An Evaluation of Different Input Techniques for a Tabletop Display Using Fitts' Reciprocal Tapping Task

User performance with a tabletop display was tested using touch-based and mouse-based interaction in a traditional pointing task. Dependent variables were throughput, accuracy, and movement time. In a study with 12 participants, touch had a better performance with average throughput of 5.53 bps in comparison to 3.83 bps for mouse. Touch also had a lower movement time on average, ranging from 403 ms to 1051 ms vs. mouse input that ranged from 607 ms to 1323 ms. Error rates were lower for the mouse at 2.1%, compared to 9.8% for touch. The high error rates using touch were substantially due to problems in selecting small targets with the finger. It is argued that overall, touch input is a preferred and efficient input technique for tabletop displays.

INTRODUCTION

Interaction methods in direct manipulation interfaces are well documented in the human-computer interaction literature. Point-select tasks, in particular, have been highly studied (e.g., Card et al., 1978; Forlines et al., 2007; MacKenzie et al., 1991; MacKenzie, 1995; Soukoreff & MacKenzie, 2004). A recent trend is in "surface computing" – a term referring to interactions that involve flat surfaces such as tabletops, walls, floors, and even ceilings (Terrenghi et al., 2007). With an ever-increasing demand for touch-based interfaces, investigating the human factors for basic tasks using these devices is essential. The investigation of performance differences among different input techniques yields a better understanding of the issues in common tasks and hence can inform the design of more appropriate interactive environments.

This paper presents a comparison between two input techniques (mouse and touch input) in a simple target acquisition task using Fitts' reciprocal tapping task (Fitts, 1954) on a tabletop. Below, we discuss the Fitts' law formulation for measuring performance, and then we outline the details of our methodology in evaluating the performance of the two techniques. Following this, the results of the study are presented and discussed.

Fitts' Law Overview

Fitts' seminal paper (1954) introduced a model that explains the tradeoff between accuracy and speed in human motor movements. His model, commonly known as Fitts' law, is based on Shannon's information theory. Fitts proposed to quantify a movement task's difficulty – *ID*, the index of difficulty – using information theory by the metric "bits". Specifically,

$$ID = \log_2\left(\frac{2A}{W}\right) \quad (1)$$

The amplitude (*A*) and width (*W*) in Equation 1 are analogous to Shannon's original formulations for signal and noise in electronic communications systems. Note the offsetting influences of *A* and *W* in the equation. Doubling the distance to a target has the same effect as halving its size.

An important thesis in Fitts' work was that the relationship between task difficulty and the movement time (*MT*) is linear. The following expression for *ID* is more commonly used today, as it improves the information-theoretic analogy (MacKenzie, 1995):

$$ID = \log_2\left(\frac{A}{W}+1\right) \quad (2)$$

Because *A* and *W* are both measures of distance, the term in the parentheses in Equation 2 is without units. The unit "bits" emerges from the somewhat arbitrary choice of base 2 for the logarithm.

Fitts' law is often used to build a prediction model with the movement time (*MT*) to complete point-select tasks as the dependent variable:

$$MT = a + b \times ID \quad (3)$$

The slope and intercept coefficients in the prediction equation are determined through empirical tests, typically using linear regression. The tests are undertaken in a controlled experiment using a group of participants and one or more input devices and task conditions.

Fitts (1954) original experiment used a reciprocal tapping task where the subjects tapped back and forth between the two rectangular targets. The width of targets and distance between them were varied (4×4 conditions) to cover a range of conditions typical of common usage (see Figure 1).

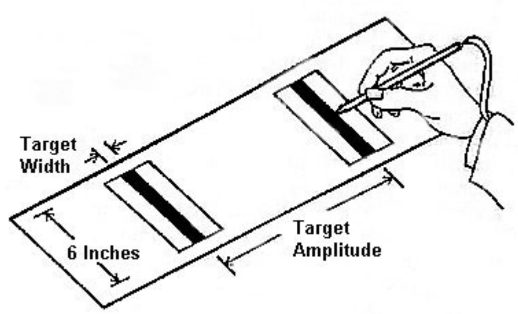

Figure 1. Fitts' original experiment (from Fitts, 1954)

The experiment discussed in this paper uses software developed to emulate the task in Fitts' original experiment. It is also used as "Task #1" in the ISO standard for evaluating pointing devices (ISO, 2000).

