Using Haptics for Mobile Information Display

Karon E. MacLean
Department of Computer Science
University of British Columbia
Vancouver, B.C., Canada
001-604-822-8169
maclean@cs.ubc.ca

ABSTRACT

Haptic feedback has a role to play in mobile display of information, with its potential for enriching technology interactions, offloading vision, and providing low-attention or eyes-free communication with networked information and other users. However, without careful and perceptually informed design, it will become just another annoying distraction; and our current knowledge of both haptic perception and the impact of its processing on multimodal attention is in its infancy.

This position paper outlines opportunities and pitfalls of designing mobile haptic interactions, with emphasis on abstract communication via *haptic icons* – brief, informative tangible signals. Past and ongoing projects relating to this effort are described, and illustrated using usage scenarios.

Categories and Subject Descriptors

H5.2. Information interfaces and presentation (e.g., HCI): User Interfaces, Haptic I/O.

Keywords

Haptic feedback, haptic icons, tactile, mobile interaction design.

1. INTRODUCTION

Today's combination of "always-on" connection devices and feature bloat bombards users with visual and audio information. This situation is particular severe with mobile devices, where screen real estate is limited and there are typically multiple demands on a user's attention.

Haptic feedback should be able to help alleviate this overload, by providing another communication channel that has several special properties. The haptic sense, comprising taction (perceived through the skin) and proprioception (body forces and motions), is underutilized in computer interfaces; yet we have a rich experience in the physical world of using it to collect information in intuitive, transparent ways [8, 9, 12]. With haptic feedback, we can also make small digital transactions physical, confirmed, and articulated [10]. In the real world, we know a door latch has engaged when it clicks. The computer doesn't usually help us out in this way, and when it does, it's generally with a sound [7] which, while effective, can be intrusive or (conversely) go un-sensed in a noisy environment. Finally, mobile devices are often held or carried in close bodily contact, providing opportunities for haptic display – delivered for example as tactor waveforms, by a vibrating screen and felt through a stylus, or by the motion of a force-feedback knob.

On the down side, we do not yet have heuristics or common expectations for how nontraditional information should be transmitted haptically in digital interfaces, especially for multitasking situations where the user is cognitively loaded. One challenge is the limited expressiveness of haptic technology in most current mobile devices, which employ actuators capable only of simple vibratory feedback (on/off). Technology that can produce richer haptic feedback is needed to research and develop effective interaction techniques that make the most of this channel. Moreover, to augment interfaces haptically without making the overload even worse requires understanding the role of attention – and its saturation – in multimodal perception.

In this position paper, I begin by defining a basic unit of communication that my research group and others have been using in our early explorations for mobile haptic communications: the *haptic icon*. I then further describe key roles that haptics will play in this domain as well as the device form factors which are emerging. For the remainder, I outline the efforts my group has made on several key research challenges before us. These relate to (a) designing perceptually distinguishable sets of haptic icons, (b) increasing usable set size, and (c) managing intrusiveness in multimodal, multitasking environments.

At this juncture, I introduce Tamara, a young professional parent who will illustrate some of these ideas. Some are near fruition, while others may never occur as we envision them. Their specificity should help demonstrate the potential breadth and richness of the haptic modality.

> *A salesperson, Tamara is often on the road. She spends a large part of her day in the car, commuting from one client to another. We catch Tamara as she as she kisses her young son goodbye and embarks on a road trip to her clients in her sales area.*

Figure 1. An example of multitasking using a mobile touchscreen device (Nokia 770 tablet). Haptic feedback could enable the user to pay more visual attention to the presenter.

1.1 Haptic Icons

Haptic icons are brief, active, tangible stimuli (either tactile display or proprioceptive force feedback) that convey information such as event notification, identity, content or state [1, 4, 14, 16]. Because most humans do not have experience in obtaining abstracted, representational information through their touch sense – as we do for vision and audition – this vocabulary must be constructed with care, and with attention to human perceptual and cognitive abilities [15, 19].

In order to be effective, haptic icons must be both meaningful and easily distinguished. They also need to be short, easy for a user to process, and must transmit a message reliably and consistently. They must not be ignorable when conveying urgent and important information. Like graphical icons, haptic icons must either be universal (generally recognized by different people in different situations) or easily learned and compatible across applications.

