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FACTORS AFFECTING PERFORMANCE OF TARGET ACQUISITION TASKS FOR TOUCHPADS

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ABSTRACT

This study investigates the effect of touchpad size, position filter, and control display gain on user performance. Observations include the behavior of user while using the touchpad to acquire color-changing targets. This study examines the effect of two touchpad sizes, which consist of large (100×60 mm) and small (65×36 mm) sizes, position filters (30, 50), and control-display gains (0.5, 1, 2) on acquiring targets that appeared in eight positions (0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°), at three distances (100, 300, 500 pixel) and 3 different levels of target size (10, 40, 70 pixel). 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 different behavior of touchpad user differs significantly regarding to performance measurements. Filter 50 and Gain 2 for primary movement and Filter 30 and Gain 0.5 for secondary movement are the best combinations for participants to achieve optimum performance. Based on Fitts' Law, the proposed model successfully predicts movement time by adding the effect of CD gain in formulating the task's difficulty index ($R^2 = 0.8147$).

The results in this study will be useful for microelectronic companies to increase touchpad performance and to offer suggestions for designing touchpads based on optimal settings. Furthermore, this study also reveals that each type of touchpad features different settings to achieve optimum performance.

Keywords: Fitts' Law; Human-computer interaction; Touchpad; Velocity curve

1. INTRODUCTION

Pointing devices play an important role in providing optimal satisfaction for computer users. If users could efficiently control a pointing device to execute tasks on a computer, then they will experience satisfaction; if not, they would believe that the device is not a reliable, controllable, and or for that matter a pleasurable gadget. Thus, fast and accurate pointing devices constitute considerable importance to users' overall task performance and to their subjective experience of system performance (Hertzum & Hornbaek, 2005).

Pointing is one of the fundamental and the most frequent tasks executed in Graphical User Interface (GUI). The most common pointing device for computers is a mouse, although other types are also available, such as joystick, trackball, and touchpad. However, the strong preference for portable, hand held computers create a different story. Due to constrained operating space for portable computers, the mouse device is generally not practical and alternative pointing devices are used. In this case, the touchpad has proven to be a common

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alternative pointing device in portable computer (Akamatsu & MacKenzie, 2002). However, comparative evaluations have established that the touchpad pointing performance is poor in comparison with a mouse (Douglas et al., 1999; MacKenzie & Oniszczak, 1998).

On the other hand, when people purchase notebooks, they usually buy a portable mouse as a replacement for the touchpad, because it is difficult to find an easy-to-use touchpad. The definition of an 'easy-to-use' touchpad consists of several criteria, some of these are related to the velocity of the device. Generally, users need the velocity of touchpad to be fast enough to reach the intended target, but also slow enough to click the target accurately. They also want the cursor to be stable enough to click the target.

Furthermore, a touchpad generally consists of several machines (position filter and control display gain) that are responsible for setting its sensitivity, velocity, and other functions. The position filter affects the smoothness of movement, and control of the display gain influences the velocity of cursor. Gain is defined as the amount of cursor movement on the display in response to a unit amount of movement in relation to the control mechanism (Arnaut & Greenstein, 1986). Control Display (CD) Gain is an important factor in touchpad design, because in comparison with the user's primary display the touchpad's small size requires greater manual dexterity. Clutching motions (lifting the finger from touchpad surface and repositioning it) are required 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 by increasing CD Gain. However, increasing CD Gain reduces accuracy, making smaller objects more difficult to target (Casiez et al., 2008).

The previous study found that plotting mean selection times against CD Gain resulted in a U-shape, with the best performance when CD Gain was near 2 (Jellinek & Card, 1990). However, another study stated that an increasing gain caused a proportionate decrease in movement distance and target size, whereas the difficulty of the task remained constant (Fernandez & Bootsma, 2004). Moreover, the optimal setting for the touchpad remains unknown. Further research focusing on optimizing touchpad settings, besides CD Gain, is necessary to achieve better performance.

Some previous studies have attempted to improve touchpad performance in the following four categories: (1) making the touchpad hardware more sophisticated (MacKenzie & Oniszczak, 1998; Hertzum & Hornbaek, 2005; Casiez et al, 2007; McCallum & Irani, 2009); (2) optimizing the control display gain (C:D Gain), which produced various results such as CD gain has appreciable effect (Graham & MacKenzie, 1995) versus a negligible effect (Jellinek & Card, 1990), and (3) still yet another is critical of gain concept (Accot & Zhai, 2003); and (4) 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 moves these targets to the vicinity of the cursor (Baudisch et al., 2003). However, none of the research focuses on improving touchpad settings in the 'Fitts' Law' methodology.

