User Perception of Touch Screen Latency

Glen Anderson, Rina Doherty, and Subhashini Ganapathy

Intel Corporation
{glen.j.anderson,rina.a.doherty,subhashini.ganapathy}@intel.com

Abstract. The goal of this study was to determine the level at which touch screen latency becomes annoying for common tablet tasks. Two types of touch screen latency were manipulated for three applications: Web page browsing, photo viewing, and ebook reading. Initial latency conditions involved an initial delay in the screen's visual response to touch inputs but with no delay after the beginning of a touch input. Continuous latency involved continuous delay for the duration of a touch input. Both types were tested from 80 to 780 ms. Touch inputs included resizing with multitouch input, panning, scrolling, zooming, and page turning. Results showed a statistically significant main effect for application, but differences were small. Continuous and initial latency showed little difference in ratings except with ebook reading. Trend graphs show levels of user ratings by latency duration.

Keywords: touch screen latency, performance perception, multitouch.

1 Introduction

The advent of the Apple iPad™ and other tablet computers has raised interest in touch screen experience on medium sized screens. Latency in visual feedback to touch input can harm the user experience, but the current literature provides little on end-user requirements for touch screen latency. Foundational research on user perception of computing responsiveness provides basic guidelines on user performance under various conditions [1, 2], and other research has provided guidelines on sub-second task events [3, 4, 5], but it has not been specific to touch screens.

In a zero latency condition, a touch screen is a zero-order control, since it involves simple position tracking. Under latency conditions, a touch screen user must anticipate future response of inputs, thus making it a higher-order control. MacKenzie and Ware [6] utilized a target acquisition task with mouse input to show that the effects of lag and task difficulty are multiplicative in a tracking task. At their highest latency of 225 ms, performance was much lower for the most difficult target acquisition tasks. "Subjects' natural tendency to anticipate motions was severely compromised by the lag." Jay, et al. [7] utilized a tracking task to measure the effects of lag in a collaborative environment, also showing the negative impact of latency on tracking.

Touch screen use, especially for multitouch screens, is different from mouse tracking. Users make a variety of gestures on the surface of the screen, such as pinching to zoom and swipes to turn pages, which have no direct implementation on mice. The current study examined how latency impacted user ratings of system performance while doing common touch screen gestures.

A. Marcus (Ed.): Design, User Experience, and Usability, Pt I, HCII 2011, LNCS 6769, pp. 195–202, 2011.

2 Research Approach

Participants. Participants were 13 females and 10 males with a mean age of 32 years. All had experience with touch screens on phones or gaming systems, but none were tablet computer (e.g., the Apple iPad™) owners.

Apparatus. A 559 mm (22 in.) diagonal 3M™ Multi-Touch Display M2256PW was used to present applications and receive touch input. A portion of the screen was used to show a tablet-sized display area. The display was tilted toward the user at approximately 25 degrees to allow comfortable viewing and touch input. The applications appeared in portrait mode in an area of 168 x 224 mm, 279 mm diagonal, which was slightly larger than an Apple iPad™. The usable content display area was 265 mm diagonal for the Web Browser and 273 mm diagonal for the Photo Viewer and the E-reader. The diagonal measure was slightly less for the Web Browser due to the navigation bar at the top of the application. Due to inherent latencies in the apparatus, a base level of approximately 80 ms was the minimum touch screen latency.

A PC with an Intel Core™ 2 Extreme CPU X9650 and Microsoft Windows™ 7 drove the applications that appeared on the touch screen. The latency conditions were created by delaying the rendering of frames to the screen. The frames were buffered for a specified period of time, depending on the latency condition.

Latency. The experiment manipulated two types of latency. Initial Latency was the time from when a finger first moved until the corresponding event began to occur on the screen. If a participant maintained contact with the screen, there was no latency after the initial onset, other than the base level latency of 80 ms. Continuous Latency was also the time from when a finger first moved until the corresponding screen event, but it occurred throughout the movement of the finger.

