

Touchplates: Low-Cost Tactile Overlays for Visually Impaired Touch Screen Users

Shaun K. Kane
UMBC Information Systems
1000 Hilltop Circle
Baltimore, MD, 21250 USA
skane@umbc.edu

Meredith Ringel Morris
Microsoft Research
1 Microsoft Way
Redmond, WA, 98052 USA
merrie@microsoft.com

Jacob O. Wobbrock
Information School | DUB Group
University of Washington
Seattle, WA 98195 USA
wobbrock@uw.edu

ABSTRACT

Adding tactile feedback to touch screens can improve their accessibility to blind users, but prior approaches to integrating tactile feedback with touch screens have either offered limited functionality or required extensive (and typically expensive) customization of the hardware. We introduce *touchplates*, carefully designed tactile guides that provide tactile feedback for touch screens in the form of physical guides that are overlaid on the screen and recognized by the underlying application. Unlike prior approaches to integrating tactile feedback with touch screens, touchplates are implemented with simple plastics and use standard touch screen software, making them versatile and inexpensive. Touchplates may be customized to suit individual users and applications, and may be produced on a laser cutter, 3D printer, or made by hand. We describe the design and implementation of touchplates, a “starter kit” of touchplates, and feedback from a formative evaluation with 9 people with visual impairments. Touchplates provide a low-cost, adaptable, and accessible method of adding tactile feedback to touch screen interfaces.

Categories and Subject Descriptors

H.5.2. Information interfaces and presentation: User Interfaces—*input devices and strategies*. K.4.2. Computers and Society: Social issues—*assistive technologies for persons with disabilities*.

General Terms

Design, Human Factors.

Keywords

Accessibility, blindness, visual impairments, touch screens, hardware, guides, touchplates.

1. INTRODUCTION

While the emergence of mainstream touch screen computing has presented usability benefits for many computer users, people with visual impairments often experience significant challenges when interacting with touch screen user interfaces [13,14]. A major feature of touch screens is their ability to enable users to directly manipulate information with their fingertips [23], but this capability often presents challenges to blind users, who cannot see or feel the visual information presented.

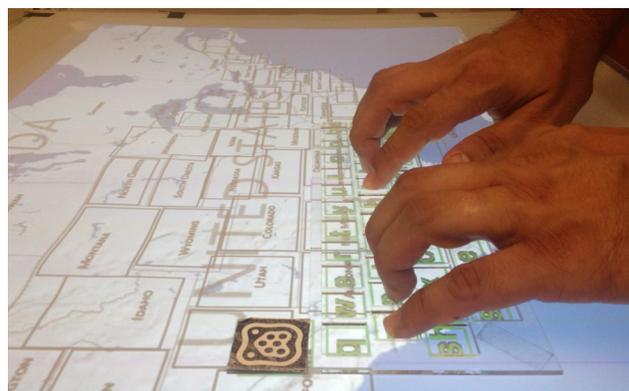


Figure 1. A QWERTY keyboard touchplate, cut from acrylic plastic, provides tactile feedback for a large touch screen user interface. The touch screen recognizes the guide and moves the virtual keyboard beneath it.

Fortunately, many mainstream touch screen devices now provide accessibility features for blind and visually impaired users. For example, Apple’s iOS¹ and Google’s Android² operating systems each provide screen reader software that can enable a blind user to navigate a touch screen using touch input and audio output.

Although screen reading software has indeed improved the accessibility of touch screen interfaces for blind people—the iPhone, in particular, has become popular among many blind users [18]—touch screen-based screen readers have limitations. First, these software solutions are typically limited to providing audio feedback, and cannot provide tactile feedback that may be useful to blind people. Second, mainstream accessibility software for touch screens has largely focused on providing accessibility for mobile phones. Larger touch screens, such as those found on interactive tabletops or touch screen kiosks, may present additional interaction challenges [15]. As larger interaction surfaces are becoming increasingly common, providing accessibility to these touch screens is a priority.

Augmenting the tactile feedback provided by touch screens could improve their accessibility to blind and visually impaired users. However, most touch screen-based devices do not provide tactile feedback beyond simple vibration. We introduce an approach for providing improved tactile and accessible feedback to touch screens via the addition of low-cost, customizable hardware guides that can be placed on top of the touch screen and recognized by the underlying application (Figure 1). These touch templates, or *touchplates*, can be used to augment the input and

¹ <http://www.apple.com/accessibility/iphone/vision.html>

² <http://code.google.com/p/eyes-free>

output capabilities of touch screen interactions by guiding users' hands and fingers, providing alternate input methods, and providing alternative "views" of on-screen content. Touchplates are more than just plastic guides over existing touch screen interfaces. Touchplates define the semantics of the interaction space around them, changing how the application responds to touches in their vicinity.

In this paper, we introduce the concept of touchplates, and describe the design and implementation of the underlying hardware and software components. We introduce a "starter set" of touchplates that are intended to explore the potential interactions enabled by this technique. We report on a formative user study with 9 visually impaired people that explored the possibilities of our starter set and identified opportunities for integrating touchplates into touch screen applications. Our work on touchplates reveals that the combination of simple hardware overlays and software that is responsive to these overlays can provide a low-cost, adaptable, and accessible tactile feedback method for touch screen interfaces.

2. RELATED WORK

Our approach complements prior work in developing hardware- and software-based techniques for improving the accessibility of touch screens for blind people. Our work also complements other approaches to providing tactile feedback for touch screens. We have also been inspired by prior work in developing lenses and other "add-ons" for touch screen tabletops and surface computers.

