UX Impacts of Haptic Latency in Automotive Interfaces

Literature Review and User Study

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immersion

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“I prefer more of a quick response for tactile feedback. I mean, I just touched the button, what are we waiting for?”

1. Executive Summary

A number of studies have demonstrated that delivering multimodal feedback (visual, audio, haptic) in touch interactions in automotive interfaces can make drivers feel more confident and perform better in driving simulations. Several studies indicate that having multiple sensory modalities represented (e.g. audio and visual, haptic and visual) can have additive benefits over one modality alone.

However, a number of engineering challenges specific to capacitive touch surface implementations can introduce latency in system response, influencing when feedback is played back to a user. In this paper, the user experience impact of haptic feedback latency in touch interactions is discussed. Drawing together research from several sources, including an original research study conducted by Immersion on the Cadillac XTS system, this report will outline recommendations for latency thresholds.

Important high-level takeaways include:

- Haptic feedback latency below 30-50 ms is generally perceived as instantaneous with touch, (but this is somewhat dependent upon the task).
- In general, subjective user satisfaction drops as haptic delay increases above this threshold.
- Feedback delays (in any modality) over 100 ms have been shown to decrease task performance.
- Delays above 180-200 ms may result in feedback being delivered after the users’ finger has completely left a touch surface, which may result in inconsistently delivered feedback.

Ratings indicated that low-latency haptic feedback made the system easy and pleasant to use, and helped participants feel more confident.

2. Background: UX Impacts of Feedback Latency

One of the greatest challenges to effectively utilizing haptic feedback in automotive touch interfaces is system latency. A number of engineering challenges specific to in-vehicle touch surface implementations can introduce latency in system response, including when haptic feedback is played back to a user. Technical reasons for haptic feedback delay may include the higher levels of filtering required in capacitive surfaces in in-vehicle implementations, having a low processor priority assigned for haptic events, and latency in the communications bus.

There is a long history of studies on the influence of feedback latency in task performance, especially in the domains that involve remote communication between an operator and the task, such as teleoperation and online gaming. MacKenzie and Ware (1993) extended the classical Fitts' Law to a situation of delayed visual feedback, and found that time delay prolonged task completion time by a multiplicative factor. The results showed that the maximum latency of 225 milliseconds significantly slowed the task by 64% from the reference condition of 8 ms delay. Similar effects have been observed in online gaming – in first-person shooter games, which typically involve a high degree of coordination, network latencies of more than 100 ms caused a significant reduction in player accuracy and performance (Quax, et al., 2004; Beigbeder et al., 2004). However, others have noted that latency tolerance in gaming is somewhat dependent upon the interaction and gameplay style – operations requiring precision and tight timing are more severely impacted by latency (Claypool & Claypool, 2006).

The impact of haptic feedback latency in simple confirmation interactions with touchscreens has been studied in mobile contexts. Kaaresoja et al. (2011) investigated the impact of constant haptic feedback latency in touchscreen keypad interactions with a handheld tablet. They experimented with latency ranging from 18 ms to 118 ms The task was to enter numbers in a keypad and short sentences in a keyboard. The latency was held constant during a task block. The results showed that for these interactions, users adapt to and tolerate consistent feedback delays well in the ranges studied, and performance did not drop significantly. However, an effect was found in subjective satisfaction reports, which dropped significantly as the delay got longer.

In another study, Kaaresoja et al. (2011b) investigated the impact of variable feedback latency in touchscreen keypad interactions. They determined that feedback latencies with small variations were found to be acceptable to most users. However, when variations exceeded 72 ms, user satisfaction dropped significantly. They also determined that users perceive touchscreen buttons with bigger tactile feedback delays to be heavier, an interesting perceptual illusion that can be used thoughtfully in UI design. It should be emphasized that in both these experiments, only simple, single virtual button presses were investigated.