These two types of latency correspond to issues in system architecture. When an operating system, or software running under an operating system, receives input from a touch screen programming interface, the system must determine what gesture the user most likely desired. A user's initial contact with a touch screen may not indicate the intended gesture immediately because enough input must be received to distinguish the gesture from the library of gestures that the system has. The software algorithms that interpret this input need processing time, and then the operating system requires additional time to make corresponding changes on the screen. Depending on the hardware capabilities of the system and on software design, the system will have some latency. Initial Latency reflects the "decision" time the system needs to determine what gesture is intended. Continuous Latency reflects the ongoing requirements for processing inputs through the hardware and software.

Durations for both types of latency were 180 ms, 280 ms, 380 ms, 580 ms, and 780 ms. There was 1 condition of the base level latency of 80 ms, which was Continuous, making a total of 11 latency conditions. In all latency conditions the screen updated smoothly in response to touch inputs. The frame rate, even if delayed, was high enough to avoid choppiness in the changing images on the screen.

Initial Latency was implemented by delaying the first screen update to a touch input. For example, under a condition of 180 ms latency the screen did not begin updating to match the location of the finger until 180 ms after the finger began moving on the screen in a new gesture. Once the screen started updating, it would continue to update with the gesture to the minimum level of Continuous Latency of 80 ms. The apparatus did not induce Initial Latency a second time as long as a finger remained in contact with the screen. Thus, for example, if a participant changed direction of an input, a new Initial Latency was not introduced. Thus the implementation of Initial Latency for this study may have been less annoying than a system that has additional Initial Latency for every change in gesture.

Continuous Latency was implemented by continuously delaying updates to the screen. Each frame to be drawn under the operating system was buffered for the given latency condition. Thus at any point in a touch gesture the screen would be that much time behind the finger.

Applications. Participants performed tasks with three applications: Web Browser, Photo Viewer, and E-reader. Content varied (5 Web pages, 11 photo albums, 11 E-reader books) and was counter-balanced across conditions to minimize learning effects. Figure 1a shows a representation of the Web Browser interface with a typical page loaded. HTML pages from actual newspapers were used and do not appear here due to copyright issues. Text appeared 2.4 mm high when the user interface launched and would get larger as the participant zoomed in. The tasks required only touch inputs on a single Web page – there were no live HTML links to click.

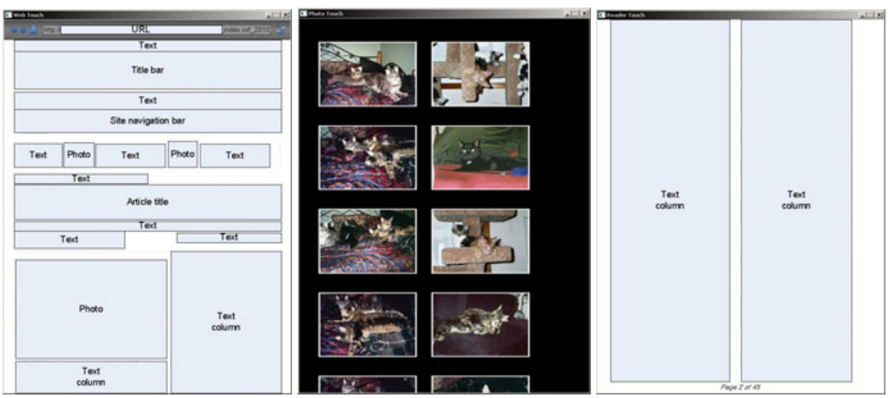

Fig. 1. 1a, 1b, 1c. Application user interfaces for Web Browser, Photo Viewer, and E-reader, respectively.

In the Web Browser application the facilitator instructed participants to use multiple touch gestures to control the screen:

- Finger and thumb in a multitouch pinch gesture to zoom in and out on the Web page.
- Single-touch movements to pan within the page.
- Single-touch swipes to scroll up and down.
- The participant could optionally hold a pinch after a resize and move the finger and thumb together to pan within the page.

