Horizontal Selection: An Evaluation of a Digital Tabletop Input Device

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Abstract

Recent advances in digital tabletop touch-and-gesture-activated screens have allowed for small group collaboration. The newest generation screens simultaneously support multiple users, multiple contact points per user, and gesture recognition. Although the usefulness and potential of these devices has been demonstrated, a formal quantitative evaluation of their performance has not been performed to date. This paper investigates the performance characteristics of a front-projected, 1:1 perspective, touch interface in consideration of Fitts' law. Specifically, this study evaluates the Mitsubishi Electric Research Laboratories' (MERL) DiamondTouch digital tabletop. This paper explores the hypothesis that selection is faster and more accurate on horizontal digital tabletops compared to a mouse.

Keywords

Fitts' law, tabletop, human performance modeling, input device evaluation, Mitsubishi DiamondTouch.

Motivation

Hurricane Katrina made landfall near Biloxi, Mississippi in late August 2005. The resulting disaster response revealed a large technological gap. Although satellite and aerial information existed, it was not used by search teams. Instead, during the night, US Geological Survey and state forestry personnel manually updated area maps based on verbal search reports. These maps were distributed to search personnel in the morning for the daily grid searches. When the teams returned that evening, updates were manually integrated by USGS and forestry personnel.

Multi-touch screens may be able to bridge the gap between the unused aerial reconnaissance information and the rescue teams on the ground. Once information on the disaster is registered to a virtual map, the command staff can quickly and interactively assess the situation. Multiple representatives from multiple agencies can have the convenience of a paper tabletop map while benefiting from the dynamic nature of this digital medium.

There are many places that a digital command and control interface can help in a disaster relief effort. Before and after comparisons of the area can be valuable to the command staff. Remaining structures can be annotated to indicate future search areas. Debris fields can be marked as a secondary search priority. The relocation of maritime structures and large boats may also be noted. Overall, the search space can be optimized and high priority given to areas with greatest potential for survivors. We envision an intelligent command and control interface that coalesces available information, e.g. combining satellite and aerial data over time with city planning layouts (street, sewer, water, gas, electric, and communication). When informed decision on the search priorities occurs, then the new maps can be simply printed and distributed to the rescuers in the field.

An enabling technology being evaluated for this purpose is the Mitsubishi DiamondTouch. Mitsubishi Electric Research Laboratories have created a touch-screen that breaks the normal monitor-keyboard-mouse paradigm. The DiamondTouch is capable of uniquely identifying multiple users simultaneously by touch. The board itself is embedded with antennas in the horizontal and vertical directions, which form a grid. The antennas continuously transmit signals. When a user touches the board, the radio signal is sent to the receiver connected to their body. The board can also recognize gestures using combinations of the change in surface area, motion, and touch sequence. The DiamondTouch display is forward projected and spill resistant. It is available in two standard sizes: 32" or 42" diagonal (MERL 2007).

The DiamondTouch has been used in many HCI oriented studies. Rich gesture recognition (Tse, 2006; Wu, 2006), orientation preference (Wigdor, 2006), spatial representation (Forlines, 2005), and gaming interfaces (Tse, 2006) have all been explored. Multi-touch systems have yet to be used for disaster response and robot control. To this end, one of our most recent research projects uses an interactive 2D map on the MERL DiamondTouch, providing a natural interface similar to pen and paper. However, before we invested significant time into developing a command and control interface for the DiamondTouch, we needed to investigate interaction performance with the device compared to a traditional computer mouse, as well as establish basic heuristics for optimally sizing user interface controls.

Evaluating Aiming Performance

Performance models allow researchers and interface designers to understand and predict human aiming performance. An example of an aiming task is the activation of a control in a graphical user interface. The most frequently applied performance model is Fitts' Law (MacKenzie, 1995; Zhai, 2004). Fitts' Law models movement time (*MT*) as the tradeoff between speed and accuracy characterized by the ratio of the movement amplitude (*A*) and target width (*W*):

$$MT = a + bID \quad (1)$$

where ID is the *Index of Difficulty* of the movement, defined as

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

The constants *a* and *b* are experimentally derived regression coefficients. Equation (2) presents the formulation of *ID* proposed by MacKenzie, which is the generally accepted form (ISO 2000; Zhai, 2004; Soukoreff & MacKenzie, 2004).

