter * Distance	.171	2	.085	.274	.760
Filter * Width	3.996	2	1.998	6.411	.002
Filter * Angle	.570	7	.081	.261	.969
Gain * Distance	1.306	4	.326	1.048	.381
Gain * Width	196.380	4	49.095	157.541	.000
Gain * Angle	4.599	14	.329	1.054	.395
TP * Filter * Distance	.142	2	.071	.228	.796
TP * Filter * Width	4.972	2	2.486	7.977	.000
TP * Filter * Angle	.674	7	.096	.309	.950
TP * Gain * Distance	2.047	4	.512	1.642	.161
TP * Gain * Width	59.533	4	14.883	47.759	.000
TP * Gain * Angle	3.660	14	.261	.839	.627
Filter * Gain * Distance	2.801	4	.700	2.247	.061
Filter * Gain * Width	1.311	4	.328	1.052	.379
Filter * Gain * Angle	2.099	14	.150	.481	.944
TP * Filter * Gain * Distance	.541	4	.135	.434	.784
TP * Filter * Gain * Width	5.580	4	1.395	4.476	.001
TP * Filter * Gain * Angle	2.647	14	.189	.607	.862

TP * Filter * Distance * Width	.707	4	.177	.567	.687
TP * Filter * Distance * Angle	3.217	14	.230	.737	.738
TP * Distance * Width	1.029	4	.257	.826	.508
TP * Distance * Angle	3.620	14	.259	.830	.637
TP * Width * Angle	2.112	14	.151	.484	.943
TP * Distance * Width * Angle	12.897	28	.461	1.478	.050
Filter * Distance * Width	.976	4	.244	.783	.536
Filter * Distance * Angle	5.825	14	.416	1.335	.177
Filter * Width * Angle	1.809	14	.129	.415	.971
Filter * Distance * Width * Angle	5.906	28	.211	.677	.900
Gain * Distance * Width	1.389	8	.174	.557	.814
Gain * Distance * Angle	6.527	28	.233	.748	.828
Gain * Width * Angle	10.619	28	.379	1.217	.199
Gain * Distance * Width * Angle	22.226	56	.397	1.274	.082
TP * Filter * Width * Angle	2.546	14	.182	.583	.880
TP * Filter * Distance * Width * Angle	7.067	28	.252	.810	.749
TP * Gain * Distance * Width	2.255	8	.282	.905	.511
TP * Gain * Distance * Angle	10.071	28	.360	1.154	.262
TP * Gain * Width * Angle	7.818	28	.279	.896	.623
TP * Gain * Distance * Width * Angle	21.791	56	.389	1.249	.100
Filter * Gain * Distance * Width	2.539	8	.317	1.018	.419
Filter * Gain * Distance * Angle	14.033	28	.501	1.608	.022
Filter * Gain * Width * Angle	4.190	28	.150	.480	.991
Filter * Gain * Distance * Width * Angle	21.958	56	.392	1.258	.093
TP * Filter * Gain * Distance * Width	3.697	8	.462	1.483	.158
TP * Filter * Gain * Distance * Angle	6.519	28	.233	.747	.829
TP * Filter * Gain * Width * Angle	6.180	28	.221	.708	.870
TP * Filter * Gain * Distance * Width * Angle	8.202	56	.146	.470	1.000
Intercept	755.426	1	755.426	47.854	.000
Block	299.936	19	15.786	9.435	.000
Error	5044.709	16188	.312		
Total	7667.000	17280			