Evaluation of Performance Using Fitts' Law

Fitts' proposed to quantify the human rate of information processing in aimed movements using "bits per second" as the units. This is a provocative idea, based purely on analogy, without any basis in human psychomotor behaviour. Fitts' index of performance, now called throughput (*TP*, in bits/s), is calculated by dividing *ID* (bits) by the mean movement time, *MT* (seconds), computed over a block of trials:

$$TP = \frac{ID_e}{MT} \tag{4}$$

The subscript e in *IDe* reflects a small but important adjustment, which Fitts endorsed in a follow-up paper (Fitts and Peterson, 1964). An "adjustment for accuracy" involves first computing the "effective target width" as

$$W_e = 4.133 \times SD_x \tag{5}$$

where *SDx* is the observed standard deviation in a participant's selection coordinates. Computed in this manner, *We* includes the spatial variability, or accuracy, in responses. In essence, it captures what a participant actually did, rather than what he or she was asked to do. This adjustment necessitates a similar adjustment to ID, yielding an "effective index of difficulty":

$$ID_e = \log_2\left(\frac{A}{W_e} + 1\right) \tag{6}$$

Calculated using the adjustment for accuracy, TP is a human performance measure that embeds both the speed and accuracy of responses. TP is most useful as a dependent variable in factorial experiments using pointing devices or pointing techniques as independent variables. Although not shown in Equation 6, it is also common to use the "effective target amplitude" (Ae) as the actual distanced moved, rather than the specified distance. The effect is usually minor, though.

Related Work

MacKenzie et al. (1991) compared the performance of three devices: a mouse, a trackball, and a stylus. They compared a standard pointing and dragging task. For the pointing task they found that stylus had the lowest mean movement time (665 ms) and trackball had the highest (1101 ms) and mouse mean movement time was very close to the stylus (674 ms). They also found that mouse was the most accurate with an error rate of 3.5% followed by the trackball at 3.9%. The stylus was least accurate with an error rate of 4.0%.

A key focus of our research is touch-based interaction. There are just a few ISO-conforming studies in this area. Fortlines et al. (2007) compared the performance between direct-touch and mouse input for bimanual and unimanual tasks on a tabletop display. They found that direct-touch input is more appropriate for bimanual tasks on a tabletop but the mouse performed better in a unimanual task. For the unimanual task (selecting and docking), direct-touch had a higher throughput (8.05 bps) as opposed to mouse (4.35 bps) in the selection portion of the task. The result also showed that selection with touch was more inaccurate with the average error rate more than twice that of the mouse, 8.5% compared to 4.1%. For the bimanual tasks (selecting, resizing, docking), touch performed better (1.45 s) than the mouse (2.43 s) in the selection portion of the task. The mouse was again more accurate, with an average error rate of 9.7% compared to 18.9% using touch.

These two studies are specifically related to this work in that the first study uses the same task and procedure but compares different input techniques and devices. The second study compares the same techniques (i.e., mouse and touch) and uses the same tabletop technology, but it uses a different task.

The main contribution of this work is the comparison of the performance between touch and mouse input methods but using the correct calculation of the throughput based on the ISO 9241-9 standard (2000).

METHOD

A user experiment was conducted to evaluate the performance of the two interaction techniques; namely, indirect interaction with a mouse and direct touch interaction using a finger. We used a simple pointing task conforming to the methodology of Task #1 of the ISO 9241 standard, part 9, for non-keyboard input devices. In particular, the study investigated the differences in throughput of each input technique in performing a simple target acquisition task. The differences in movement time and error rates were also observed. The details of the study are discussed below.

Participants

Twelve right-handed participants (9 males. 3 females; 21-29 years) were recruited from a local university. Right-handed participants were chosen to limit the location of the display, described in the next section. All participants were regular computer users and all reported some prior experience with touch input. The participants volunteered to participate in the study and were not paid.

