Tactile Interfaces for Small Touch Screens

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ABSTRACT

We present the design, implementation, and informal evaluation of tactile interfaces for small touch screens used in mobile devices. We embedded a tactile apparatus in a Sony PDA touch screen and enhanced its basic GUI elements with tactile feedback. Instead of *observing* the response of interface controls, users can *feel* it with their fingers as they press the screen. In informal evaluations, tactile feedback was greeted with enthusiasm. We believe that tactile feedback will become the next step in touch screen interface design and a standard feature of future mobile devices.

Keywords: tactile feedback, touch screen, mobile computers

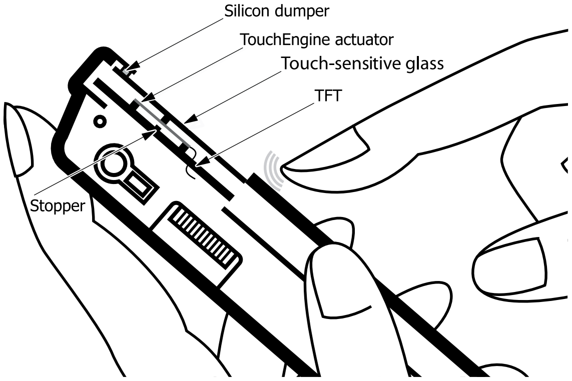

Figure 1: Haptic display for small touch screens.

INTRODUCTION

Touch screens have become common in mobile devices, such as PDAs, digital video cameras, high-end remote controls, etc. Touch screens are attractive because they save space on mobile devices by combining the display and input space and allow dynamic simulation of electromechanical controls, e.g. buttons and switches. They provide high levels of immediacy in interaction by allowing the user to touch, push, and drag information directly with their fingers [9]. This directness translates into better user acceptance, ease of use and a faster input rate [8, 9, 12]. With this, the use of touch screens will certainly grow in the future.

Despite progress, one important challenge still remains: it is difficult to provide users with sufficient feedback. Buxton [2] was the first to observe that touch screen graphical buttons cannot provide the same level of haptic response as real switches, where we can directly *feel* the action. Without haptics, the user can only rely on audio and visual feedback, which breaks the metaphor of directness in touch screen interaction. Furthermore, small display size, outside noise, social restrictions, interruptions and demands of real world tasks make visual and audio feedback significantly less effective in mobile applications [6].

We present a haptic, tactile interface design for small touch screens used in mobile computers (Figure 1). With our interface, instead of observing the response of graphical user interface (GUI) controls, users can directly feel them with their fingers, similar to physical switches. We believe that by augmenting GUI with tactile feedback, we can use mobile devices more effectively and comfortably. Indeed, touch is a superior feedback channel – five times faster than vision [5]. It can also supplement sound and vision in conditions that renders them ineffective. Finally, it reinforces the metaphor of directness and physicality of touch screen interaction, making GUI controls “more real”.

RELATED WORK

Touch screens are effective interaction devices. Sears et al. [12] found that they can be comparable to a mouse in selecting targets as small as four pixels per side and were significantly faster for larger targets. There is a large body of research that demonstrates the value of touch screens [8, 9, 12]. Most of this work, however, investigated large desktop-size devices. It gave less attention to small touch screens often used in handheld mobile devices, as well as implications of user mobility on touch screen interaction.

We believe touch screen haptic can be an important enhancement for mobile applications with many indirect indications supporting this suggestion. Indeed, despite evidence that touch screen keyboards are faster and more accurate for text entry, handwriting techniques still prevail on mobile devices [8]. This may be attributed to better kinesthetic feedback in writing: it may simply *feel* more natural to the user to write than to poke on a soft keyboard. Consumer electronics designers have known this problem for quite some time. Although there is a history of consumer electronic devices utilizing the touch screen, there has always been dissatisfaction with them as users can not feel the response of graphical buttons [7].

Without tactile feedback, the user can only rely on audio and visual senses, which have many disadvantages. First, a mobile individual must focus on real-world activities. However, because visual display demands uninterrupted user attention, it is difficult to control the device while attending to other tasks [2]. Second, as displays become smaller, GUI widgets become less visible and are easily obstructed by a touching finger, making visual feedback less effective. A pen may help, but it would occupy the second hand, can be easily lost, and is inappropriate for many devices, such as digital cameras. Third, street noise hinders audio feedback, and during a meeting it becomes inappropriate and a nuisance. Finally, the lack of tactile feedback destroys the metaphor of directness and physicality of interaction with touch screens.