On the other hand, none of the research studied the velocity pattern in touchpad design. The previous study already examined velocity pattern for the mouse, which has only one primary and one secondary movement (Thompson et al., 2007). The research also considered velocity pattern in 3D movement, which were affected by the depth and position (Lee & Wu, 2010). For the touchpad, none of the researchers focused their attention on its velocity graph. Some studies already point out about clutching (MacKenzie & Oniszczak, 1998; Hertzum & Hornbaek, 2005; Casiez et al., 2007; McCallum and Irani, 2009). Therefore none of the research indicates the connection between clutching behavior and velocity graph in touchpad design.

For that reason, this research concentrates on factors related to touchpad performance for the pointing device. The factors are as follows: position filter, CD gain, and also touchpad size.

These three factors are studied along with factors which are already well-known in Fitts' Law (distance, target size/target size, and angle/direction). Moreover, the behavior of touchpad user is also observed, with its purpose to examine the effect of different behaviors into user performance. Velocity curve of touchpad are also examined.

2. METHODOLOGY

2.1. Participants

The experiment involved 20 participants that consisted of 10 males and 10 females, aged 21–29 years old (23.4±1.9 years old). All those participating in the study declared themselves as being right-handed. 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 computers for a period of 10.7 to 2.7 years. Their weekly computer use time ranges from 45.50 to 13.7 hours, and their weekly touchpad use time is between 6.5-5.8 hours. Participants signed informed consent forms before the experiment began.

2.2. Apparatus

This experiment uses a 14-inch screen HP Notebook and two sizes of touchpads. Figure 1 is the illustration of the apparatus used in this study. The touchpad in this experiment was not a fixed touchpad, but the portable touchpad which could be connected to the notebook using a small wire.

Figure 1 Hardware in experiment

The Fitts' Law program applied in this experiment is a multi-directional tapping task. The home target was a square-shaped design and the target was a round-shaped design. The reason why this study applies a circular target is because a square target may pose a problem in that the target size is dependent on the angle of approach. The target size is not the same as when approaching a square target from a vertical or a horizontal angle or from a diagonal angle. If the target size is approached from a diagonal angle, the distance is perceptibly longer than from a horizontal angle, which will generate lower ID (Thompson et al., 2004; MacKenzie, 1995). The target was selected to appear in a random position in the screen. As shown in Figure 2, the color of target is changed if the cursor enters the target boundary. It follows the reality of a task in Windows, where the color of an icon or folder is changed when the cursor enters target boundary.

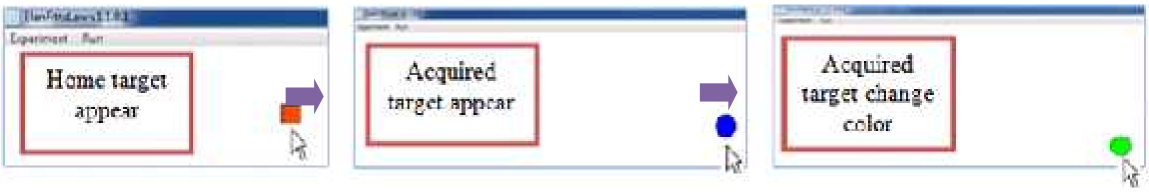

Figure 2 Illustration of the Fitts' Law Program

2.3. Tasks

Participants sat 60 cm away from the front of a display screen. In each task, they were instructed to move the cursor into the home position first. The disappearance of the home target signaled the start of a task. Subjects then attempted to point at square targets appearing in one of eight possible positions relative to home (0°, 45°, 90°, 135°, 180°, 225°, 270°, and 315°), at one of three distances from home (100, 300, and 500 pixel) and in one of three sizes (10, 40, and 70 pixel). After clicking the target, the target disappeared, signaling the completion of a successful task.