2.1 Touch Screen Accessibility

Concerns about the accessibility of touch screens have been considered for decades [5]. As the form factors of touch screens have changed, so have the approaches to making those touch screens accessible. However, we can divide prior approaches to making touch screens accessible to blind users into three categories: *software-only*, *hardware-only*, and *hybrid* approaches.

2.1.1 Software-Only Approaches

When the device hardware itself cannot be modified, many touch screens can still be made accessible by adapting the underlying software. Slide Rule [13] and NavTap [9] enabled access to uninstrumented touch screens through a combination of audio output and a set of input gestures that could be easily performed eyes-free. Similar systems have been released commercially by Apple¹ and Google². Other research has attempted to make text entry on touch screens easier for blind people (*e.g.*, [4,7]). While these systems have focused largely on making small mobile device touch screens accessible, Access Overlays [15] introduced accessible gestures that could be used to explore and locate objects on a large touch screen. While these techniques may improve accessibility even when the hardware cannot be changed, they provide very limited tactile feedback (*e.g.*, vibration only).

2.1.2 Hardware-Only Approaches

In some cases, it is not possible or practical to change the underlying software. In such cases, it may still be possible to provide some access to the underlying touch screen by placing some hardware device between the user and the touch screen. Buxton *et al.* noted in 1985 that adding physical templates over a touch screen can provide the user with kinesthetic feedback, thereby reducing attentional demands [6]. This technique was adapted for modern touch screens by Kincaid [16]; however, these researchers did not test this approach with blind or visually impaired users. A related technology is the *signature guide* used by many blind people when writing [1]. A signature guide is a hollow physical template that can be placed on a piece of paper

when a blind person wishes to fill out a check or sign their name. The blind person places the guide on the paper and signs their name inside its border.

Although prior research in HCI has not explored the use of passive overlays to improve touch screen accessibility for blind people, similar overlays have recently become available commercially. These overlays may take the form of cases or screen protectors for touch screen devices, and typically provide a series of bumps over a predefined region on the screen. For example, the TouchFire³ keyboard overlay for Apple's iPad featured a series of squishy silicon key-bumps over the screen, making it easier for users to touch type. These devices can provide some tactile feedback, which may improve usability. However, they are typically fixed to the screen, and cannot be easily moved or altered. Furthermore, such overlays do not typically communicate with the underlying device software, meaning the software is unaware whether the overlays are being used or not.

2.1.3 Hybrid Approaches

Other research projects have attempted to improve the accessibility of touch screens for blind people by combining accessible software with additional hardware. The Talking Fingertip Technique [25] consisted of a touch screen device with modified hardware and software. The touch screen software was modified to provide speech feedback when the user touched items on the screen, while a physical hardware button was used to confirm selections. The Talking Tactile Tablet [19] overlaid a touch-sensitive pad with an embossed graphical overlay to provide both audio and tactile feedback when exploring diagrams. McGookin *et al.* [20] created a prototype mobile music player which used a fixed touch screen overlay to create the sensation of physical buttons. Our approach is fundamentally similar to these aforementioned projects, but extends the association between a physical overlay and underlying software to enable additional interactions.

2.2 Tactile Feedback on Touch Screens

Currently, most commercial touch screens provide limited or no haptic feedback. However, many research projects have explored how touch screens can provide additional haptic feedback, for example by using piezoelectric actuators [21], magnetic fluids [12], or electrovibration [2]. Electro-vibration has even been used to make touch screens more accessible to blind people [29]. However, none of these technologies are widely available beyond the research lab. Other projects have attempted to provide haptic feedback to touch screen users by attaching motors [8] or magnets [27] to the user's hand. However, requiring the user to hold or wear an object may be cumbersome. Our goal with touchplates is to provide tactile feedback in a lightweight and unobtrusive way using current touch screen technologies.

2.3 Touch Screen Lenses and Add-Ons

The notion of a tactile touchplate or "touch lens" is based upon magic lenses, first introduced by Bier *et al.* [3] for graphical user interfaces, and adapted to touch screen computers in metaDESK [24]. These lenses provide users with an alternate view of the user interface, without requiring them to change application context. As changing contexts can be confusing to blind touch screen users [13], a physical lens or overlay may be used to provide alternate context without causing the user to lose his or her place.

Touchplates are not only designed to provide contextual information, but can also be used to support alternative input. As

³ <http://touchfire.com>

such, touchplates build upon prior projects such as SLAP Widgets [28], Madgets [26], and Clip-On Gadgets [30], which have used physical and mechanical overlays to enable tactile input for touch screen applications. Touchplates also build upon work from Hartmann *et al.* [11], who augmented a touch screen computer with traditional mice and keyboards. Our approach is perhaps most similar to the “transparent props” created by Schmalstieg *et al.* [22] in that both projects aim to create a set of reusable add-ons for the tabletop computer. However, our work extends this prior work by focusing on how dynamic physical add-ons can be used to improve the accessibility of a touch screen user interface for blind people. Furthermore, we introduce a customizable architecture that allows users to create touchplates using different methods (*e.g.*, laser cutters, 3D printers, or manually cutting paper), and to customize the overlays to meet their specific needs.

3. TOUCHPLATES

Touchplates are inexpensive, unpowered, and customizable tactile overlays for touch screen interfaces. The ingredients comprising a *touchplate* are: a passive tactile sheet, a visual tag, and associated software for interpreting touches on, in, or around the touchplate, wherever its placement. The visual tag enables an imaging touch screen to track the touchplate’s location and orientation. Finger touches may be tracked around the touchplate’s perimeter. Some touchplates have holes cut into their bodies so that touches may be detected inside the touchplate, while some touchplates may be made of transparent materials, such as clear acrylic plastic, so that touches *on* the touchplate can also be detected. Touchplates may contain various tactile landmarks such as edges, grooves, holes, and ridged areas. By convention, the visual tag is typically placed in the top left corner of the touchplate, where it can be felt, in order to help a blind user orient the touchplate.