Experimental Apparatus

The study took place in a quiet experimental laboratory. A 32" diagonal Mitsubishi Electronics Research Laboratories (Merl) *DiamondTouch II DT88* touch-sensitive surface with a top-projected display was used. It included DiamondTouch SDK 2.1 and mouse emulator software (DTMouse) to convert the display's touch events to mouse events. A receiver pad connected to an RCA port under the DiamondTouch was located on participants' stool to detect the low-level radio-frequency signals from an array of antennas located on the display's surface when the user touched the screen. The DiamondTouch was located on a small desk that allowed enough room for a mouse on the right side (see Figure 2).

A Logitech *MX 110* cordless laser mouse with Windows XP default sensitivity (50%) was used for the mouse condition.

Figure 2. The experimental setting

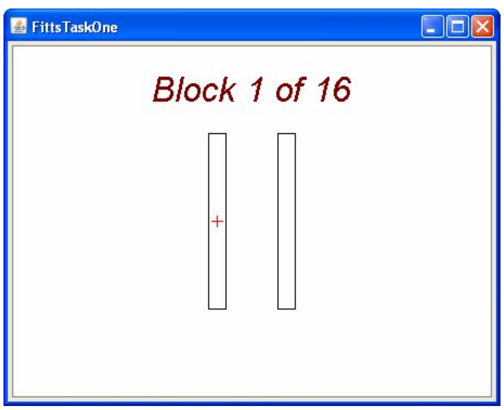

Figure 3. Software implementation of Task #1 of ISO 9241-9

Both the projector and the DiamondTouch were connected to a Lenovo *T61* laptop that used Microsoft Windows XP with SP3 and the Java v1.6.1 runtime environment. The laptop's processor was 2 GHz Intel Core Duo CPU with 1 GB of main memory. The resolution of the display was set to 800 × 600 for proper display of the targets.

Experimental Task

The task was Task #1 described in the ISO 9241 standard, part 9 which is a software emulation of original Fitts' reciprocal tapping task in one dimension as illustrated on Figure 3. Two rectangular targets were located on the screen. The target to select was marked by a red plus sign in the middle. With each selection (correct or incorrect) the plus sign moved to the other target. A beep was sounded for incorrect selections.

Experimental Design

The experiment had the following independent variables and levels:

Input Technique:	touch, mouse
Target Width:	8, 16, 32, 64 pixels
Target Amplitude:	64, 128, 256, 512 pixels
Trials:	1 … 20
Blocks:	1 … 16

A 4 × 4 (block conditions) × 2 (input technique) factorial design was used, with repeated measures on the both factors. The input techniques included touch and a mouse. In the touch condition, participants could only use one finger to interact with tabletop. In the mouse condition, participants performed the task using a mouse in the convention manner. The block conditions included four target widths (8, 16, 32, and 64 pixels) and four target amplitudes (64, 128, 256, and 512 pixels) for a total of 16 combinations. These were chosen so that the interaction would span a range of task difficulties typical for the tabletop display. The hardest task had $ID = \log_2(512 / 8 + 1) = 6.02$ bits, while the easiest task had $ID = \log_2(64 / 65 + 1) = 1.00$ bits.

To measure and compare the performance of the two interaction techniques, three main dependent variables were used: movement time (ms), accuracy (% errors), and throughput (bps). Movement time is the total time for a trial, including both the time to move from the source target to the destination target and the time to make a selection. Accuracy is the correctness of selections – the percentage of out-of-target selections. At the end of each block the number of errors was calculated and at the end of the session the mean percentage of errors for all blocks was recorded.

Procedure

Each participant began by completing an informed consent form and a background questionnaire that gathered demographic information (results above). Next, they were randomly assigned an input technique to start with. There was a full practice session administered with each input technique. In the practice sessions, participants were asked to become comfortable with the environment, the task, and the input technique. Practice sessions took approximately 6-8 minutes. Figure 4 shows a participant performing the task using touch.

Following the practice session, participants completed one full experiment session that included 16 blocks each with 20 trials/block. Each session took approximately 6-8 minutes. Participants then repeated the same procedure (one practice session + one experiment session) for the other input technique.

Participants could take breaks before starting each block. They were told that the first click in each block is not included in the performance calculation. Each block was randomly generated from the 16 possible target width and target amplitude combinations. Participants were told to select back and forth between the two targets "as quickly and accurately as possible" twenty times using the assigned technique. In total each participant performed 2 × 16 × 20 = 640 experiment trials

At the end of the final session, participants were asked to fill in a simple questionnaire and provide feedback on the task and the experimental platform. The entire experiment lasted approximately 30 minutes per participant.