The *throughput* (*TP*) of an input device is a measure of its efficiency and is as *1/b* (Zhai, 2004). Throughput is used by ISO 9421 Part 9 when comparing the efficiency of different input devices (ISO 2000; Soukoreff & MacKenzie, 2004; Douglas, Kirkpatrick, & MacKenzie, 1999). Throughput is calculated in bits per second (*bps*). ISO 9241-9 proposes that between-study comparisons of input device evaluation results should be based on throughput rather than task completion time.

The main goals of this study are to assess the performance characteristics of digital tabletop devices and to determine if Fitts' Law holds for them. This paper specifically explores the hypothesis that target selection is faster and more accurate on horizontal digital tabletop input devices compared to a mouse.

It should be noted that this study does not explore multi-target touch or multi-user collaboration. Our continuing work will build on the results established by the present study.

Methods

Hypotheses

The study sought to determine the validity of the following hypotheses:

H1: Target selection is faster using touch than using a mouse on a tabletop.

H2: Target selection is more accurate using touch than using a mouse on a tabletop.

H3: Fitts' law holds for touch selection on a tabletop.

Subjects

Nineteen participants (5 female, 14 male) were recruited from the university. They did not receive any compensation for their participation. The average age for the participants was 25 years (*sd* = 5.4). All participants were experienced computer users, but had only minor experience in using the digital tabletop interface. They had normal or corrected-to-normal vision with no other physical impairments being reported. All participants were right-hand dominant in their daily computer activities.

Apparatus

The experiments were conducted while standing at a laboratory workbench with a front projected Mitsubishi DiamondTouch (Dietz and Leigh, 2001) screen surface 92*cm* above the floor. The DiamondTouch tabletop was connected to a Dell Precision 360 (3.0Ghz CPU, 1GB RAM) and a ceiling mounted Optima EP737 Projector (1024x768 pixel resolution) located directly above the horizontal table top. The projected screen was at an angle of ninety degrees to the user, in a flat tabletop configuration. The effective screen size on the projected surface was 610*mm* × 460*mm*. The mouse used for comparison was a Dell optical mouse connected to the same computer and horizontal table top screen. Figure 1 illustrates the testing apparatus.

The experiment was conducted using the Movement Time Evaluator (MTE)[1] software, an open and configurable platform for Fitts' experiments written in Java (Schedlbauer, 2007). The Mitsubishi DiamondTouch SDK software (Esenther *et al*., 2002) was used for mouse emulation.