The following sections describe how to create touchplates, and how touchplates may interface with software applications.

3.1 Creating Touchplates

Touchplates may be designed, fabricated, and modified by end users. Touchplate source files are simple Scalable Vector Graphics (SVG) files that can be created in any vector-based drawing program such as Adobe Illustrator, or created by hand in a text editor. The SVG file describes the size, shape, and location of the touchplate and its interactive areas.

Touchplates may be fabricated using a variety of tools, and may be composed of various materials (Figure 2). The visual tags used to identify and orient the touchplate may be printed using a standard laser printer. Our initial touchplates were cut from clear acrylic plastic using a laser cutter. Using clear acrylic is beneficial, as an infrared imaging-based touch sensor can see through the plastic, allowing the system to see when a user is touching the surface of a touchplate. However, touchplates can be constructed from many materials, including paper or cardboard, and can be cut by hand or by using a tool such as a laser cutter. Touchplates may also be fabricated using a 3D printer.

Our software prototypes currently read the touchplate SVG files at runtime. Thus, the user can change the expected layout of the touchplate by editing the source file and fabricating a corresponding touchplate. For example, a user may wish to use a QWERTY keyboard touchplate, but may desire a keyboard that is larger or smaller than the default keyboard. To change the keyboard size, the user may edit the source file to produce a larger or smaller keyboard, fabricate a new overlay from the modified file, and use it with the existing application without explicit configuration or code changes.



Figure 2. QWERTY keyboard touchplates in different materials. Touchplate is flipped upside-down so that the tag can be seen. Top: Cardboard cut by a laser cutter. Bottom: Clear acrylic cut by a laser cutter. Touchplates can also be cut by hand or 3D-printed.

3.2 Interacting with Touchplates

Touchplates can be tracked and used on most imaging-based touch screen systems. We have tested touchplates on both the Microsoft PixelSense⁴ interactive tabletop, as well as a custom diffused illumination (DI) tabletop display that we constructed. Depending on the materials used to construct it, the “body” of the touchplate may be transparent to the touch screen’s sensing system, or it may be identified as a touch “blob” and ignored by the application. Thus, applications that take advantage of touchplates can typically be implemented using existing touch APIs. Figure 3 shows the system’s view of a QWERTY keyboard touchplate on an imaging interactive tabletop system.

While touchplates can be implemented using the existing touch- and tag-tracking APIs found on many touch-sensitive tabletop systems, the combination of touch and physical manipulation of the overlay permits a wide range of interactions beyond simply moving or touching the touchplate. We have experimented with the following means of interacting with touchplates:

- **Touch inside.** Touchplates may have holes cut into them. Placing a fingertip inside one of these holes creates a direct touch connection with the touch screen. The offset of the touch from the detected visual tag allows the system to determine which region of the touchplate was touched.
- **Touch upon.** Some touchplates are made from materials that are transparent to infrared light. This makes it possible to detect when the user is touching the body of the touchplate. This creates a second touch surface that can be used, for example, to preview actions on the touch screen.
- **Touch outside.** Touchplates can also serve as frames of reference for nearby touches that occur just outside the touchplate, such as along an edge or at a corner point of the touchplate.
- **Move.** The touchplate itself can be pushed across the surface of the touch screen, providing additional input.
- **Rotate.** The body of the touchplate can be rotated like a knob, or placed in a specific orientation, to provide input.

⁴ <http://www.pixelsense.com>

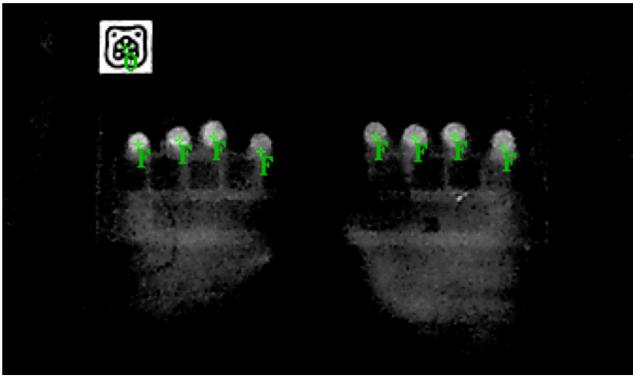


Figure 3. QWERTY keyboard touchplate, constructed from clear acrylic plastic, as seen by the camera on an infrared-based diffused illumination (DI) touch table. The overlay body is mostly invisible to the camera, while the visual tag and touches are correctly detected.

- **Place and remove.** The user may place a touchplate on the screen, or remove an existing touchplate, to change application modes or provide input.
- **Flip.** By placing a visual tag on each side of a touchplate, the system can identify which side of the touchplate has been placed down. Users can then flip the touchplate to see alternate information or enable different interaction modes.