The instructions were as follows:

- Zoom in and move the left column of the article so that it fills the whole browsing area.
- Scroll down to the bottom of the page.
- Scroll up and find the “Related Comments” (or “Related Articles”) portion in the middle of the page.
- Zoom out and move so that you can see the whole page again.
- Scroll up to the top of the page.
- Zoom in and center one of the images near the top of the article or in the header area side. Enlarge that image to fill the width of the browser.

Figure 1b shows the starting point for the Photo Viewer. After touching a photo, that photo would be the only item appearing in the Viewer. Participants were instructed to use touch gestures in a similar way as the Web Browser:

- Finger and thumb in a multitouch pinch gesture to zoom in and out of the photo.
- Single touch movements to pan within the photo.
- A locked pinch gesture to pan within the photo.

The instructions were as follows:

- In the photo viewer, touch the first photo.
- Zoom in on one portion of the photo, then move that portion so it is in the middle of the screen.
- Zoom out and until you can again see all photos.
- Select a second photo.
- Zoom in on one portion of the photo, then move that portion so it is in the middle of the screen.
- Zoom out so you can again see all photos.

Figure 1c shows the E-reader. Text appeared 4 mm high. Participants were instructed to use vertical or horizontal swipe gestures to turn pages. Swiping with a hold at the end of the gesture caused pages to turn quickly under all latency conditions. This approach was suitable for turning pages quickly but did not allow enough control to select individual pages. The instructions were as follows:

- Use your finger to turn the pages of the book. Turn several pages to go further in to the book and to come back to the beginning.
- Page ahead again to look for the bold text at the beginning of the first chapter.
- Now go further ahead to look for the bold text at the beginning of the second chapter.
- Turn pages to go to page 4.
- Turn pages to go to page 20.

Experimental Design. Participants worked with the facilitator individually and began sessions with practice. The goal of the practice was to allow participants to become knowledgeable and comfortable with using the touch screen. The facilitator coached participants until they were able to perform all gestures without assistance.

The experimental design was fully repeated measures – all participants experienced all 11 latency conditions under all 3 applications for a total of 33 conditions, counterbalanced to reduce learning effects.

The dependent variables were the participant ratings of each Gesture Type for a given trial, using the descriptions in Table 1. Participants rated Gesture Types as appropriate to the application (see Table 2). For example, after experiencing a latency condition with the Photo Viewer, they would rate the system for Pan/move usability, Zoom usability, and Overall Usability. Since the E-reader did not require Pan/move or Zoom, those Gesture Types were not rated for E-reader conditions.

Table 1. Rating scale

Rating	Description	Extended Description
5	Excellent	Usable with no annoyances
4	Good	Usable with minor annoyances
3	Fair	Usable but with multiple annoyances
2	Poor	Barely usable with many annoyances
1	Bad	Unusable – would not continue

Table 2. Sub-tasks used in applications

Gesture Type	Web Browser	Photo Viewer	eReader
Scroll	yes	no	no
Pan/move	yes	yes	no
Zoom	yes	yes	no
Turn Pages	no	no	yes
Overall Usability	yes	yes	yes

3 Results

Web Browser and Photo Viewer Analysis. To allow a balanced model for this analysis, Web Scroll was left out (Scroll was not rated in the Photo Viewer application), and E-reader data was analyzed separately. Web Scroll followed Web Zoom very closely, so offers little additional information. A 2 (Application) by 2 (Latency Type) by 5 (Latency Duration) by 3 (Gesture Type) repeated measures analysis of variance showed statistically significant main effects for Latency Duration ($F(4, 8)=27.10$, $p<.01$)) and Gesture Type ($F(2, 44)=2.16$, $p<.05$)). The Gesture Type by Latency Duration interaction was also statistically significant ($F(8, 176)=2.24$, $p<.05$).

Figure 2 shows the mean ratings for each Latency Duration by Gesture Type. At 580 ms of Latency Duration the Pan/move gesture was rated slightly lower. The 80 ms base latency is shown in the figure though it was not in the statistical analysis.