> *Scenario: Tamara receives an urgent call*
> *During an informal chat with some clients she is visiting, Tamara receives a call on her mobile phone, which is on "vibrate" mode. Reaching into her pocket and grasping the phone with her thumb on the small tactile display on its side, she immediately receives a sharp, anxiety-provoking sensation. Two traveling ridges start repeatedly from the two opposite ends of the tactile pad and meet in its center; they accelerate like a heart beating faster and faster. There is definitively something wrong at home! After apologizing to her clients, Tamara answers the phone to find out from the babysitter that her 5-year-old boy, Bobby, has cut himself with a rusted nail. The babysitter is on the way to the hospital and wondering about tetanus shots.*

It is easy to imagine Tamara's cell phone displaying other haptic icons to indicate different conditions and callers. She is able to get details about the urgent message from the phone's tactile display with a quick, discreet motion (slipping her hand into her vest). While the transmitted message must always be clear and concise, in most situations it should not demand Tamara's full attention.

Metaphorical associations: Initial design efforts have built on our social and experiential norms for manipulating tangible objects and interpreting physical feedback. Well-established metaphors for touch drive new models for association and bring intuitive meaning and affordances that relate to haptic icons. However, there have not been many deployed examples of metaphorically designed icons; a set of 7 were successful used in [4].

Arbitrary associations: The metaphorical approach does not scale well because it is difficult to simultaneously optimize metaphorical matching and stimulus distinguishability as the set grows. This is partly a function of the limited expressiveness of today's tactile display hardware, particularly constrained by requirements for small size and low power. Furthermore, abstract information items might not have an obvious tangible analog on which to base a metaphorical connection. Thus, one of our research foci has been to understand the extent to which people are able to learn and remember large collections of *arbitrarily* matched stimulus-meaning pairs, and to explore best-practices for both effective design and effective learning [5, 6]. A more extensive comparison between these two design approaches is available in [15].

Our group has worked for several years to refine the process of designing haptic icons for specific applications, beginning by satisfying the necessary (but not sufficient) requirement for perceptual distinctiveness using a perceptual optimization tool [16, 20]. We have demonstrated that users can learn a small set of icons quickly: in one typical result (using a commodity vibrotactile display embedded in a mouse) users learned 7 icons in less than 3 min, and retained and used them over a 3-hour period [3]. We have gone on to deploy haptic icons in a number of applications and device form factors [4, 6, 22]; and obtained insights into how to meet user needs with embedded tactile displays through managed intrusiveness and eyes-free operation.

Our results here and elsewhere indicate that this kind of abstract haptic feedback has sufficient expressive and information capacity to provide a real benefit in these contexts, and user feedback confirms a need for quiet, non-intrusive haptic signals in applications such as hand-held mobile devices.

2. The Hardware

The vibrations emitted by today's cell phones are usually produced by small, eccentrically weighted motors whose high-speed oscillation makes the device case buzz. These actuators are limited in expressive control – most fundamentally, bandwidth as well as independent control of the resultant vibratory amplitude and frequency. They can produce only a few discernible signals which are not particularly pleasant to feel.

New technologies such as piezoelectric ceramic actuators are emerging as suitable technologies for rendering more expressive haptic feedback (e.g. in the piezo-actuated touchscreens of [11, 21], which are also fast, strong, thin and light. Piezos allow independent control of their amplitude and frequency, leading to a greater variety of tactile waveforms. However, piezos have the disadvantage of relatively low signal strength: their feedback is rich and precise but subtle, best for engaged use. Other approaches currently in vogue include solenoids and voice coils; these, as well as eccentric motors, produce stronger percepts more appropriate for attention-grabbing roles.

We have also explored new ways of delivering this information. A force feedback knob embedded in a handheld form factor

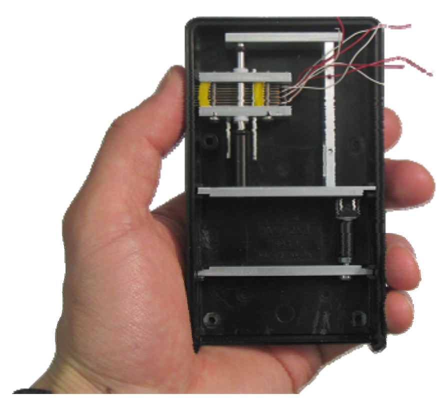

Figure 2: Piezo-based skin-stretch display

supported early interaction concept explorations [18], which more recent, embeddable knob technology could render relevant. A novel handheld tactile display [14][1] brings a skin-stretch principle to the mobile form factor. Because the sensations this device renders are completely unfamiliar, its language is truly new. Its design had to be founded on a thorough psychophysical characterization.