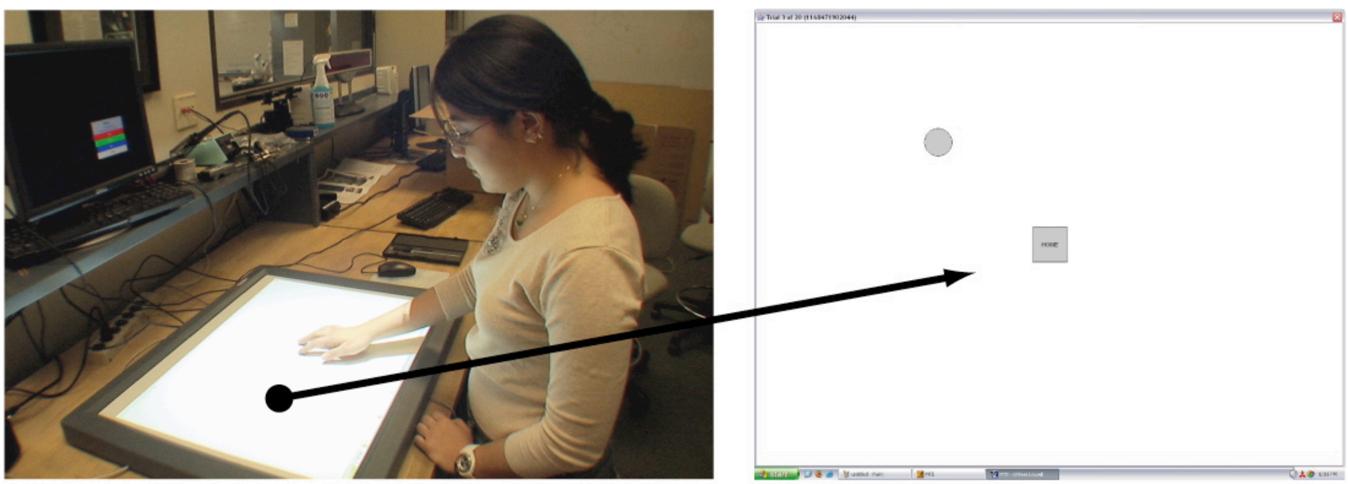

Figure 1. The Mitsubishi DiamondTouch digital tabletop (above left) was evaluated in regards to task completion time and accuracy. A standard mouse, shown to the right of the participant, was used for comparison. The screen shot (above right) shows a target presentation.

Experimental Design

Each participant was presented with four blocks of twenty trials each. Each block varied the target size, and, within each block distance and angle to the target were randomly assigned. Each participant saw the same sequence of targets in the same positions for each of the two input devices: mouse and digital tabletop. Therefore, the independent variables were target size, distance to the target, and input method. The dependent variables were movement time and error rate.

In keeping with the recommendations by Soukoreff and MacKenzie (2004), the experiment tested a broad range of *ID* values (*min* = 0.5, *max* = 5, *mean* = 3, *sd* = 1).

[1] Open source software available under GNU Public License from `http://www.cs.uml.edu/~mschedlb/mte`.

Procedure

Before testing, participants were instructed to hit the targets as quickly as possible while minimizing errors. Any click or tap outside the target area was recorded as an error. A 1-2 minute rest period was provided between input device changes. A target acquisition trial consisted of clicking a home region at the center of the screen which started the timing and caused the home region to be hidden. This was followed by selecting the target. Auditory feedback confirmed successful acquisition of the target or warned of a touch outside the target area. The experiments for mouse and touch were conducted with the participants standing as shown in Figure 1.

As the targets were positioned at various angles, a circular target shape was used in all experiments. This presented the same target width regardless of the approach angle.

The experiment used a *land-on* selection strategy, which means that the tap was recorded as soon as the finger touched the screen.

Time measurements were taken at a resolution of 10*ms*, the smallest granularity supported by the Sun JVM on Microsoft Windows XP (Green, 2007). Amplitudes were calculated using the Euclidean distance between the starting point and the end point of the movement. The recorded movement time was not adjusted to remove the initial reaction time. Therefore, the measured time reflects the total task time (Zhai, 2004).

To ameliorate any latent learning effects, each subject was given a set of warm-up trials before each experiment. The time of the warm-up trials was not recorded. After each block, the participants were allowed to rest. The presentation of the conditions was randomly varied.

Data Considerations

The collected data contained a few outliers which were not removed from the data set as it was not clear whether they were due to the complexity of the task or the characteristics of the input device. The coefficient of determination for the correlation (R^2) was calculated using averaged *MT* values over 20 *ID* ranges. There is considerable debate over whether to use the raw data values in the correlation calculations or averaged *MT* values over fixed *ID* ranges (Thompson *et al*., 2004). While the use of the raw data makes the correlation results more meaningful, a few far outliers can markedly affect the correlation. Averaging the values attenuates the effect of outliers by bringing them closer to the mean, but it may hide some effects. For instance, for finger touch, the smallest target size had a much higher selection time. When using averaged *MT* values, this effect may be hidden. Therefore, certain factors that significantly affect performance may not be accounted for. On the other hand, most published studies on Fitts' law report correlations based mean *MT* over a fixed range of *ID* values, so the use of the correlations obtained from the averaged data are more appropriate.