Another important factor to consider in touch interactions is average contact time with a surface. Knowing parameters for this will help determine the upper bound of latency, as feedback may be delivered after a user's finger has left the touch surface through which feedback would be delivered. Many factors can influence contact time, including target size. Bender (1999) reported that touch screen key entry contact time significantly decreases as target size increases. The study determined that for interactions with touchscreen buttons 10mm X 10mm, average contact time was approximately 110 ms, but for buttons 30mm X 30mm, the average contact time was approximately 50 ms. This study also showed that contact time can also be influenced by feedback duration, as longer audio feedback caused users to leave their finger on the touch surface longer, and adapt movements to better synchronize with feedback. Therefore, when evaluating the impact of feedback latency in a haptic implementation, it is important to consider variables such as target size and feedback duration.

3. Study Design

3.1 Study Design: Test Vehicle

The 2013 Cadillac XTS is the first commercial implementation of haptic feedback in an automotive touchscreen. The haptic technology in this vehicle was licensed from Immersion via a tier supplier. The CUE system provides haptic feedback when a virtual button is pressed, which provides confirmation to the user. Haptic confirmation is also displayed when a user presses a capacitive button on the button panel below the touchscreen. Reviews of the CUE system ranged from positive to lukewarm. Many reviews on the system raised the question as to the user experience impact of perceived latency in the system (Barth, 2012). Immersion decided to embark upon an original UX research study to discover how end-users perceived haptic feedback latency in the CUE, and how it impacted their experience with the interface.

Figure 1. Cadillac XTS vehicle used in the study.

In preparation for the study, Immersion rented a 2013 Cadillac XTS vehicle from a commercial agency (Figure 1). This vehicle included the standard market version of the CUE system.

Members of the Immersion engineering team took measurements of feedback latency in the touchscreen and touch panel of the vehicle in order to assess the system latency on these two independent systems. Using an accelerometer, measurements of touch activation to onset of haptic feedback response were collected, as well as magnitude of haptic response. An example of an accelerometer output, and corresponding delay measurements, is shown in Figure 2.

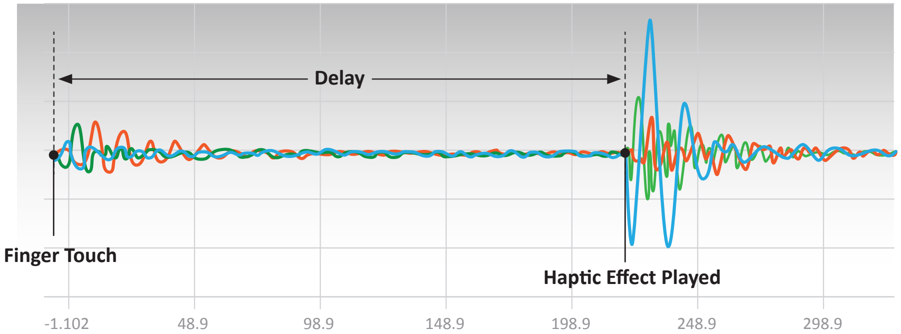

Figure 2. Accelerometer trace of touch event and haptic effect playback.

Five trials were run for the touchscreen and touch panel, and the average score and standard deviation were calculated. We also compared the response of these touch systems to the latency of haptic feedback initiated by touch in a Galaxy Note 10.1 tablet device. The results of these measurements are shown in Figure 3a and 3b. As can be seen, the latency in the CUE touchscreen was approximately 100 ms, as compared to the touch panel, which was over 200 ms. Feedback latency in the Galaxy Note 10.1 tablet was approximately 30 ms. Additionally, the magnitude of the haptic feedback in these three systems was measured and recorded, shown in Figure 3b.

"Way more responsive. Very positive experience. I can connect my actions with what I feel." [study participant describing interface with low latency]

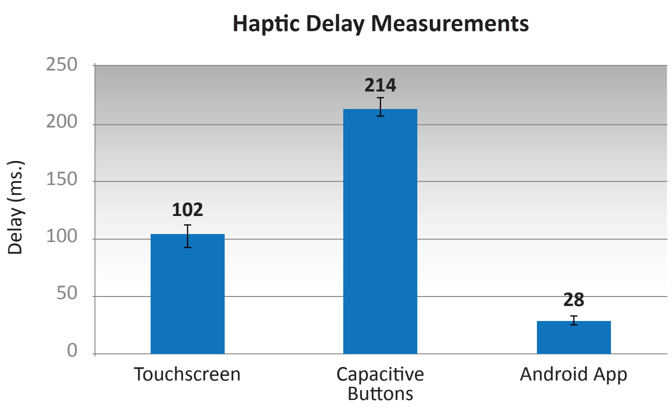

Figure 3a. Haptic feedback delay measurements of a Cadillac XTS touchscreen, capacitive button panel, and compared to a Galaxy Note 10.1 tablet device.