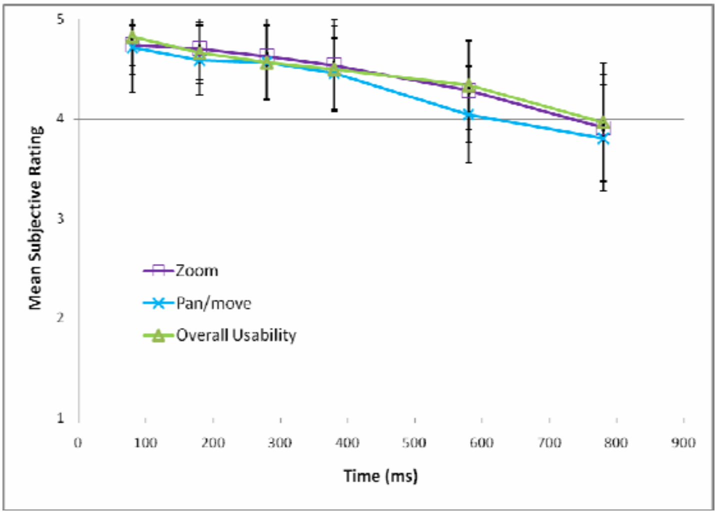

Fig. 2. Mean ratings for Zoom, Pan/move, and Overall Usability (error bars denote 95% confidence intervals)

E-reader analysis. A 2 (Latency Type) by 5 (Latency Duration) by 2 (Gesture Type) repeated measures analysis of variance showed statistically significant main effects for Latency Type (F(1, 22)=10.43, p<.01)), Latency Duration (F(4,88)=6.74, p<.01)), and Gesture Type (F(1,22)=14.31, (p<.01)). The Gesture Type by Latency Type interaction was statistically significant (F(1, 22)=4.50, p<.05)), as was the Latency Type by Latency Duration interaction (F(4,88)=2.74, p<.05)). Though the Gesture Type by Latency Duration interaction was significant, the differences among the means, relative to Gesture Type, were not practically significant. Differences between means for the main effect of Gesture Type were also not practically significant.

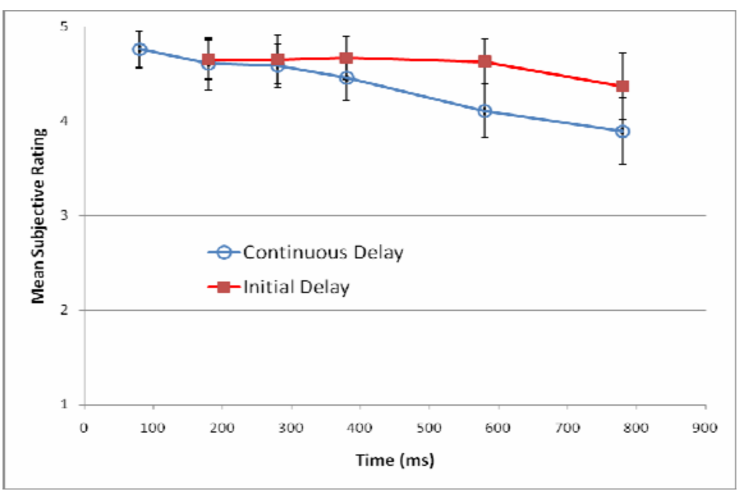

Fig. 3. Mean ratings for e-reading (error bars denote 95% confidence intervals)

Figure 3 shows the Latency Type by Latency Duration interaction. At the higher levels of Continuous Latency, the mean ratings dropped lower than under Initial Latency. The 80 ms base latency is shown in the figure though it was not in the statistical analysis.

Ratings for Web Gesture Types. Figure 4 shows the percentage of participants who gave a 3 rating or lower for Web Browser conditions, which had some of the lowest mean ratings in the study. Though the mean ratings in Figure 2 stayed at or above 4 for 580 ms Latency Duration, up to 30% of participants gave ratings of 3 or lower.