The earlier research on tactile displays for mobile devices has been limited to vibrating the entire device body. For example, in [10] we reported design of "full body" tactile displays that were used to enhance gestural interaction with mobile devices and to provide expressive tactile notifications for mobile users. We used a novel tactile actuator, TouchEngine™, to communicate the tactile feeling to the hand holding the device or, when the device was tacked away in a pocket, to the user's body, via vibrating the entire device.

This paper investigates an entirely different class of haptic applications for mobile devices: adding tactile feedback to the GUI on small touch screens. We aim to simulate a feel of real mechanical controls, e.g. when pressing a GUI button on a touch screen the user would feel as if she presses a real electromechanical switch. The key challenge here is localization of tactile feedback to the touch screen. This means that only the finger pressing a GUI control should feel its response; no vibration should be transferred to the hand holding the device. Indeed, in early tests we founded that device vibrations would partially mask vibrations perceived by a touching finger, significantly reducing the perceived strength of tactile feedback from the touch screen. Designing tactile display structure that addresses this challenge is one contribution of this paper.

Secondly, unlike real switches, in which feel is determined by their mechanical structure, the TouchEngine enables us to design a wide variety of tactile feelings, so different tactile sensations can be associated with various GUI element. Investigation on how tactile feedback can be combined with touch screen GUI is another novel aspect of this work.

We are unaware of previous attempts to enhance small touch screens with tactile feedback and investigate its implications on GUI design. The earliest reported tactile interface for touch screens, Active Click [4], was developed for relatively large touch screens and its off-the-shelf coil-type actuators were too large for small devices. Therefore, in a PDA, it would vibrate the entire device, somewhat similar to vibrating motors. Conversely, TouchEngine actuators can be embedded inside touch screens of virtually any size so that tactile sensations are felt only by the touching finger. Furthermore, Active Click generated only a single frequency of vibration resulting in a limited vocabulary of tactile feelings. TouchEngine, on the other hand, enables *independent* control of both the amplitude and frequency of vibration, which allows designing an infinite variety of tactile feelings for different GUI elements.

TACTILE FEEDBACK FOR SMALL TOUCH SCREENS

We embedded four custom-designed TouchEngine actuators in Sony's Clié PDA touch screen (Figure 1). Actuators were placed at the corners of the touch screen between the TFT display and the touch-sensitive glass plate. The glass plate is larger than the display; hence, the actuators are not visible. Important design features are:

1. *Actuation of the touch screen*. When a signal is applied, actuators bend rapidly, pushing the touch-sensitive glass plate towards the user's finger (Figure 1). Because the actuators are very thin (~0.5 mm, Figure 2a) we could embed them *inside* the touch screen. Therefore, only the lightweight touch-sensitive glass is actuated, not the entire touch screen unit which includes a heavy TFT display. Hence, we can produce sufficient tactile sensation with very little force and power. Also, actuators do not significantly increase the distance between the glass and the TFT display, avoiding the parallax problem which makes precise target selection difficult [9].

2. *Localized tactile feedback*. Vibration of touch screen glass produces tactile sensations *only* to the touching finger, not to the hand holding the device. To prevent the entire device from vibrating, a soft silicon damper is installed between the glass panel and frame ridges. It allows the glass panel to move when pushed by the actuators while cushioning the impact on the device frame. In addition, it seals the display from dust.

3. *Small high-speed displacement*. Although the displacement of actuators is small (about 0.05 mm), its fast acceleration produces a very strong tactile sensation [5].

4. *Silent operation*. Large audible noise defeats the purpose of tactile display. Noise can be sharply reduced by a) wave shape design and b) mechanical design, i.e. prevent loose parts from rattling when the actuators move.

5. *Reliability*. Bending the fragile ceramic actuators more then 0.1 mm by pushing on the glass can damage them. Therefore, a stopper is placed under the actuators to prevent their excessive bending (Figure 1).