3.3 Touchplates Starter Kit

In order to explore the possibilities of touchplates for augmenting interaction with touch screens, we developed a set of demonstration touchplates that support the exploration of a variety of interactions. We imagine that such a starter kit might become standard issue, such that the hardware templates are distributed alongside commercial touch screen systems. Alternatively, SVG files of the starter kit could be packaged with software, and could be fabricated on-demand by users via a home 3D printer or 3D printing service. Our starter kit of touchplates is illustrated in Figure 4:

- QWERTY keyboard.** A laptop-sized keyboard. Keys may be cut out of the touchplate body, or may be marked with tactile features in the case of a transparent touchplate.
- Numeric keypad.** Similar to the QWERTY keyboard, but designed to mimic a traditional numeric keypad.
- Menu bar.** A notched, ruler-shaped overlay. May be used to retrieve a system menu by touching over or along the touchplate, with each notch corresponding to a menu item.
- Ring.** A hollow, ring-shaped overlay. May be used to adjust

parameters by touching on or around the ring, and to confirm a parameter by touching inside. May also be rotated like a knob.

- Window.** A hollow, window-shaped overlay. Primarily used to provide an alternative view of the touch screen. May be flipped over to present an additional view.
- Mouse.** May be slid across the surface like a mouse. Provides two button-shaped cut-outs for alternate selection.
- Map.** An example of a domain-specific tactile graphic cutout. Such cutouts might be fabricated and used as needed.
- Tokens.** These overlays provide no interactive cut-outs, but each has a unique shape. May be used by placing the token on screen, rotating the token, or touching around the token.

4. FORMATIVE EVALUATION

To explore the potential uses of touchplates, and to identify usability issues surrounding them, we conducted a formative evaluation of our touchplates prototype application with 9 adults with visual impairments.

4.1 Participants

We recruited 9 participants (4 female, average age 50.9, range 39 to 74) with the assistance of a recruiting agency. Of these participants, 5 were blind or had light perception only, while 4 had some level of impaired vision. Five participants used a screen reader exclusively when using a computer, 1 participant used only a magnifier, and 3 used some combination of screen readers and magnification. Seven participants used a touch screen-based smartphone. All participants stated that they had some ability to touch type, while 7 had some ability to read Braille. Five of our participants came from technical occupations (4 engineers and 1 computer instructor), and were generally comfortable with computer technology.

4.2 Apparatus

Participants tested each of the starter touchplates shown in Figure 4. The touchplate SVG files were designed in Adobe Illustrator, and were cut from clear 0.125-inch acrylic plastic on a VersaLaser laser cutter. Microsoft PixelSense byte tags were printed using a laser printer and adhesive paper, and were attached directly to the touchplates. To stop some of the touchplates from sliding on the surface of the PixelSense, we applied double-sided tape to sections of the touchplates to increase friction.

We used the Microsoft SUR40 PixelSense as an interactive tabletop. The PixelSense table has a 40-inch diagonal touch screen, and uses infrared imaging sensors to detect touches and visual tags. Participants used the touchplates to interact with a custom map application, which we created in C#. The map

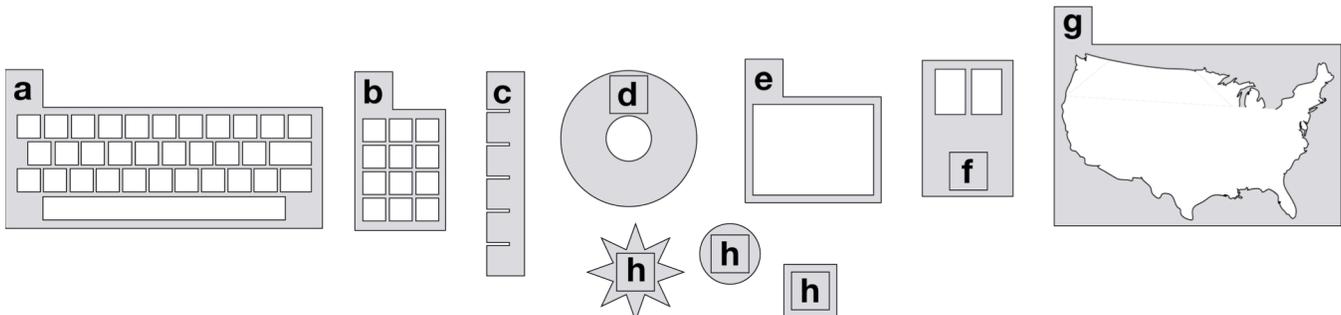


Figure 4. Our starter kit of touchplates: (a) QWERTY keyboard; (b) Numeric keypad; (c) Menu bar; (d) Ring; (e) Window; (f) Mouse; (g) Map cutout (showing a map of the United States); (h) Shape tokens.

application was similar to the application used in Access Overlays [15]. The map presented a view of a city, with several “hotspot” locations. Touching the locations, or activating them using touchplates, spoke their name. In addition, this application supported tracking the touchplates and recording a log of all touchplates and touch interactions with the system. Figure 5 shows a participant using touchplates during the study.

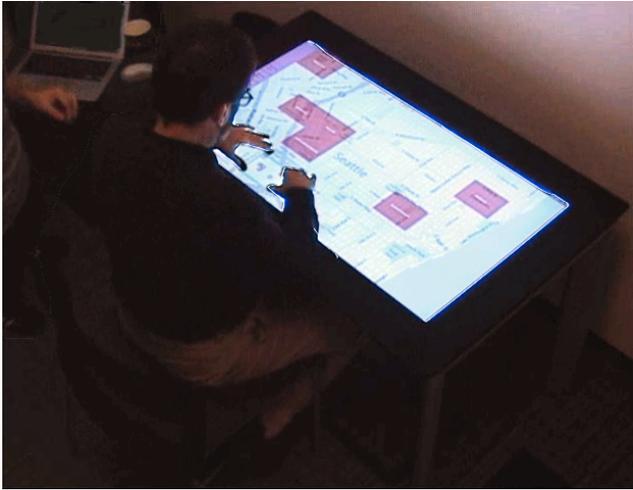


Figure 5. Study participant using a *Window* touchplate to explore an alternate view of a map application on the Microsoft PixelSense tabletop.