2.4 Experimental procedure

The workstation consists of a desk and an adjustable chair. Participants were 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 were conducted before the actual experiment started 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. In each setting, distance, target size, and angle were randomly assigned to each setting of design variables (Touchpad, Filter and Gain). Each session lasted about 120 minutes. A rest period of 3 minutes between settings was provided in order to prevent cumulative local muscle fatigue. Each participant completed all experimental tasks in 2 sessions, lasting for approximately four hours. In total, each participant performed 2,592 trial movements (2 touchpad size × 3 position filter × 3 control display gain ×3 distance ×3 target size ×8 moving direction × 3 repetitions). Figure 3 shows an illustration of experiment.

Figure 3 Illustration of experiment running

2.5. Independent variables
The independent variables of this experiment are touchpad size, position filter, gain, distance, target size, and angle. Two sizes of touchpads are prepared which consist of large (100×60 mm) and small (65×36 mm). In addition, the position filter is set at 2 different levels: 30 and 50, respectively. The position filter in touchpad technology has the function of receiving a sensing signal transmitted by sensing pen, thus filtering and outputting the sensing signal utilized. Filter 30 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. 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, 3 different levels of target size, and 8 directions.

2.6. Dependent variables
The dependent variables from this experiment are performance measurements from several variables including: movement time, number of errors, number of movement count, and number of re-entry count. Movement time (in miliseconds) is defined as the time between when the home target disappeared (the cursor moved away from the home target) and the acquired target being clicked. Error is defined as the number of failures to click the target. Movement count is defined as number of finger movements the participants execute from home until the target is acquired on the touchpad. During touchpad target acquisition, the participants often move several times to reach the target, especially for long distance targets. It is because of the limited size of the touchpad. However, mouse target acquisition does not need movement count as a dependent variable, because when participants use the mouse, they can move their arms freely in one movement. Target re-entry count is identified as number of times that cursor enters the target boundary before clicking the target. Movement time and error count are used for measuring performance, while movement count and re-entry count are highly related to comfort.

2.7. Research model
The means and standard deviations of all measurements were calculated using standard methods. This study uses split-plot analysis of variance (ANOVA) calculations to determine the effect of factors, which consists of 6 independent variables: touchpad size, position filter, control display gain, distance, target size, and angle. The touchpad size, position filter, and control display gain serve as a 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 size, and angle are addressed as a subplot, because they are classified as easy-to-change factors. The subplot consists of 72 combinations of distance, target size, and angle. The block for this experiment is 20, derived from 20 participants. Three replications for each combination are averaged to achieve one single data entry. The LSD and Tukey test were used for Post-Hoc comparisons. The ANOVA one-way is used to compare the different behavior patterns of each user. An alpha value of 0.05 was selected as the minimum level of significance; data were presented as means or standard deviations (SD).

3. RESULTS AND DISCUSSION
3.1 Movement Time (MT) and Movement Count (MC)
Consistent with Fitts' Law, movement time increases with the Index of Difficulty (range from 1.28 to 5.6). With regard to the variables that compose this index, MT significantly increases as a function of distance ($F=35504.649$, $p=0.000$), and decreases as a function of target size ($F=19571.914$, $p=0.000$). As for the main plot, touchpad size affects MT ($F=14.114$, $p=0.000$) when a small touchpad has higher movement time than a large touchpad. MT also had

significantly increased as a function of gain (F=218.848, p=0.000), the higher the gain the lower the MT factor. The angle of approach also has significance to MT (F=579.327, p=0.000), in which angle 45° and angle 225° have the lowest movement times. The interaction of all 6 factors also can be studied from the analysis. 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*target size (F=241.658, p=0.000), touchpad size*target size (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). Table 1 summarizes ANOVA results for movement time, movement count, error count, and re-entry count, which lists only significant variables. Moreover, Table 2 summarizes mean and standard deviation values of movement time, movement count, error count, and re-entry count, and Table 3 summarizes the Post-Hoc comparison of movement time and error count. Figure 4 illustrates the trend line effect of touchpad size, gain, and angle to movement time.

On the other hand, touchpad size (F=195.003, p=0.000) affects movement count significantly. The small touchpad has higher movement count than a large touchpad. Gain affects movement count significantly (F=542.952, p=0.000), with the lower gain generating a higher movement count. Distance (F=81733.47, p=0.000) and target size (F=2622.646, p=0.000) also have an influence, in which longer distance and smaller target size derive a higher movement count. Angle (F=2119.738, p=0.000) also affects movement count significantly, in which angle 0° and and angle 225° have the lowest movement counts, respectively. 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).