TouchEngine actuators

The TouchEngine actuator was developed explicitly to design tactile interfaces for small handheld devices. Thus, it is extremely thin and small, can be battery-operated, has low latency and allows for independent control of both the amplitude and frequency of vibrations. This makes it possible to create an infinite variety of tactile waveforms, which is not possible with any other tactile actuators. Finally, it can

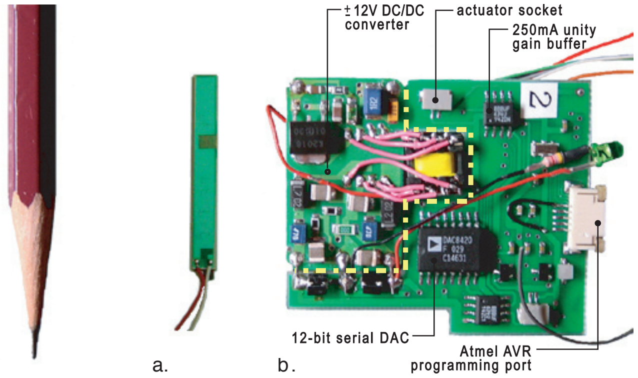

Figure 2: a) TouchEngine actuator b) control board

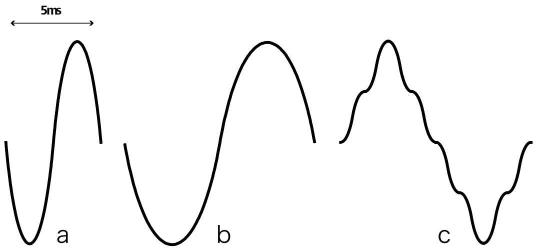

Figure 3: Waves shapes used in our interface design.

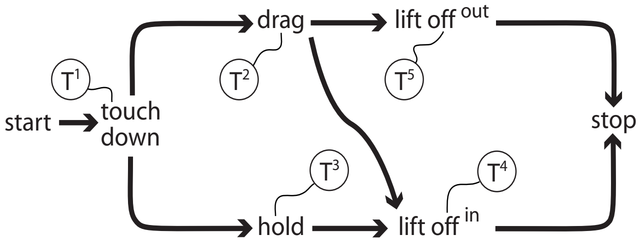

Figure 4: Structure of touch screen gesture

be manufactured in various sizes, making it versatile for any small device. The TouchEngine was described in details elsewhere [10, 11]; here, we provide only brief overview.

The TouchEngine actuator (Figure 2a) is constructed as a multilayer sandwich of thin (0.28 μm) piezoceramic films with adhesive electrodes in between. The piezoceramic film either shrinks or expands depending on the polarity of the signal. The top and bottom layers of the TouchEngine beam have opposite polarity, so when a signal is applied the entire structure bends. This configuration is called a “bending motor”. Current bending motors have one or two layers, requiring a large voltage for bending (80 - 350V). By sandwiching multiple layers of thin piezo, we can reduce voltage to ±8-10V while producing roughly the same amount of force.

The relationship between the voltage and actuator displacement is approximately linear – the higher the voltage, the larger the displacement. We drive the actuators using a control board that fits inside the PDA and communicates with Palm OS applications via RS232 link (Figure 2b). Tactile waveforms are stored in the flash memory of an Atmel AVR 8-bit RISC microprocessor. Figure 3 provides wave examples: shape A creates a sharp “click” feeling; shape B has twice the frequency of A, generating softer tactile sensations; shape C is a combination of high and low frequency vibrations and provides a soft “springy” feeling, useful in creating a feeling of transition. We will describe their use in the next section.

TOUCH SCREEN GUI AND TACTILE FEEDBACK

There was no prior research that explored how tactile feedback can enhance touch screen GUI, although we refer to previous work on gestural interaction [3] and tactile displays for desktop GUI [1]. There are two basic directions for exploration. First, we can investigate application specific tactile interfaces, e.g. enhancing drawing applications with tactile feedback. Second, we can investigate how tactile feedback can be combined with general-purpose GUI for mobile devices. Since our immediate objective is to introduce tactile feedback into generic mobile devices, we have chosen the latter as our current research direction.

Gestures and tactile feedback

Interaction with touch screens is essentially based on *gestures*. The gesture starts when the user touches the screen with a finger (or pen) and finishes when the user lifts it up from the screen. Figure 4 presents a basic gesture structure for touch screen interaction. Notice that unlike desktop GUI the interaction starts the moment the user touches the GUI element, we can not roll the pointer over GUI objects to first select and then click on it as we do it with the mouse. Each component of the gesture can be augmented with a distinct tactile feeling to provide the user with a feedback at each step of interaction. Therefore, we can classify all tactile feedback during touch screen interaction into five generic types: tactile feedback provided when the user starts a gesture by *touching* a GUI element (T1), when the user then either *drags* (T2) or *holds* (T3) her pen/finger, and, finally, when the user *lifts* it off either inside (T4) or outside (T5) the GUI widget.