Each of the touchplates we tested was mapped to one or more functions for exploring the map. These mappings were not intended to represent a finalized application, but instead to provide the participant with an opportunity to explore the various shapes and sizes of the touchplates, and to explore the affordances and interaction modes of the touchplates. The following mappings were used:

- (a) **QWERTY keyboard.** The keyboard could be used to enter text, including city names, to re-center the map accordingly.
- (b) **Numeric keypad.** The numeric keypad was used to punch in numbers, such as specific ZIP postal codes.
- (c) **Menu bar.** Touching areas of the menu bar set the volume of the speech synthesizer.
- (d) **Ring.** The ring touchplate was used as an alternate control for selecting volume. Tracing a finger clockwise around the ring, or on top of the ring, raised the volume, while tracing counterclockwise lowered the volume. Flipping the ring onto its opposite side allowed the user to control speech volume by rotating the ring itself clockwise or counterclockwise, much like a volume knob.
- (e) **Window.** The window presented a “world-in-miniature” view of the entire screen. Touching the area within the window that corresponded to a hotspot would read out the name of that location. Flipping the window on the other side activated a high-verbosity mode: touching a location read its name and full address.
- (f) **Mouse.** The user could slide the mouse over the touch screen surface. When the user moved the mouse over a location, the system spoke the location’s name. Tapping the left button cut-out prompted further spoken detail about the location (its name and full address). Tapping the right button cut-out provided simulated walking directions to a location.

(g) **Map.** The U.S. Map was presented as an example of a specific tactile graphic that might be created by an end user. Touching inside the map revealed the names of the states being touched.

(h) **Tokens.** Participants tested several shape tokens (circle, rounded rectangle, square, octagon, star). Each token was pre-assigned to a saved map location. Placing a token on the touch screen caused the map to snap to the saved location.

4.3 Procedure

Given that the fundamental interactions surrounding touchplates were new to our participants, our study focused on an exploratory usability observation of how touchplates were manipulated, interpreted, and utilized. In particular, we were interested in which touchplates (and modes of interaction) were enjoyed by participants, and what usability challenges participants encountered using our starter kit.

Each participant tried each touchplate on the custom map application. Each participant was given between 5 and 10 minutes to test each touchplate, and was encouraged to think aloud throughout the study. Initially, we intended to give each participant a set of fixed tasks to perform with each touchplate. However, we found during pilot testing that participants became quite engaged in exploring touchplates on their own, and thus we allowed participants to explore freely, and provided example tasks to perform if requested, or if participants seemed to disengage.

For each study task, participants tested both the touchplate and an equivalent touch screen-only interface. For the QWERTY keyboard, numeric keypad, window, and map, participants used both touchplates and an on-screen version. For the mouse, participants explored the map using multi-finger gestures instead of pressing the virtual mouse buttons. For the volume setting (provided by the menu bar and ring touchplates) and location saving (provided by the token touchplates), participants used an on-screen menu along the left edge of the screen. As these alternatives were not extensively usability tested, the comparison between touchplates and gesture interactions were not meant to be definitive, but were instead intended to provide reference interactions to enable participants to better articulate the differences between touchplates and the more common gesture-based interaction styles.

All participants tested the touchplates in the same order. Participants first experienced the touchplate interactions, and then the comparable gesture-based interactions. Touchplates were presented in the following order: *numeric keypad, menu bar, ring, window, map, mouse, tokens, QWERTY keyboard*. This order was chosen so that participants started with more familiar shapes, such as the numeric keypad, followed by more novel user interface controls. At each step, participants were shown how to use the touchplate or gesture and given several minutes to explore the test application. The experimenter provided the participant with tasks to perform if requested, or if the participant seemed confused.

After testing each touchplate and the corresponding gesture-based interaction, participants stated which mode of interaction they preferred, and provided informal feedback about their experience. At the end of the study session, participants rated their overall experience using touchplates and provided general feedback about using touchplates.

5. FINDINGS

5.1 Touchplate Preferences

We asked participants a variety of questions regarding their experience using each of the touchplates.

Preference of touchplates vs. on-screen gestures. For each touchplate, we asked participants whether they preferred the tangible interaction of the touchplate versus the non-touchplate gestural equivalent. Figure 6 shows the number of participants out of 9 who preferred each touchplate to the gesture-based alternative input method. Overall, participants preferred the map and token touchplates the most.

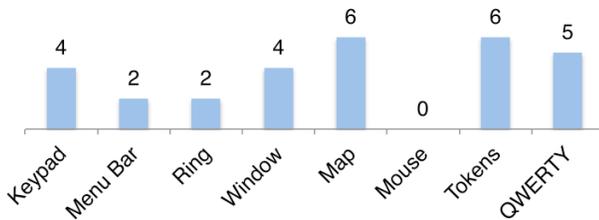


Figure 6. Number of participants (N=9) who preferred each touchplate to the on-screen alternative.

Favorite and least favorite touchplates. Following the study session, we asked participants to list their favorite and least favorite touchplates, and to list any others that they especially liked or disliked. Figure 7 shows the number of participants who made either positive or negative comments about each touchplate. The mouse touchplate received exclusively negative feedback; and several participants disliked the QWERTY keyboard.