3. Roles for Haptics in Mobile Computing

There are many ways that haptic feedback will be able to contribute to user's transparent access to networked information while on the go. The following provides a few examples.

3.1.1 System to user: signal, monitor and navigate

In the natural world, we often use touch to detect events and monitor states – the pencil sharpening is finished; the road is rough, so we must slow down. Touch is also an obvious choice for spatial cueing: a tap on the shoulder can tell us which way to look. Further, we often obtain this information and act on it sub-consciously. We can use a similar approach with synthetic and abstracted haptic displays, and aim for the same kind of low-attention, background human processing of ongoing system processes and network events. However, this entails knowing about the limits of our tactile perception, our cognitive models for associating signals with meanings, and the role attention and workload play in what gets through.

Hence, lacking proven heuristics for this modality, usability means combining top-down with bottom-up design: identifying valuable use cases via contextual study, while closely examining candidate solutions with respect to basic human abilities. In this manner, we have related a number of system-user communication scenarios (including GPS-guided urban navigation and signaling applications) to the specific display capabilities of a given device [14]. In [5, 6], we have further focused on mechanisms that users find natural for learning haptic representations for system notifications and labels.

3.1.2 Lightweight communication

Haptic feedback can be used to mediate background communication among users, freeing voice and ears for other tasks. For example, we used the vibrotactile mouse-based icons described above in a fully simulated, remote collaboration task to mediate turntaking. We found improved collaborative quality by metrics such as equitability of time in control and control turnover rates, through a background awareness of others' wish to participate [3, 4]. In upcoming work, we will deploy this concept on mobile devices in a classroom setting.

> *Scenario: haptically-mediated turn-taking*
>
> *Tamara enters the room for a meeting with several people at her client's company, with others connected by video, and notices Karl (known for endless monologues, important to not offend).*
>
> *She takes hope from her next observation that the room has haptic chairs that help speakers be aware of how urgently others wish to take the floor. Soon, Karl raises a criticism that Tamara can address, but doesn't give her an opening. Instead of trying to interrupt verbally, Tamara reaches for the button on her armrest. Both Tamara's and Karl's chairs emit a firm, brief vibratory burst, indicating that a new and urgent request has entered the queue, which recurs every 20 seconds or so. After a minute, Karl pauses in mid-harangue, looks down at his chair, mildly surprised, then looks around the room. This time Tamara is able to catch his eye, and quickly takes the floor. Karl pushes a release button on his own chair to stop his queue-signal.*
>
> *In the middle of her answer, Tamara gradually notices a mild pulse on her own chair. Someone else wants to talk next, but not urgently. The faces around her tell her nothing. She wraps up her point a bit more briskly and presses her release button. In the ensuing pause, someone on the video link introduces a different topic.*

The haptic signals that Karl and Tamara feel must be matched to both the task and the users. For Tamara, it provided extra contextual information, without distracting her from her speech. In contrast, the haptic cue that Karl received was so evocative that it demanded his attention. To make these interactions possible, application designers need a solid understanding of how people react to haptic stimulation under cognitive load.

3.1.3 Structuring the handheld workspace

Haptics on a mobile platform can also be used in a more local way, to provide immediate guiding feedback and constraints in basic GUI operations. Vibrotactile feedback can display object edges, button click confirmation, scrollbar position and progress bar status [13]. In the future, we plan to extend this to facilitating handheld interactions with large projected workspaces

4. Interaction Design Challenges

I close with brief comments on a selection of the core questions which currently pose the most serious obstacles to embedded haptic feedback; these center on haptic stimulus design given a piece of hardware, rather than improvement of the hardware itself. However, the first two are indeed rooted in the primitive state of current embeddable display technology, which is akin to a (very) low-resolution monochrome graphic screen. One can hope that demonstration of potential value will lead to hardware improvements. A more general discussion of haptic interaction design issues can be found in [17].

4.1 Potential Set Size

How *much* abstract information can we communicate through touch? What perceptually-guided heuristics will facilitate the largest distinguishable stimulus sets? Metaphorically guided icon sets seem to work well up to a dozen items or so, but beyond this more systematic approaches are required. Amplitude, frequency and waveform are the most commonly modulated variables; rhythm shows promise for more range [1, 25]. In [23, 24], we carried out a more comprehensive analysis of rhythm, and used it with frequency and amplitude to create a distinguishable set of 84 stimuli. In ongoing work, we are using this set to study limits on the number of stimulus-meaning *associations* users can learn and utilize in realistic contexts.

