Usability Parameters for Touchscreen-based Haptic Perception

Hari Prasath Palani and Nicholas A. Giudice

Abstract—**Despite the advancements in touchscreen technologies, there is a surprising dearth of research on touchscreen-based haptic perception and guidance on best practices for haptic interface-design employing these devices. We address these shortcomings by investigating several key usability parameters and spatio-cognitive abilities pertinent to haptic information access via touchscreen devices. Two preliminary psychophysically-inspired usability studies investigated the haptic thresholds for detecting (Exp 1) and tracing (Exp 2) graphical stimuli rendered on a touchscreen interface. We found that a minimum of 1mm width is necessary for detecting lines using haptic feedback (i.e., vibro-tactile or electrostatic stimulation) and a width of at least 3mm should be maintained for effective line tracing. Results provide foundational guidelines for designing information content that is optimized for rendering on touchscreen displays. Findings also demonstrate the importance of and need for further investigations into the usability parameters and cognitive abilities required for the design of effective haptic interfaces.**

I. Introduction

The advent of touchscreen devices has amplified reliance on digital information displays. A major accessibility advantage of these devices is their ability to provide multimodal feedback (e.g., haptic, visual, and auditory). Although touch is the primary mode for interacting with touchscreen devices, it is often undervalued as a potential channel for providing feedback as compared with visual or auditory output [1]–[3]. However, there are many situations where providing visual feedback is impractical or not suitable. For instance, applications for blind and visually impaired (BVI) users or those requiring eyes-free interactions, such as in-car touchscreen displays. In such situations, haptic feedback is the primary source for accessing information. Despite this potential, haptic feedback is generally relegated to providing alerts (e.g., vibration of the phone) or used as a secondary output. We argue that the haptic channel can be a primary interaction style for touchscreen devices and that its functionality is currently being vastly under-utilized. Many researchers and designers have documented the perceptual parameters and best practices for touchscreen interface-design using visual and auditory interactions [2]. By contrast, no work, to our knowledge, has identified similar factors or guidance for touchscreen-based haptic interactions. We address this gap in the literature by investigating two key perceptual parameters (i.e., detection and tracing) involved in touchscreen-based haptic information access.

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H. P. Palani is with The School of Computing and Information Science at The University of Maine, Orono, ME 04469 USA (phone: 207-404-1587; e-mail: hariprasath.palani@maine.edu).

N. A. Giudice is with The School of Computing and Information Science at The University of Maine, Orono, ME 04469 USA (e-mail: nicholas.giudice@maine.edu).

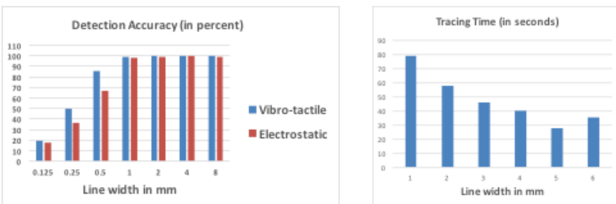
II. Touchscreen-based Haptic Perception

Unlike traditional haptic perception, where an object's shape and texture intrinsically provides meaningful information to the user, touchscreens do not provide any cutaneous cues except for the perception of a featureless glass surface that conveys no meaningful tactual information/reinforcement. To overcome this absence of intrinsic cues, touchscreen-based haptic interactions must rely on extrinsic feedback (e.g., vibration, friction, or electrostatic cues) to indicate contact with an on-screen graphical element. Thus, known empirical haptic parameters based on physical stimuli are not applicable to touchscreen-based haptic interactions, as the on-screen graphical element do not rely on physical attributes to innervate pressure-sensitive mechanoreceptors [4]. In addition, established parameters based on static finger position or stimuli are not appropriate for touchscreen interactions as they demand active finger movements. For accurate perceptual interpretation of the stimuli on these displays, users must follow a three-step process: (1) employ proprioception (i.e., force, position and motion sensors) to keep track of their finger position within some frame of reference, defined by the body or external landmarks such as the display frame, (2) extract the spatial information by synchronously interpreting the haptic cues, and (3) interpret the on-screen stimuli by associating the perceived sensory information [5]. As such, we argue that the value at which a user can perform this 3-step process (as opposed to the value at which cutaneous detection or discrimination occurs) represents the optimal usability parameter for touchscreen-based haptic interactions. While studies have shown that users can effectively perform this three-step process for accessing graphs, polygons and maps [6], [7], no empirical investigations have addressed the optimal usability parameters governing such haptic interactions on touchscreen interfaces. We address this gap in the literature by identifying usability parameters for detecting (Exp 1) and tracing (Exp 2) line stimuli rendered on touchscreen interfaces via the three-step process involving active finger movements and dynamic haptic cuing.