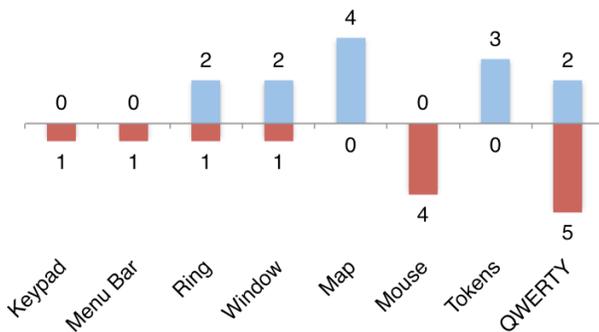


Figure 7. Number of participants (N=9) who stated that they either liked (upward blue) or disliked (downward red) a particular touchplate.

Suggested touchplates. We asked participants to suggest other touchplates that they might like to use. In general, participants did not have many suggestions for devising new touchplates. Two participants suggested additional tactile graphics-style touchplates, including additional maps, and shapes of plants and animals. Two participants suggested alternative user interface widgets: one participant suggested a two-handed split-keyboard overlay, while another participant suggested a two-sided menu, similar to our menu bar, but with a sliding knob, and a zoom magnification control.

5.2 General Feedback

We asked participants what they liked most and disliked most about the set of touchplates that they tested, and requested general feedback on the touchplate starter kit and the touchplates concept.

Benefits. Participants cited several benefits to using touchplates. Three participants noted positively that the touchplate could be

placed anywhere on the display, and that the user interface would move to match the touchplate's position. In the words of one participant, using a template "does anchor me, rather than groping around the screen." Three participants also commented positively about how touchplates provide tangible edges. One participant noted that the touchplates "give high confidence that I'm not accidentally going to activate something." Two participants commented positively about the possibility that touchplates could provide a uniform interaction experience across devices, if they were usable on multiple touch-based devices. In the words of another participant, "When you have something that you can depend upon, and you know how to use, life is much easier, especially when you come to new screens." Participants were also quite excited about the ability to use touchplates as interactive tactile graphics, especially in educational settings. One participant stated, "I could have used this [map] in school, let me tell you!"

Concerns. Participants did express some concerns about using touchplates in the real world, especially about the reliability and availability of touchplates. Some participants were concerned about having to carry around a set of physical objects for using screens, or about the possibility that the touchplates would be lost or broken. One participant stated, "Having to keep track of the little physical overlays... that's just one more thing to go wrong." When we suggested that touchplates might be made available at public touch screens, some participants seemed unwilling to trust that touchplates would be available in a public setting.

5.3 Observed Usability Challenges

We observed several usability issues when participants used the current touchplate designs.

Material friction. The acrylic plastic used to create the touchplates was quite slippery on the touch surface. Participants often felt the need to use a second hand to keep the touchplate still while interacting with it (Figure 8). Our very first prototypes, prior to our study, were developed on a different surface with higher friction than the Microsoft PixelSense, and did not slip as much. Thus, we did not anticipate that participants would grip the touchplates as they sometimes did, and these grips sometimes caused false touch events.

Bimanual interaction. Beyond gripping the touchplate to steady it, several participants expressed interest in using both hands to explore the touch screen. As with most current accessible touch screen interfaces, our system is optimized to support interaction with a single hand, but our participants wished to use both hands to explore the touch screen, especially on a larger touch screen such as the PixelSense. In considering his desire to interact bimanually on the touch screen, one participant stated, "I feel like I have untapped potential... there's so much more of me that I could be using to get information."

Visual contrast. Although we designed the test application to provide some visual feedback, several low vision participants requested an improved high contrast mode. The touchplates themselves were made of clear plastic, and thus difficult to see. Placing a touchplate on the screen caused the area beneath the touchplate to light up, making it easier to find, but some participants still had difficulty locating the touchplates.

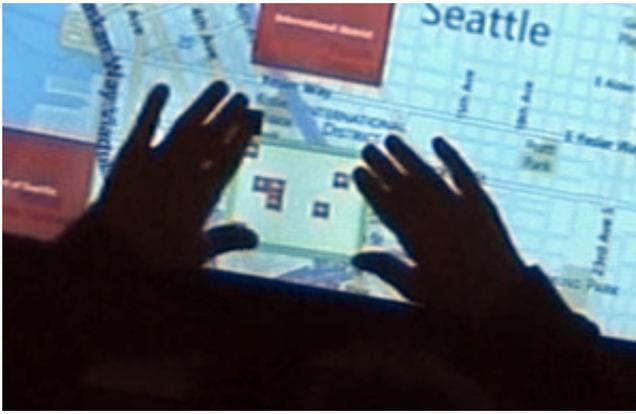


Figure 8. A participant uses both hands to hold a touchplate steady, causing some false touch events.

6. DISCUSSION

Overall, participants were divided in their appraisal of touchplates. Participants were positive about some of the touchplates, such as the map and window touchplates, but were uniformly negative about others, such as the mouse. They were generally open to and interested in interacting with touchplates, but were concerned about losing, breaking, or not having access to touchplates in the “real world.”

While we must consider these results in light of the limited amount of time participants had to try touchplates, our participants’ feedback showed clear trends in preference for certain types of touchplates. Participants were nearly unanimous in liking the tactile map overlay, and expressed interest in using additional overlays of that type. While the map overlay shares many similarities with previous interactive tactile graphics systems, such as the Talking Tactile Tablet [19], their implementation here provides several advantages beyond prior systems—namely the ability to easily create, modify, and fabricate touchplates, as well as the ability to position multiple touchplates in different regions of a touch screen. Participants also liked the token touchplate, and appreciated the ability to bookmark specific areas of the map (and potentially other applications) and return to them later.