[1] Built in collaboration with V. Hayward of McGill University.

4.2 Associability

Given a set of distinguishable stimuli, the associability problem is to match these to a comparable number of meanings; or in a less constrained but still difficult problem, to choose from the possible stimuli the best matches to a smaller set of meanings. The solution will lie both in the structure of the matches themselves, and in the mechanisms by which users are asked to learn them.

Progress on this front has begun even with the smaller validated stimulus sets available in the past. For example, we hypothesized that when users can choose the stimuli which will represent specific concepts, their learning and recall will be eased and enhanced relative to having arbitrary associations imposed on them. We tested this idea by comparing the two cases for 10-icon sets. This produced two surprising results. Participants recalled 86% of the previously learned associations 2 weeks later without any intervening reinforcement (despite zero *expectation* of ability to recall); and there was no difference between arbitrary and user-chosen association conditions [5].

These results underscore the eminent practicality of using haptic icons in everyday interface design, suggesting high learnability and a surprising user ability to find their own mnemonics for carefully composed stimuli, regardless of how associations are assigned. However, this is a small set, and we anticipate that more structure will be required to support users attempting far more.

4.3 Design for Attention

Designing with awareness of multitasking operating environment is all-important; otherwise, mobile haptics will be just another annoying distraction. To manage intrusiveness and allow the user to optimize where they direct their attention, signals must be designed with variable salience: important events or urgent events/changes should register as "louder" than less important ones [3]. Furthermore, beyond issues of sensory adaptation to the signals, the user's *interruptibility* is not a constant. In the car, for example, pulled over vs. engaged in a turn differ substantially in what kind of additional distractions the driver can safely deal with; in the office, some tasks require protection from routine interference, and yet certain events might always be important enough to come through. Eventually (we hope) interfaces will become smart enough to know when to intrude.

For haptic icons to be capable of variable-intrusion signaling, it is necessary to test them as sets while controlling workload intensity in multimodal task simulations. We have developed techniques for prototyping realistic contexts of specific test applications, to explore more basic questions such as how cognitive workload is impacted by haptics communication, and whether conscious attention is required to make use of haptic signals. These have been in the context of urgency-based mediation of turntaking in remote collaboration [2, 3] and in more abstracted instances, iconic rendering of ordinal data [22] and GUI augmentations [13] for their efficiency and robustness under workload. The importance of workload testing is generally apparent in the diversity of response patterns that different types of icons elicit as load increased. For turn-taking, some icons were intended to be more intrusive than others, whereas for the ordinal renderings, our aim was for uniform salience; workload testing allowed iteration to achieve both of these goals.

4.4 Summary

In this paper, I have suggested how haptic information display can potentially enrich and lower the cognitive and attentional load involved in utilizing mobile information appliances, particularly in multitasking environments. Haptic icons are one possible mechanism, whether implemented through today's vibrotactile displays or the high efficiency, miniature force-feedback knobs and sliders we will soon see on the market. Successful and scalable design efforts in this area need to be undertaken in a user-centered fashion with attention to user capabilities, and will inform improved device design.

5. ACKNOWLEDGMENTS

The work described here is due to the devoted efforts of many students in the Sensory Perception and Interaction (SPIN) Lab.

6. REFERENCES

[1] Brown, L. M., Brewster, S. A., et al., "A First Investigation into the Effectiveness of Tactons," in Proc. of 1st Worldhaptics Conference (WHC '05), Pisa, Italy, pp. 167-176, 2005.

[2] Chan, A., Designing Haptic Icons to Support an Urgency-Based Turn-Taking Protocol, M.Sc. Thesis, University of British Columbia, 2004.

[3] Chan, A., MacLean, K. E., *et al.*, "Learning and Identifying Haptic Icons under Workload," in Proc. of 1st Worldhaptics Conference (WHC '05), Pisa, Italy, pp. 432-439, 2005.

[4] Chan, A., MacLean, K. E., *et al.*, "Designing Haptic Icons to Support Collaborative Turn-Taking," *to appear in the Int'l J of Human Computer Studies*, 2008.

[5] Enriquez, M. and MacLean, K. E., "The Role of Choice in Longitudinal Recall of Meaningful Tactile Signals," in Proc. of IEEE Haptic Symp (HAPTICS '08), Reno, pp. TBA, 2008.