Soukoreff and MacKenzie state that obvious outliers should be removed from the calculation of *ID*, which they define as being farther than three standard deviations from the mean. They attribute the presence of outliers to 'misfires' where a subject accidentally double-clicks on a target or pauses during the movement. The outliers observed in this experiment do not fall into any of these categories. Rather, they appear to be caused by the imprecision of touch input for small targets. The driver for the DiamondTouch device reports a single coordinate position to the testing software even though the probe covers much more than a single pixel on the screen. The reported position is an average of the covered pixels. Therefore, targets that are smaller than the probe often require repeated attempts before a successful selection occurs. Consequently, the trial completion time measured by *MT* captures the actual difficulty of the task and outliers generally represent selections of small targets. Because an overall performance model was sought, all data points were included in the analysis.

Task Completion Time

The average task completion time was 861*ms* ($sd = 284$) for the mouse and 772*ms* ($sd = 593$) for the digital tabletop. A paired *t*-test showed the difference of 89*ms* to be significant ($t_{1519} = 6.495$, $p < 0.001$). As illustrated in Figure 2 and shown by a one-way ANOVA, target size is a factor in the task completion time for both devices ($F_{3,1516} = 270.31$, $p < 0.001$ for the mouse and $F_{3,1516} = 184.78$, $p < 0.001$ for the tabletop).

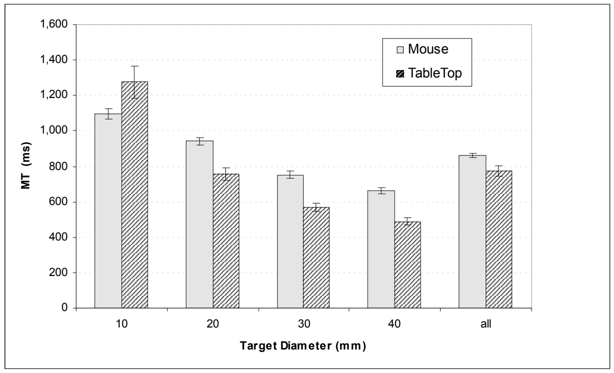

Figure 2. Mean target selection time (*MT*) for both devices by target diameter along with the 95% confidence interval.

Interestingly, for the smallest target size of 10*mm*, selection on the tabletop was 182*ms* slower compared to the mouse, although for all other target sizes, tabletop selection was faster. As summarized in Table 1, the differences in performance across the four different target sizes were all significant.

Table 1. Mean task completion time (in *ms*) and standard deviation by target size and input method.

	Mouse		Tabletop		
Target Size (*mm*)	*mean*	*sd*	*mean*	*sd*	*t*
10	*1,094*	*296*	*1,276*	*896*	*-3.97****
20	*941*	*219*	*757*	*371*	*9.66****
30	*751*	*214*	*568*	*239*	*14.09****
40	*661*	*170*	*488*	*188*	*15.99****
All	*861*	*284*	*772*	*593*	*6.49****

*** $p < .001$

Accuracy

The mean error rate across all target sizes for the mouse was 0.041 (*sd* = .214) compared to an error rate of 0.192 (*sd* = .699) for the digital tabletop, a significant increase of 370% ($t_{1519} = -8.11$, $p < 0.001$). As illustrated in Figure 3 and Table 2, accuracy of the mouse was better for the two smaller target sizes, but essentially the same for the two larger sizes. The accuracy results for the mouse are consistent with other published studies (MacKenzie, 1995; Thompson *et al.*, 2004).