Table 1 The complete ANOVA table

Source	DF	F	p
Movement Time			
TP	1	14.114	.000
Gain	2	218.848	.000
TP * Gain	2	14.676	.000
Filter * Gain	2	4.459	.013
D	2	35504.649	.000
W	2	19571.914	.000
A	7	579.327	.000
D * W	4	3.851	.004
D * A	14	113.137	.000
W * A	14	5.626	.000
TP * D	2	368.362	.000
TP * W	2	135.701	.000
TP * A	7	32.318	.000
Filter * D	2	26.773	.000
Filter * A	7	2.894	.005
Gain * D	4	2969.919	.000
Gain * W	4	241.658	.000
Gain * A	14	103.350	.000

Table 1 The complete ANOVA table (continued)

Error count			
TP	1	9.899	.002
Gain	2	34.189	.000
TP * Gain	2	8.825	.000
Distance	2	3.299	.037
Target size	2	811.360	.000
TP * Target size	2	49.307	.000
Filter * Target size	2	6.411	.002
Gain * Target size	4	157.541	.000
Movement count			
TP	1	195.003	.000
Gain	2	542.952	.000
TP * Gain	2	34.389	.000
D	2	81733.470	.000
W	2	2622.646	.000
A	7	2119.738	.000
D * W	4	5.399	.000
D * A	14	353.504	.000
W * A	14	2.758	.000
TP * D	2	3101.965	.000
TP * W	2	4.197	.015
TP * A	7	202.826	.000
Filter * D	2	16.486	.000
Filter * A	7	4.682	.000
Gain * D	4	8164.255	.000
Gain * W	4	66.090	.000
Gain * A	14	294.624	.000
Re-entry count			
TP	1	39.752	.000
Filter	1	6.718	.010
Gain	2	276.020	.000
TP * Gain	2	15.512	.000
W	2	2648.009	.000
A	7	5.572	.000
W * A	14	3.566	.000
TP * W	2	143.694	.000
TP * A	7	2.217	.030
Filter * W	2	12.985	.000
Gain * W	4	477.110	.000
Gain * A	14	1.772	.037

Table 2 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	4.086 (2.872)	1.129 (0.39)
Filter				
30	2.151 (0.895)	0.202 (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 (0.629)	3.626 (1.839)	1.156 (0.5)
500	2.755 (1.011)	0.221 (0.629)	5.385 (2.875)	1.162 (0.5)
Width (pixel)				
10	2.655 (0.841)	0.45 (0.957)	3.918 (2.621)	1.353 (0.739)
40	1.973 (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 (2102)	1.156 (0.483)
225	1.963 (0.835)	0.202 (0.598)	3.143 (2.090)	1.149 (0.048)
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)

Table 3 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			
10	C	C	
40	B	B	
70	A	A	
Angle (deg)			
0	B		
45	A		
90	F		
135	E		
180	C		A<B<CD<E<F
225	A		
270	E		
315	D		