[6] Enriquez, M., MacLean, K. E., *et al.*, "Haptic Phonemes: Basic Building Blocks of Haptic Communication," in Proc. of 8th Int'l Conf. on Multimodal Interfaces (ICMI '06), Banff, Canada, pp. 302-309, 2006.

[7] Gaver, W., "Synthesizing Auditory Icons," in Proc. of CHI'93, Amsterdam, pp. 228-235, 1993.

[8] Heller, M. A. and Schiff, W., "The Psychology of Touch." New Jersey, USA: T. L. Erlbaum, Hillsdale, 1991.

[9] Katz, D., *The World of Touch*. New Jersey: Erlbaum, 1925/89.

[10] Kontarinis, D. A. and Howe, R. D., "Tactile Display of Vibratory Information in Teleoperation and Virtual Environments," *Presence*, vol. 4, pp. 387-402, 1995.

[11] Laitinen, P. and Maenpaa, J., "Enabling Mobile Haptic Design: Piezoelectric Actuator Technology Properties in Hand Held Devices," in Proc. of HAVE '06, 2006.

[12] Lederman, S. J. and Klatzky, R. L., "Action for Perception: Manual Exploratory Movements for Haptically Processing Objects and Their Features," in *Hand and Brain: Neurphysiology and Psychology of Hand*, A. Wing, et al., Eds. San Diego: Academic Press, 1996, pp. 431-446.

[13] Leung, R., MacLean, K. E., *et al.*, "Evaluation of Haptically Augmented Touchscreen GUI Elements under Cognitive Load," in Proc. of 9th Int'l Conf on Multimodal Interfaces (ICMI '07), pp. 374-381, 2007.

[14] Luk, J., Pasquero, J., *et al.*, “A Role for Haptics in Mobile Interaction: Initial Design Using a Handheld Tactile Display Prototype,” in Proc. of ACM CHI '06, CHI Letters, vol. 8, no. 1, Montreal, Canada, pp. 171-180, 2006.

[15] MacLean, K. E., “Haptics in the Wild: Interaction Design for Everyday Interfaces,” to appear in *Reviews of Human Factors and Ergonomics*, M. Carswell, Ed. Santa Monica, CA: Human Factors and Ergonomics Society, 2008.

[16] MacLean, K. E. and Enriquez, M., “Perceptual Design of Haptic Icons,” in Proc. EuroHaptics, Dublin, Ireland, 2003.

[17] MacLean, K. E. and Hayward, V., “Do It Yourself Haptics, Part II: Interaction Design,” *IEEE Robotics and Automation Society Magazine*, vol. 15:1, 2008.

[18] MacLean, K. E., Shaver, M. J., *et al.*, “Handheld Haptics: A USB Media Controller with Force Sensing,” in Proc. of IEEE Haptic Symposium (HAPTICS '02), Orlando, FL, pp. 311-318, 2002.

[19] Pasquero, J., “Survey on Communication through Touch,” Center for Intelligent Machines, McGill University, Montreal, Canada TR-CIM 06.04, 2006. http://www.cim.mcgill.ca/~haptic/pub/JP-CIM-TR-06.pdf.

[20] Pasquero, J., Luk, J., *et al.*, “Perceptual Analysis of Haptic Icons: An Investigation into the Validity of Cluster Sorted MDS,” in Proc. of 14th IEEE Haptic Symposium (HAPTICS '08), Alexandria, Virginia, pp. 437-444, 2006.

[21] Poupyrev, I., Okabe, M., and Maruyama, S . “Haptic Feedback for Pen Computing: Directions and Strategies,” *Extended Abstracts of CHI 2004*, pp. 1309–1312, 2004.

[22] Tang, A., McLachlan, P., *et al.*, “Perceiving Ordinal Data Haptically under Workload,” in Proc. of 7th Int'l Conf on Multimodal Interfaces (ICMI '05), Trento, Italy, pp. pages 244-251, 2005.

[23] Ternes, D., Building Large Sets of Haptic Icons: Rhythm as a Design Parameter, and between-Subjects MDS for Evaluation, M.Sc. Thesis, Univ. of British Columbia, 2007.

[24] Ternes, D. and MacLean, K. E., “Designing Large Sets of Haptic Icons with Rhythm,” in Proc. of submitted to Eurohaptics, 2008.

[25] van Erp, J. B. F. and Spapé, M. M. A., “Distilling the Underlying Dimensions of Tactile Melodies,” in Proc. of Eurohaptics, Dublin, Ireland, pp. 111-120, 2003.