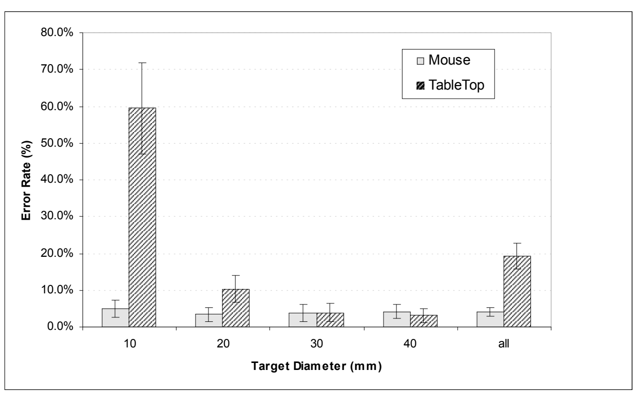

Figure 3. Mean error rates for both devices by target diameter along with the 95% confidence interval.

The error rate for the digital tabletop was almost 60% for the smallest target size of 10*mm*, but reached a more reasonable rate of 3.9% for the 30*mm* target and 3.2% for the 40*mm* target. As illustrated in Table 2, the differences between mouse and digital tabletop accuracy are not statistically significant for the two larger target sizes ($p > 0.05$).

Table 2. Mean error rate and standard deviation by target size and input method.

	Mouse		Tabletop		
Target Size (*mm*)	*mean*	*sd*	*mean*	*sd*	*t*
10	.050	.230	.595	120	-8.51***
20	.034	.196	.103	.360	-3.35***
30	.037	.227	.039	.243	-0.15#
40	.042	.201	.032	.190	0.73#
all	.041	.214	.192	.699	-8.11***

*** $p < .001$, # $p > .05$

Spatial variability, *i.e.*, dispersion, of the selection endpoints about their mean is another measure of accuracy. It is calculated as the mean least square distance of the selection end points to the mean selection end point. For the mouse the mean deviation was 8.81, whereas for the digital tabletop it was 9.86, a statistically significant increase in the dispersion ($t_{79} = 3.96$, $p < 0.001$). This suggests that touch selection is overall less precise and that it exhibits more variability leading to an increase in targeting errors.

Performance Models

The linear correlation between *MT* and *ID* has an R^2 of 0.98 for the mouse and 0.89 for the tabletop ($p < 0.001$). Linear regression of *MT* against *ID* results in the following Fitts models for task completion time:

$$MT_{Mouse} = 193 + 219\log(A/W + 1) \quad (1)$$

$$MT_{TableTop} = -187 + 329\log(A/W + 1) \quad (2)$$

The regression intercepts are within the range suggested by Soukoreff and MacKenzie, who have argued that intercepts outside the range of [-200,400] should be interpreted with caution as they might point to problems with the experimental methodology. The increased slope for the tabletop device suggest that movement time increases more rapidly as the difficulty of the task increases compared to the mouse. This is evidenced by the high movement times for smaller targets.

The accepted measure of the efficiency of input devices is *throughput* (*TP*), which is defined in ISO 9241-9 as the reciprocal of the regression slope and is calculated in bits per second (*bps*) (Douglas *et al*., 1999; Soukoreff and MacKenzie, 2004). Throughput is 4.57*bps* for the mouse and 3.04*bps* for the digital tabletop, making the mouse more efficient by 1.53*bps*.

Conclusion

Fitts' law was found to be a good predictor of target selection time on a horizontal digital tabletop operated in a standing posture. Consequently, hypothesis *H3* (Fitts' law holds for touch selection on a tabletop) must be accepted. Specifically, task completion time for the tabletop was faster than the mouse in all targets except those that had a diameter of 10*mm*, leading to a conditional acceptance of hypothesis *H3* (Target selection is faster using touch than using a mouse on a tabletop). The mean error rate was comparable to the mouse interface for targets of 30*mm* and 40*mm*, but substantially higher for target diameters of 20*mm* and smaller, which leads to a rejection of hypothesis *H2* (Target selection is more accurate using touch than using a mouse on a tabletop).

Efficient task completion can be expected only when target elements in the user interface are larger than approximately 30*mm* in size. Furthermore, due to the increased spatial variability of target selections on the digital tabletop, user interface controls should be spaced further apart to avoid false selections.