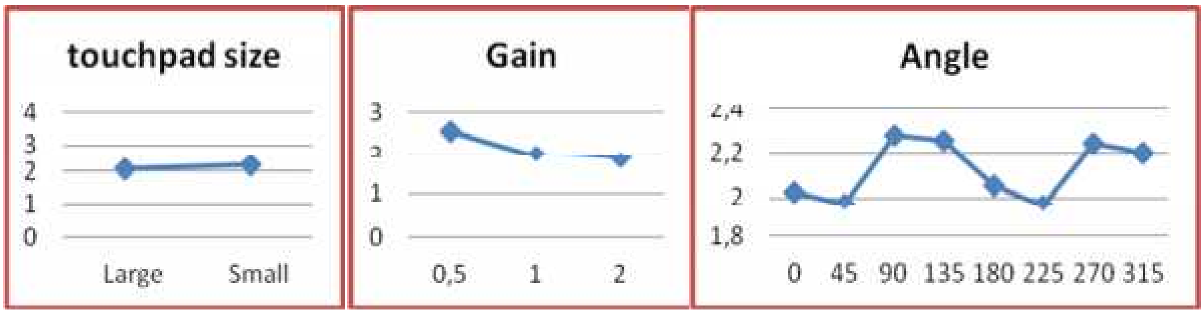

Figure 4 Touchpad size, gain, and angle effect in movement time

3.2. Error count and Re-entry count

From result of ANOVA Split Plot, the main factors affecting error count significantly are touchpad size (F=9.899, p=0.002). The large touchpad has a higher error count than a small touchpad. The gain (F=34.189, p=0.000), introduces a margin of error increased by a higher gain with distance factors calculated as (F=3.299, p=0.037). The margin of error increased as distance became longer. The target size factors (F=811.360, p=0.000), caused a higher margin of error in parallel with a smaller target size. Interaction of gain and target size factors generate significantly higher value factors (F=157.541, p=0.000), followed by touchpad size*target size (F=49.307, p=0.000), touchpad size*gain*target size (F=47.759, p=0.000), touchpad size*gain (F=8.825, p=0.000), and touchpad size*filter*target size (F=7.977, p=0.000). Figure 5 illustrates the interaction of gain and distance factors in movement time and the interaction of gain and target size in the margin of error count.

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), target size (F=2648.009, p=0.000), and angle (F=5.572, p=0.000) have a significant effect. The large touchpad has a higher re-entry count than a small touchpad, and filter 50 has higher re-entry count than filter 30. Higher gain and smaller target size caused a higher re-entry count value. Moreover, the different angles produced a different re-entry count. The interaction of all 6 factors also can be studied from the analysis. The interaction of gain and target size generates a significant value (F=477.110, p=0.000), followed by touchpad size*target size (F=143.649, p=0.000), and touchpad size*gain*target size (F=86.776, p=0.000).

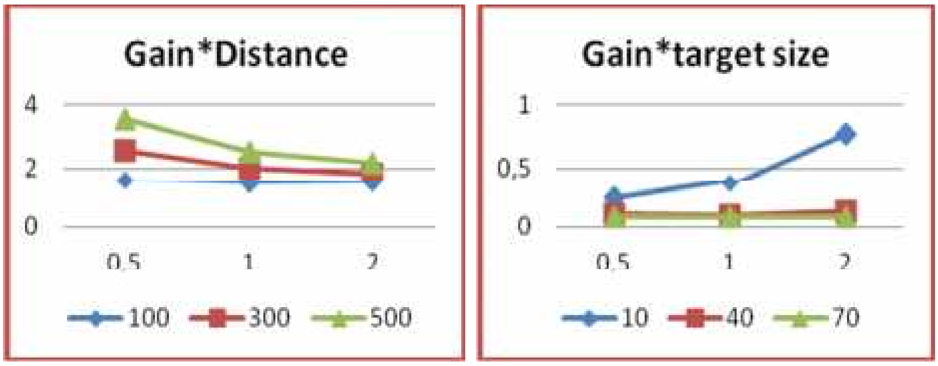

Figure 5 Interaction of gain and distance in movement time and interaction of gain and target size in error count

3.3. User behavior

We observed user behavior in the experiment to examine the effect of different behavior patterns on user performance. The strong behavior pattern that particular users exhibit in using a touchpad is divided into 4 categories, 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. Users 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. Users that combine one hand (surface) and two hands (button) behavior in different combinations : 2 users

Figure 6 Behaviors of touchpad user

The different user behavior patterns significantly affected all of the dependent variables. By running ANOVA one-way, the type of hand movements used are being tested. The results are that the type of hand movement significantly affected movement time (F=7.948, p=0.005), movement count (F=13.927, p = 0.000), error count (F=8.038, p=0.005), and re-entry count (F=69.685, p=0.000). Moreover, a one-handed user has higher movement time and re-entry count than a two-handed user. Otherwise, a one- handed user has a lower movement count and error count than a two-handed user.

3.4. Velocity curve

The velocity curve that users obtained when using the mouse consists of two parts: primary and secondary movements, as Jagacinski et al., (1980), Walker et al. (1993) and Thompson et al., (2007) described in their previous researches. For all pointing tasks, there are cases with and/or without a "secondary sub-movement." Identification of a "secondary sub-movement" is based on the size of the global peak velocity of the primary sub-movement and the subsequent local peak velocity. Following Thompson et al., (2007), the secondary sub-movement should fulfill criteria of : (1) the subsequent local peak velocity must have been at least 15% of the global peak velocity; (2) local minimum velocities surrounding the local peak velocity must have been at most 15% of the global peak velocity and at most 50% of the local peak velocity; and (3) a local minimum velocity 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.