Table A.3 The complete ANOVA table for Movement Count

Source	SS	DF	MS	F	Sig.
TP	14359.889	1	14359.889	195.003	.000
Filter	23.256	1	23.256	.316	.575
Gain	79965.138	2	39982.569	542.952	.000
TP * Filter * Gain * Participant	15390.595	209	73.639		
TP * Filter	274.751	1	274.751	3.731	.055
TP * Gain	5064.719	2	2532.360	34.389	.000
Filter * Gain	210.989	2	105.494	1.433	.241
TP * Filter * Gain	36.824	2	18.412	.250	.779
D	119472.838	2	59736.419	81733.470	.000
W	3833.619	2	1916.809	2622.646	.000
A	10844.747	7	1549.250	2119.738	.000
D * W	15.783	4	3.946	5.399	.000
D * A	3617.111	14	258.365	353.504	.000
W * A	28.216	14	2.015	2.758	.000
D * W * A	19.786	28	.707	.967	.514
TP * D	4534.257	2	2267.128	3101.965	.000
TP * W	6.135	2	3.067	4.197	.015
TP * A	1037.673	7	148.239	202.826	.000
Filter * D	24.098	2	12.049	16.486	.000
Filter * W	.871	2	.435	.596	.551
Filter * A	23.952	7	3.422	4.682	.000
Gain * D	23867.986	4	5966.997	8164.255	.000
Gain * W	193.213	4	48.303	66.090	.000
Gain * A	3014.644	14	215.332	294.624	.000
TP * Filter * D	79.829	2	39.914	54.612	.000
TP * Filter * W	.046	2	.023	.032	.969
TP * Filter * A	34.717	7	4.960	6.786	.000
TP * Gain * D	1734.695	4	433.674	593.368	.000
TP * Gain * W	20.929	4	5.232	7.159	.000
TP * Gain * A	497.089	14	35.506	48.581	.000
Filter * Gain * D	30.627	4	7.657	10.476	.000
Filter * Gain * W	.368	4	.092	.126	.973
Filter * Gain * A	27.811	14	1.987	2.718	.001
TP * Filter * Gain * D	11.993	4	2.998	4.102	.003
TP * Filter * Gain * W	4.421	4	1.105	1.512	.195
TP * Filter * Gain * A	15.893	14	1.135	1.553	.084

TP * D * W	3.408	4	.852	1.166	.324
TP * D * A	446.653	14	31.904	43.652	.000
TP * W * A	11.504	14	.822	1.124	.330
TP * D * W * A	15.720	28	.561	.768	.803
Filter * D * W	2.927	4	.732	1.001	.405
Filter * D * A	13.368	14	.955	1.306	.194
Filter * W * A	14.334	14	1.024	1.401	.143
Filter * D * W * A	27.660	28	.988	1.352	.101
Gain * D * W	9.586	8	1.198	1.640	.108
Gain * D * A	984.070	28	35.145	48.087	.000
Gain * W * A	9.700	28	.346	.474	.992
Gain * D * W * A	33.398	56	.596	.816	.836
TP * Filter * D * W	4.751	4	1.188	1.625	.165
TP * Filter * D * A	7.967	14	.569	.779	.694
TP * Filter * W * A	13.689	14	.978	1.338	.176
TP * Filter * D * W * A	19.789	28	.707	.967	.514
TP * Gain * D * W	4.357	8	.545	.745	.652
TP * Gain * D * A	267.512	28	9.554	13.072	.000
TP * Gain * W * A	32.146	28	1.148	1.571	.028
TP * Gain * D * W * A	33.473	56	.598	.818	.833
Filter * Gain * D * W	3.849	8	.481	.658	.729
Filter * Gain * D * A	21.435	28	.766	1.047	.396
Filter * Gain * W * A	8.241	28	.294	.403	.998
Filter * Gain * D * W * A	27.256	56	.487	.666	.974
TP * Filter * Gain * D * W	9.130	8	1.141	1.562	.131
TP * Filter * Gain * D * A	22.179	28	.792	1.084	.347
TP * Filter * Gain * W * A	15.554	28	.555	.760	.813
TP * Filter * Gain * D * W * A	20.308	56	.363	.496	.999
Intercept	656953.857	1	656953.857	2205.105	.000
Participant	5660.557	19	297.924	4.046	.000
Error	37090.115	50748	.731		
Total	990108.000	51840			