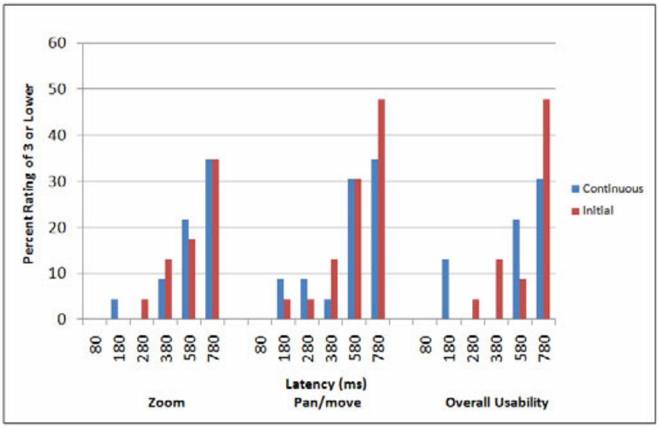

Fig. 4. Percent rating of 3 or lower for Web Browser

4 Discussion

Participants were satisfied with touch screen latency at relatively high levels. Two factors could help explain this. One, under all levels of latency, the screen used in this study updated smoothly. In other words, the rate of delivery of frames displayed on the screen was high enough so that it did not look choppy. Two, even though all participants had had some level of experience with small touch screens, most had no experience with tablets. The experience of using a tablet was novel and therefore often interesting and positive, even when the latency was high. Additional studies with users who have been exposed to tablets would show whether expectations will rise as people are exposed to these devices more.

The data showed that 580 ms as a requirement for touch screen latency may be too high for a significant portion of individual users (see Figure 4). To ensure acceptance, latency should be somewhat lower than 580 ms for a group like these participants.

In general, participants were only slightly more annoyed with Continuous Latency than with Initial Latency, even though Continuous included Initial Latency at the beginning of each new touch input. In this study Gesture Types (Zoom, Pan/move, Page Turn) were relatively brief, as is common in current real-world tablet usage. It is possible that longer gestures, like continuous tracking, would be more prone to annoyance with Continuous Latency.

E-reader page turning under Continuous Latency was an exception. The participants found these conditions less usable than Initial conditions. This may be for two reasons. First, with Initial Latency, by the time the relatively time-consuming page-turn gesture was finished, part of the latency period was over. With Continuous Latency, the system kept the latency level through the end of the page-turn gesture, thus making the user wait for the full latency period at the end of the gesture. Second, the page turning task was highly repetitive and one page turn was much like another, affording the development of more precise expectations. This may have allowed participants to make more sensitive judgments.

Since there is little published literature on touch screen responsiveness, additional research could explore several related areas:

- Screen size – Touch screens are being used in many differently sized devices.
- Other tasks – Touch screens are also used in gaming, point of sale, and other categories.
- Smoothness – Some touch screens have a slightly choppy appearance in response to touch inputs. This variable may interact with latency.
- User experience – As users are exposed to more touch screens, their standards for performance may change.
- Performance variables – Additional studies could include error rate and task completion time.

Acknowledgments. Special thanks to Daniel Theophanes for development of the test platform.

References

1. Miller, R.B.: Response time in man-computer conversational transactions. In: Proc. AFIPS Fall Joint Computer Conf., vol. 33, pp. 267–277 (1968)
2. Shneiderman, B.: Response Time and Display Rate in Human Performance with Computers. ACM Computing Surveys 16(4), 265–285 (1984)
3. Seow, S.C.: Designing and Engineering Time. In: The Psychology of Time Perception in Software. Addison-Wesley Professional, Reading (2008)
4. Dabrowski, J., Munson, E.V.: Is 100 Milliseconds Too Fast? In: Proc CHI 2001, Extended Abstracts, pp. 317–318 (2001)
5. Anderson, G.J., Doherty, R., Baugh, E.: Diminishing returns? Revisiting perception of computing performance. Publication pending for Proc. CHI (2011)
6. MacKenzie, S., Ware, C.: Latency as a Determinant of Human Performance in Interactive Systems. In: Proceedings of the ACM Conference on Human Factors in Computing Systems – INTERCHI 1993, pp. 488–493 (1993)
7. Jay, C., Glencross, M., Hubbold, R.: Modeling the effects of delayed haptic and visual feedback in a collaborative virtual environment. ACM Trans. Comput.-Hum. Interact (TOCHI) 14(2) (2007)