Furthermore, the combined velocity curve consists of one primary movement, and one secondary movement. However, the target acquisition task using a touchpad is different than using a mouse, mainly because of the operational area differences. When using mouse, the user can move their arm freely within a free boundary, while, in contrast, when using mouse, the users only can move their wrist or arm in a limited area, depending on the touchpad size. This difference will create a different velocity curve. The velocity curve for the touchpad has several primary movements and one or multiple secondary movements, depending on the target size.

Moreover, to examine the velocity curve of touchpad, we divided it into two parts: primary and secondary movement. We tried to determine the duration of the primary and secondary phases to know about the curve characteristics for each different factor (touchpad size, position filter, and control display gain).

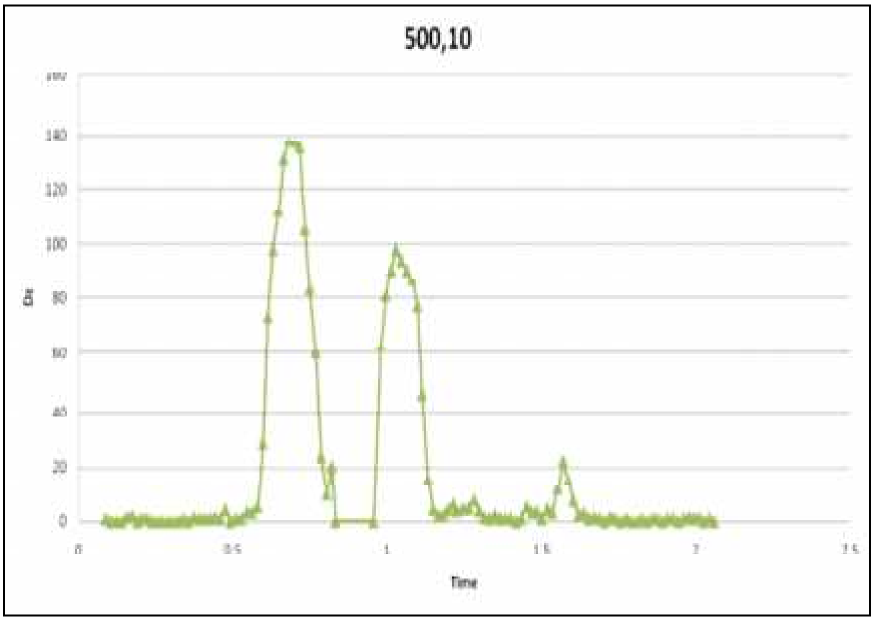

Figure 7 Sample of velocity graph in touchpad

As the result, in terms of touchpad size, the large touchpad has a lower movement time than a small touchpad in the field of primary movement, while in the case of secondary movements, the small touchpad results in lower movement time than large touchpad. For the primary movement count, a small touchpad has a higher value than a large touchpad. Furthermore, a Filter 50 is better than a Filter 30 in primary movement conditions. However, in secondary movement conditions, Filter 30 and Filter 50 do not differ significantly. In primary movement, the Gain 2 factor has the lowest movement time, but in secondary movement, the Gain 0.5 factor has the lowest movement time.

3.5. Fitts' law model

Increased target acquisition time with increasing movement distance and decreasing target size, indicates that data from this study conform to Fitts' paradigm. Therefore, we are able to deduce that Fitts' regression model is based on moving distances (D) and target size (W). The calculation of the task difficulty index ($ID=\log_2((D/W)+1)$ of each and every combination shows the R^2 range from 0.6943 to 0.9853. Moreover, the regression model for the overall combination is 0.659.

Based on the R^2 results (R^2=0.6593), which illustrates that each and 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 strong, with reversed effect. For this reason, we can formulate that:

$$\frac{1}{Gain} \times Distance \propto Movement\ Time \qquad (1)$$

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:

$$MT = a + b\log_2\left(\frac{D}{W}\frac{1}{G} + 1\right) \qquad (2)$$

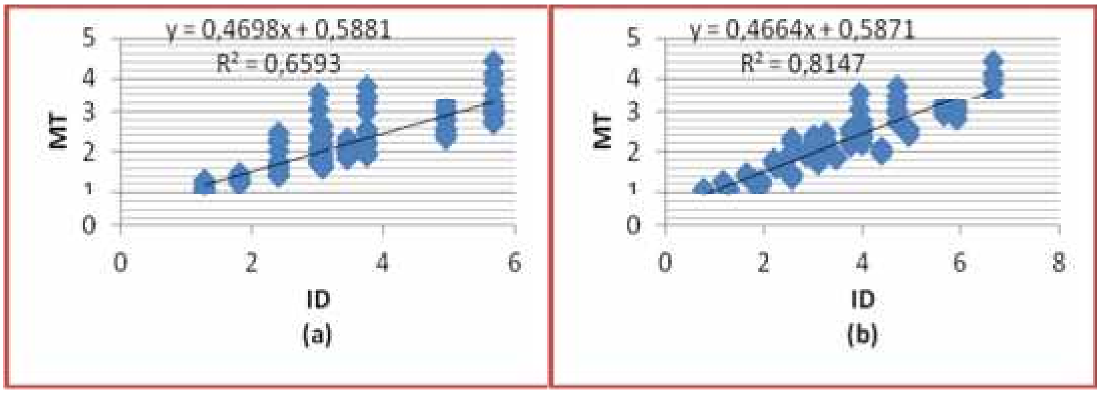

Figure 8 Comparison of Fitts' Law regression model, (a) with Shannon formulation, (b) with Johnsgard equation

Furthermore, after designing the regression model, those two formulas are compared. The formula proposed by Johnsgard (1994) has higher a R^2 factor than the Shannon formulation. It explained the 81.4% variance in data levels obtained during this experiment. Thus, the Johnsgard equation is a better and more suitable model to be implemented in predicting movement time, especially in the case of target acquisition tasks for the touchpad.

3.6. 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 it has difficulty in final acquisition of the target. Low-gain setting, on the other hand, facilitates fine positioning of the cursor, but increases the time to advance the cursor over large distances (Akamatsu &MacKenzie, 2002). However, Jellinek & 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 studies 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 (Arnaut & Greenstein, 1986). Moreover, the gain effect in pointing movement with the hand is appreciable (Graham & MacKenzie, 1995). Based on our results and findings, despite the different results shown by previous researches, gain has a large effect of target acquisition task in touchpad design. The Gain 2 Factor is the best for obtaining high speed, but fails in terms of accuracy. On the other hand, Gain 0.5 Factor is better for accuracy, as observed in its low error count and re-entry count value. In contrast, Gain 1 Factor served as a medium gain level, with medium speed and medium accuracy. Furthermore, we propose for applying non-linear gain in touchpad design to reduce clutching and increase accuracy.

3.7. Effect of angle

An interesting fact of angle (direction) for touchpad performance measurement reveals that angles of 45° and 225° respectively have higher performance values than other angles 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 of the size of touchpad, which is rectangular-shaped, whereas the length is longer than the target size, 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 studies. Whisenand and Emurian (1996), Thompson et al (2004), and Fernandez and Bootsma (2004) stated that performance in mouse manipulation was generally best along the lateral angles (0° and 180°, to a lesser extent at 315°), the longest occurs along the vertical axis (90° and 270°), and remaining diagonal falling somewhere in between. This finding reflects the result that the impact of angle for mouse and touchpad is not the same.

3.8. Fitts' law modification

For interactions of main effect, we also found same pattern. Control display gain and distance interaction have the highest value than other interactions in terms of 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 relation to the factors of error count and re-entry count, interaction of target size 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 relation to speed matters; however interaction of target size and gain is the most important factor in terms of accuracy. A highly 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, Johnsgard's equation generates a better fit in terms of measuring touchpad performance, especially in relation to low gain (0.5).

4. CONCLUSION

The findings from this research are as summarized below.

Touchpad size significantly affects movement time, error count, movement count, and re-entry count. A large touchpad is better for primary movement, because the movement time and movement count spent with large touchpad is overall lower than a small touchpad.

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 the 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.

A large touchpad requires a slower gain than small touchpad in terms of the secondary movement to improve accuracy.

The finger velocity in the touchpad creates a pattern of several primary movements in velocity graph because of clutching behavior patterns.

A one-handed user has a lower error count factor and a two-handed user has less movement time. However, in terms of higher gain (2), a two-handed user has less error count than a one-handed user. We can conclude that a two-handed user has more advantage in touchpad performance, especially in terms of higher gain.

Johnsgard's equation that included Gain into Index of Difficulty formula produced better regression line than Shannon Formulation means, therefore, Johnsgard's equation of ID is better applied in target acquisition tasks in touchpad operations.