Table A.4 The complete ANOVA Table for Re-entry Count

Source	SS	DF	MS	F	Sig.
TP	39.061	1	39.061	39.752	.000
Filter	6.602	1	6.602	6.718	.010
Gain	542.440	2	271.220	276.020	.000
TP * Filter * Gain * Participant	205.366	209			
TP * Filter	2.038	1	2.038	2.074	.151
TP * Gain	30.484	2	15.242	15.512	.000
Filter * Gain	2.602	2	1.301	1.324	.268
TP * Filter * Gain	.755	2	.378	.384	.681
D	1.101	2	.550	2.828	.059
W	1030.308	2	515.154	2648.009	.000
A	7.588	7	1.084	5.572	.000
D * W	.905	4	.226	1.163	.325
D * A	4.196	14	.300	1.541	.088
W * A	9.713	14	.694	3.566	.000
D * W * A	5.545	28	.198	1.018	.438
TP * D	.213	2	.107	.547	.578
TP * W	55.910	2	27.955	143.694	.000
TP * A	3.020	7	.431	2.217	.030
Filter * D	.153	2	.077	.394	.675
Filter * W	5.052	2	2.526	12.985	.000
Filter * A	.983	7	.140	.722	.653
Gain * D	1.061	4	.265	1.364	.244
Gain * W	371.276	4	92.819	477.110	.000
Gain * A	4.827	14	.345	1.772	.037
TP * Filter * D	.685	2	.343	1.761	.172
TP * Filter * W	1.795	2	.898	4.614	.010
TP * Filter * A	2.564	7	.366	1.883	.068
TP * Gain * D	.580	4	.145	.745	.561
TP * Gain * W	67.527	4	16.882	86.776	.000
TP * Gain * A	6.443	14	.460	2.366	.003
Filter * Gain * D	.335	4	.084	.430	.787
Filter * Gain * W	3.591	4	.898	4.615	.001
Filter * Gain * A	2.505	14	.179	.920	.536
TP * Filter * Gain * D	.147	4	.037	.189	.944
TP * Filter * Gain * W	2.221	4	.555	2.854	.022
TP * Filter * Gain * A	3.260	14	.233	1.197	.269

TP * D * W	.498	4	.125	.641	.634
TP * D * A	2.651	14	.189	.973	.478
TP * W * A	4.484	14	.320	1.646	.059
TP * D * W * A	5.248	28	.187	.963	.520
Filter * D * W	.626	4	.156	.804	.522
Filter * D * A	3.009	14	.215	1.105	.347
Filter * W * A	.904	14	.065	.332	.990
Filter * D * W * A	5.450	28	.195	1.001	.464
Gain * D * W	1.253	8	.157	.805	.598
Gain * D * A	4.890	28	.175	.898	.620
Gain * W * A	6.779	28	.242	1.245	.174
Gain * D * W * A	11.474	56	.205	1.053	.367
TP * Filter * D * W	.349	4	.087	.448	.774
TP * Filter * D * A	1.801	14	.129	.661	.814
TP * Filter * W * A	3.557	14	.254	1.306	.194
TP * Filter * D * W * A	2.918	28	.104	.536	.978
TP * Gain * D * W	1.178	8	.147	.757	.641
TP * Gain * D * A	5.108	28	.182	.938	.559
TP * Gain * W * A	11.570	28	.413	2.124	.000
TP * Gain * D * W * A	9.805	56	.175	.900	.686
Filter * Gain * D * W	.820	8	.102	.527	.837
Filter * Gain * D * A	4.600	28	.164	.844	.700
Filter * Gain * W * A	1.743	28	.062	.320	1.000
Filter * Gain * D * W * A	9.838	56	.176	.903	.680
TP * Filter * Gain * D * W	.565	8	.071	.363	.940
TP * Filter * Gain * D * A	8.171	28	.292	1.500	.043
TP * Filter * Gain * W * A	3.880	28	.139	.712	.866
TP * Filter * Gain * D * W * A	11.873	56	.212	1.090	.300
Intercept	69358.823	1	69358.823	12251.270	.000
Participant	107.566	19	5.661	5.762	.000
Error	9872.718	50748	.195		
Total	81887.000	51840			