Participants also expressed interest in the “world-in-miniature” functionality of the window touchplate, as reaching across the table was sometimes difficult. However, participants were split about whether they preferred this functionality attached to a tangible object, or simply confined to a region of the larger touch screen. Our participants’ feedback suggests that providing multiple simultaneous views to an accessible touch screen application may be extremely valuable, although this feature does not necessarily require tangible interaction.

In general, participants seemed less positive about touchplates that provided alternative input mechanisms, such as the menu bar, ring, and mouse. This attitude seemed strongest among those participants who already owned accessible touch screen-based devices—since they were already able to use a touch screen via gestures, they were not eager to learn new methods of controlling a touch screen. Thus, an input-based touchplate would likely need to provide significant performance benefits for users to adopt it. The QWERTY keyboard touchplate provides a potential example of such a touchplate, as participants acknowledged that existing soft keyboards are quite difficult to use. However, the version of the QWERTY keyboard we tested was not popular with participants. Some participants felt it was too large, while others

felt it was too small, and the transparent material of the keyboard sometimes resulted in false touches being registered. Several participants indicated that they would be interested in a refined, more accurate version of the QWERTY touchplate.

While participants were willing to discuss the benefits and drawbacks of our touchplates, some participants raised concerns about becoming dependent upon touchplates. These participants were concerned that, if touchplates became popular, they would become mandatory for non-visual touch screen use, even if they were originally optional. Participants also expressed the opinion that a truly accessible user interface would use the touch screen alone, and that they would prefer to use the same hardware and interaction methods as sighted users. While we intended touchplates to provide additional usability and feedback beyond what is possible given a purely gesture-driven interface, some participants were concerned that touchplates would become a less desirable and reliable alternative for providing touch screen access to blind users. While we believe that we can address concerns about the availability, reliability, and performance of touchplates in future work, we acknowledge that many blind and visually impaired touch screen users are happy with the status quo of accessible gestures, and we must carefully consider how to introduce new methods for interacting with touch screens.

While not all participants were enthusiastic to adopt touchplates, even some participants who did not wish to use them for themselves noted that they might be useful for other people, such as individuals who have recently lost their vision. One participant stated that he did not wish to be dependent on any additional physical objects in order to use a touch screen, but that “there are blind people for whom [gesture-based touch screen interaction] is so hard that they can’t even get started ... and all of these physical kinds of things are probably very meaningful to them.” This suggests the possibility that touchplates may be optimally used as a training tool for individuals who are learning to use touch screens, or people who have recently lost their vision.

7. FUTURE WORK

We envision several possibilities for future development and refinement of touchplates. Perhaps the most obvious next step is to extend interactions beyond a single touchplate to enable bimanual use. Several of our participants attempted to use the existing touchplates with two hands, which sometimes caused problems with our current touch-tracking system. Supporting bimanual interaction using the kinematic chain [10] could provide new opportunities for interaction. Another possibility is to allow participants to interact bimanually with multiple touchplates at once. Participants could place multiple touchplates on the touch screen and use them to delineate a personal workspace, or to quickly switch between application contexts.

We designed touchplates to be easy to design, fabricate, and modify. However, there are multiple opportunities to extend the physical design of touchplates. For example, we found that touchplates were sometimes slippery on the touch screen device used in our study. As touchplates may be used on multiple touch screen devices, it is important to identify materials that will sit comfortably on a variety of touch screen surfaces. Furthermore, the current implementation of touchplates requires the touch screen to track a visual tag, which cannot be accomplished with current capacitive touch screens. Future touchplates could be made of conductive materials, such as conductive 3D-printed plastic [17], to enable interaction with capacitive touch screens. Finally, the current set of touchplates is made up primarily of flat, passive pieces of plastic. We could use more advanced fabrication

techniques to create more complex touchplates, such as a keyboard with moving mechanical keys.

The portability of touchplates was a major concern among our study participants. Participants were clear that they did not wish to carry around a set of accessories for any touch screen that they might encounter. We might address the portability issue by creating smaller touchplates, or by creating touchplates that may be folded or rolled up. Another option would be to create ad-hoc touchplates using “found” objects; for example, a user might place her credit card on the surface and use the physical affordances of the card in a manner similar to our custom touchplates, such as tracing along the card’s edges to explore menu options.

8. CONCLUSION

Although there is hope that future touch screen technology will provide improved haptic feedback, most current touch screens provide extremely limited haptic feedback. Touchplates provide a promising solution for increasing haptic feedback on today’s touch screens. Touchplates are inexpensive to manufacture, easy to modify, and can provide multiple forms of passive haptic feedback. Given the ease of creating, modifying, and using touchplates, we envision a future in which a standard set of touchplates are readily available, and custom touchplates can be easily fabricated as needed. Furthermore, the addition of inexpensive, easily modifiable tactile feedback for existing touch screens may provide accessibility benefits for older users, users with motor impairments, or other touch screen users.