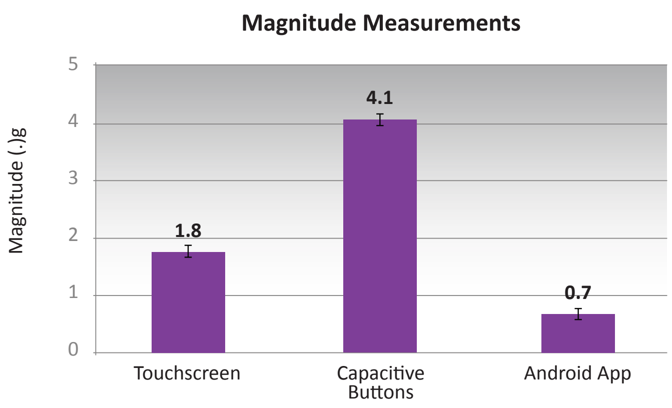

Figure 3b. Haptic feedback magnitude measurements of a Cadillac XTS touchscreen, capacitive button panel, and compared to a Galaxy Note 10.1 tablet device.

> "The Cadillac buttons were less reliable. Sometimes touches didn't result in what I expected. The Android app buttons were more immediate and reliable."

3.2 Design Study: Participants

12 drivers were selected to participate in the study, ranging in age from 20-59. They were gender-balanced and drive daily. 50% of study participants owned vehicles with touchscreens. The remaining participants had used a touchscreen device mounted in their vehicle, such as a GPS or tablet.

The study was conducted inside the rental vehicle, and participants sat in the driver's seat, while a moderator sat in the passenger seat and guided them through a set of tasks to be completed with the CUE interface. The vehicle remained parked during the test. Participants were first allowed to familiarize themselves with the CUE system, then they were prompted to operate the touch panel in order to execute a defined set of basic tasks, such as turning up or down the radio volume, turning on defrost, and adjusting the vehicle's temperature. Figure 4 shows a study participant interacting with the Cadillac CUE interface in the XTS test vehicle.

Following task execution, participants completed a rating survey about their experience, rating their degree of agreement with the following statements on a scale of 1 (strongly disagree) to 7 (strongly agree):

- The system was easy to use.
- The system was pleasant to use.
- I felt confident using these buttons.
- The buttons felt responsive to my touch.
- I always knew the system received my touch.
- The buttons in this interface felt like real physical buttons.

Figure 4. A participant interacts with the CUE touch panel in the study

In order to simulate a low-latency haptic feedback condition, we created an Android application that could run on the Galaxy Note 10.1 device, a 10 inch touchscreen tablet. This app contained a screenshot of the CUE touch panel, showing the controls and functionality in the vehicle, and is shown in Figure 5. Both visual and haptic feedback was provided when the user interacted with regions of the app mapped to interface functions. For instance, sliding along the volume slider played a series of haptic effects similar to that in the CUE, but with lower latency (30 ms latency versus 200 ms latency).

“[Android App] Seemed faster. I felt it more. I got more cues from it.”

Figure 5. Screenshot of the Android interface emulating the CUE interface.

In the next task block, study participants were asked to execute the same tasks they had completed on the CUE touch panel with the Android application, which was mounted in the center stack beside the touch panel using a tablet holder. Following these tasks, participants completed a rating survey about their experience using the same questions as they answered in the CUE touch panel condition. When making ratings in this category, participants were asked to imagine that the Android app was implemented in the dashboard with surface features.

Finally, users were prompted more directly about whether they noticed a delay in feedback within the two systems they tested, or if they experienced noticeable difference between the two. Finally, they were asked to comment about the consumer appeal of haptic feedback features for automotive touchscreens more generally.