5. REFERENCES

Accot, J. and Zhai, S. 2003. Refining Fitts' Law Models for Bivariate Pointing. *In:* Proceedings of the SIGCHI conference on Human factors in computing systems: ACM.

Akamatsu, M., MacKenzie, I. S. 2002. Changes in Applied Force to a Touchpad during Pointing Tasks, International Journal of Industrial Ergonomics, Volume 29, pp. 171-182.

Arnaut, L. Y., Greenstein, J. S. 1986. Optimizing the touch tablet: the effects of control-display gain and method of cursor control, Human Factors, Volume 28, Number 6, pp. 717-726.

Baudisch, P., Cutrell, E., Robbins, D., Czerwinski, M., Tandler, P., Bederson, B., and Zierlinger, A. 2003. Drag-and-Pop and Drag-and-Pick: techniques for accessing remote screen content on touch- and pen-operated systems. *In:* Proceedings of Interaction 2003, pp. 57-64.

Casiez, G., Vogel, D., Pan, Q., Chaillou, C. 2007. RubberEdge: reducing clutching by combining position and rate control with elastic feedback. *In:* Proceedings of UIST, pp. 129-138.

Douglas, S.A., Kirkpatrick, A.E., MacKenzie, I.S. 1999. Testing pointing device performance and user assessment with the ISO 9241, Part 9 standard. *In:* ACM Conference in Human Factors in Computing Systems e CHI '99, New York.

Fernandez, L., Bootsma, R. J. 2004. Behind Fitts' law: kinematic patterns in goal-directed movements, International Journal of Human-Computer Studies, Volume 61, Issue 6.

Graham, E.D., MacKenzie, C.L. 1995. Pointing on a computer display. *In:* CHI '95 Conference Companion, Denver, Colorado, May, pp. 314-315.

Hertzum, M., Hornbaek, K. 2005. TouchGrid: Touchpad Pointing by Recursively Mapping Taps to Smaller Display Recognition, Behaviour & Information Technology, Volume 24, Number 5, pp. 337-346.

Jagacinski, R. J., Repperger, D. W., Moran, M. S., Ward, S. L., Glass, B. 1980a. Fitts' law and the microstructure of rapid discrete movements, *Journal of Experimental Psychology: Human Perception and Performance*,Volume 6, pp. 309-320.

Jellinek H. D., Card, S. K. 1990. Powermice and User Performance. *In:* Proceedings of the CHI's 90 Conference on Human Factors in Computing Systems. New York: ACM.

Johnsgard, T. 1994. Fitts' Law with a Virtual Reality Glove and a Mouse: Effects of Gain. *In:* Proceedings of Graphics Interface 1994, pp. 8-15.

Lee, Y. H., Wu, S. K., Liu, Y. P. 2010. Performance of remote target Acquisition Hand Movements in a 3D environment, Human Movement Science SCI (in printing)

MacKenzie, I.S. 1995. In: Barfield, W., Furness, T.A. (Eds.), Virtual environments and advanced interface design. Oxford, New York, pp. 437–470.

MacKenzie., Oniszczak. 1998. A Comparison of Three Selection Techniques for Touchpad. *In:* Proceedings of the CHI '98 Conference on Human Factors in Computing Systems, pp. 336-343 New York: ACM.

McCallum, D. C., Irani, P. 2009. ARC-Pad: Absolute + Relative Cursor Positioning for Large Displays with a Mobile Touchscreen. *In:* Proceedings of UIST.

Thompson, S., Slocum, J., Bohan, M. 2004. Gain and Angle of Approach Effects on Cursor-Positioning Time with a Mouse in Consideration of Fitts' Law. *In:* Proceedings of the Human Factors and ergonomics Society 48^{th} annual meeting.

Thompson, S.G., McConnell, D. S., Slocum, J. S., Bohan, M. 2007. Kinematic Analysis of Multiple Constraints on a Pointing Task, Human Movement Science, Volume 26, pp. 11-26.

Walker, N., Catrambone, R. 1993. Aggregation bias and the use of regression in evaluation models of human performance, Human Factors, Volume 35, pp. 397-411.

Whisenand, T. G., Emurian, H. H., (1996), Effects of Angle of Approach on Cursor Movement with a Mouse: Consideration of Fitts' Law, Computers in Human Behavior, Volume 12, Number 3, pp. 481-495.