9. REFERENCES

- [1] Arya, S., Kalia, A., Pant, K. and Sood, S. Low vision devices, *Nepalese Journal of Ophthalmology*, 2, 1 (2010), 74–77.
- [2] Bau, O., Poupyrev, I., Israr, A. and Harrison, C. TeslaTouch: electrovibration for touch surfaces. *Proc. UIST '10*, ACM Press, 2010, 283–292.
- [3] Bier, E.A., Stone, M.C., Pier, K., Buxton, W. and DeRose, T.D. Toolglass and magic lenses: the see-through interface. *Proc. SIGGRAPH '93*, ACM Press, 1993, 73–80.
- [4] Bonner, M., Brudvik, J., Abowd, G. and Edwards, W.K. No-Look Notes: Accessible eyes-free multi-touch text entry. *Proc. Pervasive '10*, ACM Press, 2010, 409–427.
- [5] Buxton, W., Foulds, R., Rosen, M., Scadden, L. and Shein, F. Human interface design and the handicapped user, *SIGCHI Bulletin*, 17, 4 (1986), 291–297.
- [6] Buxton, W., Hill, R. and Rowley, P. Issues and techniques in touch-sensitive tablet input. *ACM*, 1985, 215–224.
- [7] Frey, B., Southern, C. and Romero, M. Brailletouch: mobile texting for the visually impaired. *Proc. UAHCI '11*, Springer-Verlag, 2011, 19–25.
- [8] Goncu, C. and Marriott, K. GraVVITAS: generic multi-touch presentation of accessible graphics. *Proc. INTERACT '11*, Springer-Verlag, 2011, 30–48.
- [9] Guerreiro, T., Lagoa, P., Nicolau, H., Gonalves, D. and Jorge, J. From tapping to touching: making touch screens accessible to blind users, *IEEE Multimedia*, 15, 4 (2008), 48–50.
- [10] Guiard, Y. Asymmetric division of labor in human skilled bimanual action: The kinematic chain as a model, *Journal of Motor Behavior*, 19, 4 (1987), 486–517.
- [11] Hartmann, B., Morris, M.R., Benko, H. and Wilson, A.D. Augmenting interactive tables with mice & keyboards. *Proc. UIST '09*, ACM Press, 2009, 149–152.
- [12] Jansen, Y., Karrer, T. and Borchers, J. MudPad: tactile feedback and haptic texture overlay for touch surfaces. *Proc. ITS '10*, ACM Press, 2010, 11–14.
- [13] Kane, S.K., Bigham, J.P. and Wobbrock, J.O. Slide Rule: Making mobile touch screens accessible to blind people using multi-touch interaction techniques. *Proc. ASSETS '08*, ACM Press, 2008, 73–80.
- [14] Kane, S.K., Jayant, C., Wobbrock, J.O. and Ladner, R.E. Freedom to roam: a study of mobile device adoption and accessibility for people with visual and motor disabilities. *ACM Press*, 2009, 115–122.
- [15] Kane, S.K., Morris, M.R., Perkins, A.Z., Wigdor, D., Ladner, R.E. and Wobbrock, J.O. Access Overlays: Improving non-visual access to large touch screens for blind users. *Proc. UIST '11*, ACM Press, 2011, 273–282.
- [16] Kincaid, R.. Tactile guides for touch screen controls. *Proc. BCS-HCI'12*, British Computer Society, 339-344.
- [17] Leigh, S.J., Bradley, R.J., Pursell, C.P., Billson, D.R., and Hutchins, D.A. 2012. A simple, low-cost conductive composite material for 3d printing of electronic sensors. *PLoS ONE* 7(11): e49365.
- [18] Kornowski, L. 2012. How the blind are reinventing the iPhone. *The Atlantic*.
- [19] Landau, S. and Wells, L. Merging tactile sensory input and audio data by means of the Talking Tactile Tablet. *Proc. Eurohaptics '03*, IEEE, 2003, 414–418.
- [20] McGookin, D., Brewster, S. and Jiang, W. Investigating touchscreen accessibility for people with visual impairments. *Proc. NordiCHI '08*, ACM Press, 2008, 298–307.
- [21] Poupyrev, I. and Maruyama, S. Tactile interfaces for small touch screens. *Proc. UIST '03*, ACM Press, 2003, 217–220.
- [22] Schmalstieg, D., Encarnação, L.M. and Szalavári, Z. Using transparent props for interaction with the virtual table. *Proc. SI3D '99*, ACM Press, 1999, 147–153.
- [23] Shneiderman, B. Touch screens now offer compelling uses, *IEEE Software*, 8, 2 (1991), 93–94, 107.
- [24] Ullmer, B. and Ishii, H. The metaDESK. *Proc. UIST '97*, ACM Press, 1997, 223–232.
- [25] Vanderheiden, G.C. Use of audio-haptic interface techniques to allow nonvisual access to touchscreen appliances, *Human Factors and Ergonomics Society Annual Meeting Proceedings*, 40, (1996), 1266.
- [26] Weiss, M., Schwarz, F., Jakubowski, S. and Borchers, J. Madgets: actuating widgets on interactive tabletops. *Proc. UIST '10*, ACM Press, 2010, 293–302.
- [27] Weiss, M., Wacharamanotham, C., Voelker, S. and Borchers, J. FingerFlux: near-surface haptic feedback on tabletops. *Proc. UIST '11*, ACM Press, 2011, 615–620.
- [28] Weiss, M., Wagner, J., Jansen, Y., Jennings, R., Khoshabeh, R., Hollan, J.D. and Borchers, J. SLAP Widgets: bridging the gap between virtual and physical controls on tabletops. *ACM Press*, 2009, 481–490.
- [29] Xu, C., Israr, A., Poupyrev, I., Bau, O. and Harrison, C. Tactile display for the visually impaired using TeslaTouch. *Proc. CHI EA '11*, ACM Press, 2011, 317–322.
- [30] Yu, N.-H., Tsai, S.-S., Hsiao, I.-C., Tsai, D.-J., Lee, M.-H., Chen, M.Y. and Hung, Y.-P. Clip-on gadgets: expanding multi-touch interaction area with unpowered tactile controls. *Proc. UIST '11*, ACM Press, 2011, 367–372.