4. Study Findings: Feedback Latency Impacts the User Experience

Participants’ ratings indicate that the perceived system latency appeared to influence the subjective ratings of usability, confidence, and responsiveness. The restuls are shown in Figure 6. The differences were statistically significant for all questions (Mann Whitney test, $p < 0.05$), except for the question, “The buttons in this interface felt like real physical buttons.”

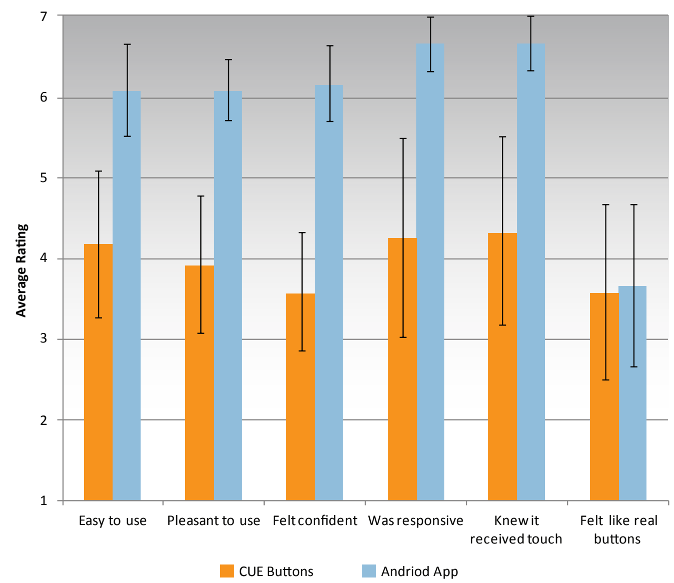

Figure 6. Mean ratings data for all participants for the CUE (200 ms delay) and Android app (30 ms delay) conditions. Error bars represent 95% confidence intervals.

Participants’ verbal comments supported the valuation of low-latency haptic feedback expressed through the survey ratings.

“The Cadillac buttons were less reliable. Sometimes touches didn't result in what I expected. The Android app buttons were more immediate and reliable.” (Study participant)

“Seemed faster. I felt it more. I got more cues from it.” (Study participant, describing the Android app condition).

5. Conclusions and Design Implications

Comparing the ratings of the CUE haptic interface with a large latency to the interface with low latency showed that participants place high value on haptic feedback delivered below recommended latency levels. Ratings indicated that low-latency haptic feedback made the system easy and pleasant to use, and helped participants feel more confident.

"Way more responsive. Very positive experience. I can connect my actions with what I feel." (Study participant)

"I prefer more of a quick response for tactile feedback. I mean, I just touched the button, what are we waiting for?" (Study participant)

There were some limitations to this study that should be noted. This was a small-scale study, conducted with only 12 individuals, and driving performance was not measured. Furthermore, there were some possible confounding elements to the study that may have impacted the subjective rating scores. For instance, the CUE button panel had surface features, whereas the tablet device did not. Also, the type of actuator in the CUE system differed from that in the Android tablet, which may have resulted in the two systems delivering feedback with a different frequency and attack profile that users may have reacted to. In the future, more work should be done to expand upon the literature that demonstrates the impact of feedback latency on driving safety, as well as consumer preference, for haptic-enhanced automotive systems.

Moreover, in this study, as well as the literature reviewed here, researchers have primarily focused on haptic feedback latency tolerance for systems using only simple press. More work should be done to better understand the impact of latency on dynamic gestures, such as scrolling or zooming, and/or rapid-fire presses, as compared to that measured for simple presses. As some research indicates that operations requiring higher motor coordination and precision are more sensitive to latency, it is likely that dynamic gestures will be more sensitive to latencies than simple touch interactions. However, exact tolerance parameters have not yet been established.