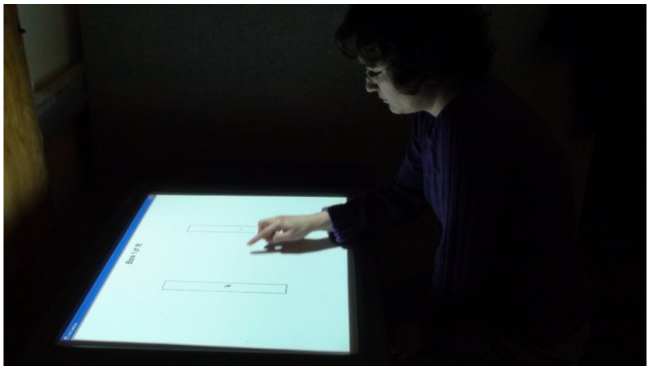

Figure 4. A participant performing the experimental task

RESULTS AND DISCUSSION

Throughput

Touch interaction yielded a higher throughput compared to the mouse. The overall mean throughput for touch interaction was 5.52 bps, which was 41.1% higher than the 3.83 bps observed for the mouse. Across target amplitude (*A*) and target width (W) conditions, throughput ranged from 3.69 bps to 7.41 bps for touch and from 2.53 bps to 4.49 bps using the mouse. The effect is seen in Figure 5. There are slight tendencies seen in the figure within each of the target amplitude/width conditions. For example, the lowest throughput during touch occurred at *W* = 8 pixels. The effect is even more dramatic for error rates (discussed next). The effect of input technique on throughput was statistically significant ($F_{1,11}$ = 35.51, p < .0001).

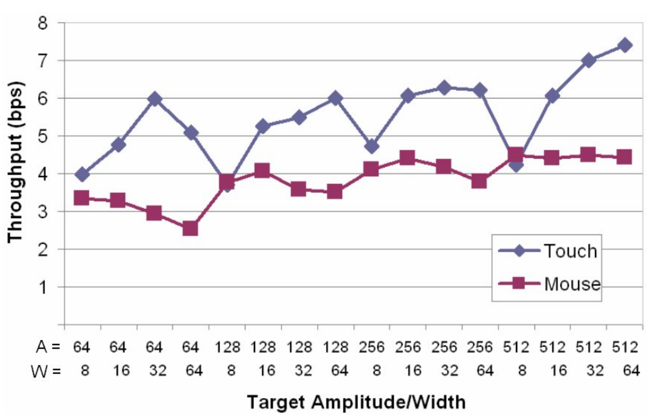

Figure 5. Throughput by block (*A* / *W*) and input technique

Accuracy

The error rates overall were much higher for touch-based interaction (*mean* = 9.8%) than with the mouse (*mean* = 2.1%). Touch interaction yielded error rates as high as 32.9% for some target amplitude-width conditions. The highest per-condition error rate for the mouse, at 6.7%, was much less by comparison. Not surprisingly, the effect was statistically significant ($F_{1,11}$ = 74.17, p < .0001). See Figure 6.

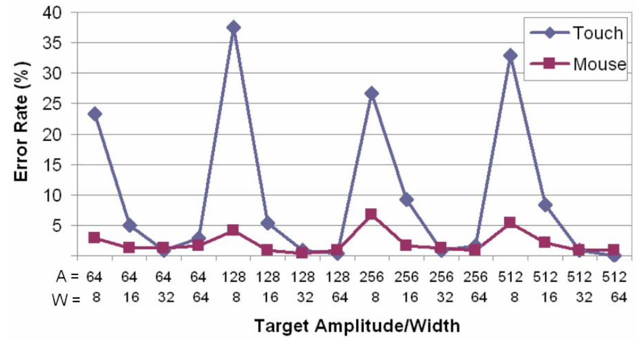

Figure 6. Error rates (%) by block (*A* / *W*) and input technique

The error rates for touch interaction were very high for small targets. Clearly, the four conditions in Figure 6 at *W* = 8 pixels are highly anomalous. Error rates were above 20% for all four such conditions. This result is very similar to that reported by Forlines et al. (2007), who also found significantly higher error rates for small targets using touch interaction. The effect is also found in touched-based mobile environments, where it is sometimes called the "fat finger" problem (Wigdor et al., 2007). Clearly, selecting very small targets is problematic for touch-based interaction.