The initial results from in this study indicate that the mouse is overall slightly more accurate, particularly for smaller targets, and more efficient as measured by throughput than the digital tabletop. However, the study did not address multi-finger or multi-handed input, an input method not available for the mouse. In conclusion, the Mitsubishi DiamondTouch is a viable alternative to mouse input as long as appropriate provisions for target size adjustment are made.

Future Work

Tabletop devices often use multi-finger target selection and gesturing. The results of this experiment will need to be extended to determine the differences between selection using the dominant versus non-dominant hand as well as selecting two targets simultaneously using both hands. In addition, tabletop devices are used in computer supported collaborative work. Therefore, selection performance must be tested for the condition where multiple users select different targets concurrently. Lastly, the accuracy of selections could be affected by the probe size, *i.e.*, the size of the pointing finger. Therefore, probe size should be addressed as a factor in a future study.

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References

Douglas, S., Kirkpatrick, A., & MacKenzie, S. (1999). Testing pointing device performance and user assessment with the ISO 9241, Part 9 Standard. In *Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI 1999)*, ACM Press, New York, NY, 215-220.

Dietz, P.H., & Leigh, D.L. (2001). DiamondTouch: A multi-user touch technology. In *Proceedings of UIST 2001*, ACM Press, New York, NY, 219-226.

Esenther, A., Forlines, C., Ryall, K., & Shipman, S. (2002). DiamondTouch SDK: Support for multi-user, multi-touch applications. In *Proceedings of CSCW 2002*, ACM Press, New York, NY.

Forlines, C.; Shen, C. (2005). DTLens: Multi-user Tabletop Spatial Data Exploration. In *ACM Symposium on User Interface Software and Technology (UIST)*, ISBN: 1-59593-271-2, pp. 119-122.

Green, R. (2007). Online resource at http://mindprod.com/jgloss/time.html.

MacKenzie, S. (1995). Movement time predictions in human-computer interfaces. In *Readings in Human-Computer Interaction, 2nd Edition*, Morgan Kaufman, 483-493.

Mitsubishi Electric Research Laboratories (2007). Online resource at http://www.merl.com/projects/DiamondTouch/.

Schedlbauer, M. (2007). An extensible platform for the interactive exploration of Fitts' law and related movement time models. In *Extended Abstracts of the ACM Conference on Human Factors in Computing Systems (CHI 2007)*, ACM Press, New York, NY.

Soukoreff, W., & MacKenzie, I. S. (2004). Towards a standard for pointing device evaluation, perspectives on 27 years of Fitts' law research in HCI. *International Journal of Human-Computer Studies*, 61(6), 751-789.

Tse, E.; Greenberg, S.; Shen, C. (2006). Multiuser Gesture/Speech Interaction Over Digital Tables by Wraping Single Applications. In *International Conference on Multimodal Interfaces (ICMI),* ISBN: 1-59593-541-X. pp. 76-83, ACM Press.

Tse, E.; Greenberg, S.; Shen, C.; Forlines, C. (2006) Multimodal Multiplayer Tabletop Gaming. In *International Workshop on Pervasive Gaming Applications (PerGames)*.

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 *Proc. of the HFES 48th Annual Meeting*. Human Factors and Ergonomics Society, 823-827.

Wigdor, D.; Shen, C.; Forlines, C.; Balakrishnan, R. (2006). Effects of Display Position and Control Space Orientation on User Preference and Performance. In *ACM Conference on Human Factors in Computing Systems (CHI)*, ISBN: 1-59593-372-7, pp. 309-318.

Wu, M.; Shen, C.; Ryall, K.; Forlines, C.; Balakrishnan, R. (2006). Gesture Registration, Relaxation, and Reuse for Multi-Point Direct-Touch Surfaces. In *IEEE International Workshop on Horizontal Interactive Human-Computer Systems* (TableTop 2006), pp. 185-192.

Zhai, S. (2004). Characterizing computer input with Fitts' law parameters – the information and non-information aspects of pointing. *International Journal of Human-Computer Studies*, 61(6), 791-809.