III. Experiment 1- Line Detection

Fifteen blindfolded-sighted participants (ages 19-32) took part in this study. It followed a within-subject design and consisted of two conditions; 1) vibro-tactile cuing, and 2) electro-static cuing. The stimuli set consisted of seven different line widths (0.125, 0.25, 0.5, 1, 2, 4, and 8mm) with 0.125mm (average size of a pixel on most touchscreen displays) as a base value and increasing linearly by a factor of 2 up to 8mm, a size known to be effective for performing the three-step process [5], [6]. The vibro-tactile lines were rendered on a 5.6inch *Galaxy Note4 Edge* phablet and the cues were based on Immersion (www2.immersion.com) Corp's UHL effect "Engine1_100" which uses a repeating loop at 250 Hz with 100% power. The electro-static lines were rendered on a 7.0inch *Nexus7* tablet overlaid with Sensegs' (www.senseg.com) Feelscreen. A trial could have 1, 2, or 3 lines, all of the same width. In each condition, the 7 line widths and 3 line counts were balanced across 84 trials. In each trial participants were asked to scan across the screen and count the number of lines. Each trial was scored based on the number of lines perceived by the participant. For example, a participant response of 2 lines on a trial with 3 lines would receive a score of 2 (i.e., 66% accurate). Accuracy in line detection was compared between the 7 line widths and across the 2 conditions using repeated measures ANOVAs and post-hoc paired sample t-tests.

Figure 1. (left) Percent accuracy of line detection as a function of cuing-condition, (right) Path tracing time (Exp2) as a function of line width.



Results revealed that a minimum of 1mm line width was always detectable for both cuing-conditions (see Fig 1.) suggesting that an on-screen graphical element should be of at least 1mm width for effective detection using haptic feedback on touchscreen devices. Findings also showed that the detection accuracy with vibro-tactile cuing was significantly better than the electro-static cuing for line widths 0.125, 0.25, and 0.5mm (all ps<0.05). We believe this difference is primarily because of the novelty and the weak signal strength of electro-static cue in the Senseg Feelscreen.

IV. Experiment 2- Line Tracing

While 1mm is sufficient for accurate line detection, it is not clear whether this line width is also sufficient for line tracing. Line tracing (i.e., contour following) is a basic behavior that is critical for exploration and extraction of information for haptic perception of complex stimuli. To be truly useful, the stimuli rendered on touchscreens should maintain a line width that can achieve similar tracing and exploratory performance as compared to standard embossed tactile stimuli. Experiment 2 was designed to identify the optimal functional threshold for effective haptic line tracing via the three-step process involving active finger movements and dynamic haptic cuing. Fifteen new blindfolded-sighted participants (ages 18-32) took part in this study. The experiment also followed a within-subject design. The stimuli set consisted of 6 line widths with 1mm being the base value as identified from Exp 1 and increasing linearly (by 1mm) up to 6mm. The widths were compared in a path learning task where each path was comprised of a start point, an end point, and three line segments connected by two vertices (see Fig 2.). The apparatus was similar to Exp 1 with the addition of speech output to indicate the start point, end point, and vertices. The stimuli set consisted of 24 paths (6 line widths and 4 patterns). Each participant performed 24 trials and in each trial they traced the path once from the start point to the end point. They then performed a matching task where they identified the experimental path from three geometrically similar alternatives embossed on hardcopy paper.

Figure 2. Four different path patterns used as the Experimental stimuli.

In the electro-static condition, cuing occurred only when the finger moved from a featureless part of the screen to the stimuli. This motion-dependence forced the users to constantly move their finger to confirm whether they were on or off of the paths. Since only 2 participants were able to perform tracing in the electro-static condition, it was excluded from the analysis. The time taken to trace each path, and time spent on individual line segments and the vertices, as well as accuracy in the matching task were measured and compared between the 6 line widths using repeated measures ANOVAs and post-hoc paired sample t-tests. Overall, the results showed that performance was significantly worse with 1mm and 2mm line widths as compared with the other 4 line widths (all ps < 0.05). Results also showed that participants spent significantly (p<0.05) more time at vertices comprised of acute-angles (M = 29.59sec) compared to those with obtuse-angles (M = 20.17sec) or right-angles (M = 10.59sec).

V. Conclusion and Future Work

Given the magnitude of touchscreen usage (~ 2.8 billion touchscreen panels will be shipped in 2016 alone [8]), it is necessary to investigate and identify the key usability parameters and cognitive abilities pertinent to use of these interfaces. Findings from these two studies provide some initial guidelines for designing information content that is haptically perceivable on touchscreen interfaces. We strongly believe in the need, and are working towards, the development of a theoretical framework to guide touchscreen-based haptic interactions in order to enhance their overall usability and to provide improved haptic information access supporting non-visual applications.

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