Movement Time

Movement times differed significantly between input techniques, with touch interaction significantly faster than the mouse ($F_{1,11}$ = 66.99, p < .0001). See Figure 7. Movement times ranged from 403 ms to 1051 ms using touch and from 607 ms to 1323 ms using the mouse. There are clear patterns within target amplitude (*A*) and width (*W*) conditions. Movement times tend to increase with increases in movement amplitude and decrease with increases in target width. These effects are well documented in Fitts' law studies (e.g., MacKenzie, 1992).

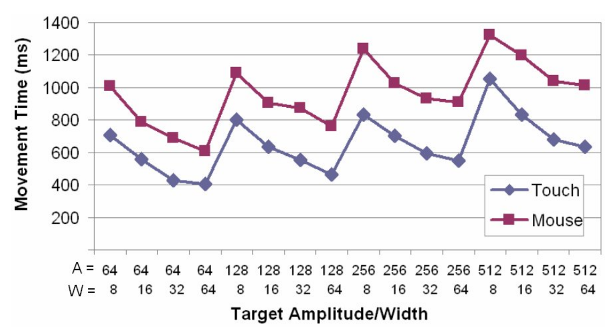

Figure 7. Movement time (ms) by block (A / W) and input technique

Qualitative Results

After the last session, participants completed a questionnaire gathering opinions on the two input techniques. They were asked to rank the techniques. Eleven participants ranked touch interaction as better than the mouse; one participant preferred the mouse.

Participants were also asked to rate the ease of use for each technique using a 10-point Likert scale with 9 as "very easy to use" and 0 as "very hard to use". The result in Figure 8 reveals that participants liked touch interaction and thought it was easier to use than the mouse. This result is predictable since using the fingers and hands to interact with real-life objects is more natural.

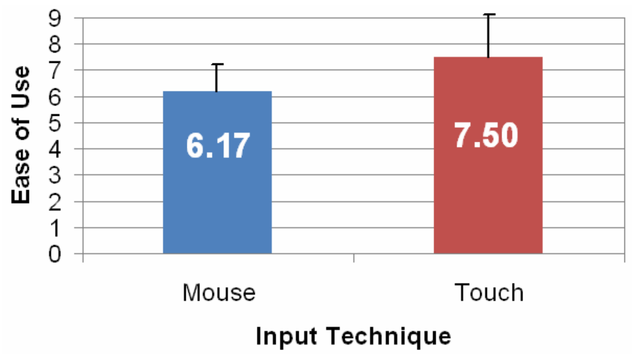

Figure 8. Results for ease of use. 9 = "very easy to use", 0 = "very hard to use". Error bars show +1 *SD*.

Five participants reported that hearing beeps (sounded for each miss) in some of the hard trials affected their performance. This could explain the throughput results for the two blocks in which the performance of the mouse input was slightly better than with touch input (see Figure 5). These blocks in fact had the highest error rates. Anecdotal observations also showed that the mouse emulator for the DiamondTouch device was not 100% accurate, which affected some of the mouse errors in blocks with small widths.

Participants also reported hand fatigue while using the mouse, especially during the last couple of blocks.

Our observations also confirm Forlines et al.'s (2007) suggestion that the distorted perspective on the horizontal tabletop display causes misses with increased distances between the participant and the graphical object. It was also noticed that participants' touch strategy differed among target distances and widths. For targets with small widths and large amplitudes, participants tended to use the pad of their fingertip (similar to giving a finger-print scan). This caused some misses, whereas with closer targets people used the tip of their finger (i.e., the skin close to the nail), and this was more accurate.

CONCLUSION

This research provides evidence that for tabletop interactive surfaces touch input is superior to the mouse in terms of throughput and movement time. However, our results indicate that a conventional mouse is more accurate overall compared to touch, which showed a high number of misses with small targets. This supports the findings by Forlines et al. (2007) who found a similar result in a tabletop environment. While touch interaction is natural and efficient, problems selecting small target remain a challenge. Further research evaluating alternative touch-based selection techniques is needed.

In addition, a subsequent study with stylus would provide a better means for comparison of performance among input techniques.

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