Although there are only five basic tactile feedback conditions in generic touch screen GUI, they allow development of rich and expressive tactile interfaces. Indeed, each instance of tactile feedback is different for a specific GUI element and, furthermore, the tactile wave shapes can also change depending on the current interaction context.

Case study: Tactile GUI elements

We augmented basic GUI elements with tactile feedback, including several variations of buttons, scroll bars and menus. The particular instances of tactile feedback were made primarily for prototyping and evaluation; certainly other tactile feelings might be more effective. Below we discuss tactile feedback for each GUI control.

On touch down (T1). When the user touches the GUI element, such as a button, it “clicks” under the user’s finger. We used the “click” feeling (Figure 3a) for button elements, because it closely resembled the feeling of an actual plastic switch, evoking a feeling of completion, or the switching of a button state. On the other hand, for menus and scroll bars, we used a “springy” feeling (Figure 3c) to create a feeling of transition, preparing the user for further interaction with the interface element.

On holding (T2). Each GUI element responds differently to this interaction. For buttons that implement a repeating action, such as buttons at the end of a scroll bar, we provided continuous tactile “click” pulses for each repetition. We found this to be useful because the user can receive feedback even if a finger obscures the button and also, it allows the user to feel the button state during short interruptions.

When the system detects a certain delay period on the hold of a menu or scroll bar element, we assume the user was interrupted before task completion. We wanted to maintain user awareness of the interface state without having the user look at the display. To do this, we provided a low frequency vibration (Figure 3b) alerting the distracted user that the GUI element is still active and the current operation has not been completed.

On dragging (T3). Buttons do not respond to dragging. For menus and scroll bars, we used a "click" feeling each time the user moves the scroll bar handle by one item or selects the next menu item. This interaction for the scroll bar was particularly effective and well-received by users. Due to fine tactile feedback resolution, it helped the user scroll data more quickly and precisely.

On lift off (T4 and T5). Most GUI buttons, such as buttons in dialog boxes, execute commands only when the user lifts up the finger *inside* the button (T4); if the finger is lifted outside the button (T5) nothing happens, which provides a simple "undo" mechanism. To distinguish these two cases, we provided a "click" feeling for the T4 condition and did not provide any feedback for the T5. For menus and scroll bar handles, we played a "springy" tactile feedback to inform the user that the interaction is finished.

Tactile feedback at lift off is possible since most touch screen drivers generate a lift off event even though the user's finger is still touching the screen – just does not press it hard enough. Therefore, the user can still feel the touch screen vibrations. Furthermore, these tactile impulses are not recognized as new touch down events because touch screen drivers usually filter out all high frequency input components as noise, based on the assumption that humans can not touch faster then 20-30 Hz. Therefore, 200 Hz tactile impulses are filtered out and not recognizes by touch screen hardware.

DISCUSSION AND FUTURE WORK

We evaluated our prototypes in several informal usability studies, asking 10 colleagues to test our interfaces in audio, tactile and no feedback conditions. Tactile feedback was exceptionally well-received by our users who often remarked how similar tactile feedback felt to an actual mechanical switch. Only one user rated tactile feedback to be less effective than audio, but that was because audio feedback felt more familiar. Others also noted that since they did not expect tactile feedback on the touch screen, they required some time to get used to it. However, they did not see this as a problem.

We observed that tactile feedback was most effective when the GUI widgets needed to be held down or dragged on the screen. The combination of gestures and tactile feedback resulted in a strong feeling of physicality in interaction. We also found tactile feedback effective in interacting with small GUI elements, as it provided fast and reliable feedback.

Further research efforts are required to investigate how tactile feedback can be used effectively in combination with GUI interaction. In particular controlled experimental user studies are crucial to better understand its performance characteristics and develop formal tactile interface design guidelines.

CONCLUSIONS

This paper reported the design and implementation of tactile feedback interfaces for small touch screens, including the design of localized touch screen haptic display and investigation of how tactile feedback can be effectively combined with screen interfaces. We believe that touch screen haptic opens many new and exciting possibilities in interface design for portable devices and hope it will become a standard feature of future mobile computing devices.

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