Important high-level takeaways from this report include:

- Haptic feedback latency below 30-50 ms is generally perceived as instantaneous with touch, (but this is somewhat dependent upon the task) (Okomoto et al., 2009). In this study, haptic feedback in the regime of 30 ms was preferred over more latent feedback.
- In general, subjective user satisfaction drops as haptic delay increases above this threshold (Jay & Hubbold, 2005; Kaaresoja, et al., 2011a; Kaaresoja, et al., 2011b).
- Feedback delays (in any modality) over 100 ms have been shown to decrease task performance (Jay & Hubbold, 2005).
- Delays above 180-200 ms may result in feedback being delivered after the users' finger has completely left a touch surface, which may result in inconsistently delivered feedback.
- Users may adapt their behavior to a high latency that is consistently applied (Jay & Hubbold, 2005); however they will perceive virtual controls with more latent feedback as being stiffer and more resistant (Kaaresoja, et al., 2011).

Participants' ratings indicate that the perceived system latency appeared to influence the subjective ratings of usability, confidence, and responsiveness.

6. References

Barth, L. (2012). New Cadillac CUE infotainment system frustrates. ConsumerReports.org. Retrieved Jan. 22, 2013, from http://news.consumerreports.org/cars/2012/11/new-cadillac-cue-infotainment-system-frustrates.html

Beigbeder, T., Coughlan, R., Lusher, C., Plunkett, J., Agu, E., & Claypool, M. (2004). The effects of loss and latency on user performance in unreal tournament 2003®. In Proceedings of 3rd ACM SIGCOMM workshop on Network and system support for games (pp. 144-151). ACM.

Bender, G. (1999). Touch Screen Performance as a Function of the Duration of Auditory Feedback and Target Size. Wichita State University.

Claypool, M., & Claypool, K. (2006). Latency and player actions in online games. Communications of the ACM, 49(11), 40-45.

Jay, C., & Hubbold, R. (2005). Delayed visual and haptic feedback in a reciprocal tapping task. In Eurohaptics Conference, 2005 and Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems, 2005. World Haptics 2005. First Joint (pp. 655-656). IEEE.

Kaaresoja, T., Anttila, E., & Hoggan, E. (2011). The effect of tactile feedback latency in touchscreen interaction. In World Haptics Conference (WHC), 2011 IEEE (pp. 65-70). IEEE.

Kaaresoja, T., Hoggan, E., & Anttila, E. (2011). Playing with tactile feedback latency in touchscreen interaction: two approaches. In Human-Computer Interaction–INTERACT 2011 (pp. 554-571). Springer Berlin Heidelberg.

MacKenzie, I. S., & Ware, C. (1993). Lag as a determinant of human performance in interactive systems. In Proceedings of the INTERACT'93 and CHI'93 conference on Human factors in computing systems (pp. 488-493). ACM.

Okamoto, S., Konyo, M., Saga, S., & Tadokoro, S. (2009). Detectability and perceptual consequences of delayed feedback in a vibrotactile texture display. Haptics, IEEE Transactions on, 2(2), 73-84.

Quax, P., Monsieurs, P., Lamotte, W., De Vleeschauwer, D., & Degrande, N. (2004). Objective and subjective evaluation of the influence of small amounts of delay and jitter on a recent first person shooter game. In Proceedings of 3rd ACM SIGCOMM workshop on Network and system support for games (pp. 152-156). ACM.

About Immersion

Founded in 1993, Immersion is the leading innovator in haptic technology; the company's touch feedback solutions deliver a more compelling sense of the digital world. Using Immersion's high-fidelity haptic systems, partners can transform user experiences with unique and customizable touch feedback effects; excite the senses in games, videos and music; restore "mechanical" feel by providing intuitive and unmistakable confirmation; improve safety by overcoming distractions while driving or performing a medical procedure; and expand usability when audio and visual feedback are ineffective. Immersion's TouchSense technology provides haptics in mobile phone, automotive, gaming, medical and consumer electronics products from world-class companies. With over 1,300 issued or pending patents in the U.S. and other countries, Immersion helps bring the digital universe to life. Hear what we have to say at blog.immersion.com.

For additional information about tactile feedback, haptics, and the human response to specific haptic effects and performance parameters, contact Immersion at focus@immersion.com.

Many consumer studies and whitepapers are also available on Immersion web site. To access and download these documents, please visit http://www.immersion.com/whitepapers

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