T-Bars: Towards Tactile User Interfaces for Mobile Touchscreens

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ABSTRACT
Mobile device user interface elements tend to be based on desktop widgets that were not originally intended for small screen finger-based interfaces. Mobile usage scenarios afford many completely different interactions, so should be designed accordingly. This paper presents a new type of widget, the T-Bar, designed specifically for finger-based touchscreen interfaces using tactile feedback. Using the tactile feedback for orientation, the user's fingertip is guided along the T-Bar until an item is successfully selected. This paper offers observations on our finger-based touchscreen widget and two applications of the T-Bar widget. Both, *File-o-Feel* and *Touch 'n' Twist* are multi-touch information browsing applications that deviate from traditional desktop GUI paradigms and are tailored for fingertip input where all interaction takes place through the use of T-Bars; eliminating the need for any other widgets.

Categories and Subject Descriptors
H.5.2. [**User Interfaces**]: Haptic I/O

General Terms
User interface design.

Keywords
Mobile phone, touch screen, tactile, widgets, multi-touch.

1. INTRODUCTION
Touchscreen mobile devices often use cut-down versions of desktop user interfaces that may prove awkward to use in mobile settings. These mobile UIs are based on mouse pointer-based input designs, with a stylus replacing the mouse. For example, there are normally scroll bars on the right hand side of windows, rectangular buttons, and check boxes. However, styli were intended for high precision applications such as free-hand drawing. These UI widgets are so small that extreme accuracy is necessary with the stylus and a steady hand is essential, making mobile use very difficult in everyday situations, such as walking along a street or travelling on a bus.

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In contrast, some more recent touchscreen mobile devices, such as Apple's iPhone (www.apple.com/iphone), feature interfaces designed specifically for finger input. The iPhone has a large touchscreen and its touch detection system can differentiate between scrolling gestures and selection taps on the same area of screen space, for example a screen can be scrolled even if the initial touch is on a button. Thus, accidental touches do not necessarily lead to selection errors, and interaction with the device does not require delicate handling or excessive accuracy. This 'fingers-on' approach works well to alleviate inaccuracies and frustrations with input when mobile; a sharp contrast to the fiddly point and tap stylus methods.

Touchscreens on mobile devices are advantageous in that each application's input can be customised, and use of screen space is more flexible. Furthermore, the screen can be much bigger since a physical keyboard is no longer required. Although styli are awkward and finger input may be more suitable, without tactile feedback from on-screen buttons, typing errors still occur more often than when using physical keyboards [5]. Since fingers are relatively large they may obscure the interface, making traditional visual feedback like button-pressed effects hard to see. This further strengthens the need for alternative forms of feedback on such devices. Whilst tactile touchscreen technologies exist, there is little research into tactile interface designs. Currently, many available devices support tactile feedback through the use of standard built-in vibrotactile actuators. These may be leveraged to provide user feedback; not just to enhance traditional widgets but to enable new types of widgets to be created.

In this paper we offer a novel user interface design for touchscreen mobile devices. We employ this 'fingers-on' approach with vibrotactile feedback to allow users to feel the interface, or even touch it accidentally, without causing erroneous selections and to reduce the load on the visual modality. The paper describes the T-Bar, a tactile finger-based interface widget designed to replace traditional GUI buttons on mobile touchscreen devices. We then examine two applications of the T-Bar, along with initial findings from pilot studies.

2. RELATED WORK
Despite the benefits of fingertip interactions, there are still issues relating to the use of a finger rather than a stylus that can lead to problems. Although audio feedback is sometimes utilised, it can be socially inappropriate in situations such as meetings and lectures or can go unnoticed in noisy environments like factories or concerts. Consequently, in many cases, the major feedback provided by the touchscreen is via the visual modality. Unfortunately, as mentioned, when pressing small buttons with a fingertip, the button is occluded, resulting in obscured visual feedback. Vogel and Baudisch have investigated this issue with

the ‘Shift’ technique [10]. In Shift a callout is created to show a copy of the occluded screen area, such as the button, and this copy is displayed on a non-occluded area of the screen. This method has been shown to be effective when working with map icons or for text cursor movement; a similar technique is already present on the standard iPhone keyboard. However, in some cases there may not be additional screen space to display the copy, other areas of the screen can become obscured instead, and it may feel unnatural to receive dislocated visual confirmation of successful touch input. Furthermore, this solution is simply an addition to traditional mobile interfaces based on desktop designs. The novel opportunities provided by fingertip interaction are not exploited. Instead of augmenting desktop widgets in this manner, designers now have the opportunity to create completely new types of widgets for use with the fingertip.

A key feature lost when the physical keyboard is removed from a mobile device is the ability to run one’s fingers over the device and physically feel the buttons. Whilst traditional keyboards provide a natural haptic response, there has been recent research on emulating this response with the addition of tactile feedback to touchscreen buttons [8] [2]. Hoggan *et. al.* [5] showed that tactile feedback can reduce errors and increase speed when typing on a mobile touchscreen. In this case, the most effective tactile feedback came from multiple specialist actuators attached to a PDA providing short localised pulses on button clicks and slips, allowing users to feel the edges of the buttons. Given that tactile feedback can improve interaction with common desktop-style buttons, perhaps tactile feedback could also be effective during interaction with other widgets.

Several research projects focus on the addition of tactile feedback to other types of UI widget [6] [4], showing that using the sense of touch can improve the usability of many types of widget. Most research is conducted using vibrotactile actuators built in to the mobile devices; however, lateral skin stretch displays [7] and piezo-electric actuators are also becoming important research platforms. Kaaresoja *et. al.* [6] created applications of tactile feedback for touchscreen using ‘Snap Crackle Pop’ with piezo-electric actuators that can provide localised feedback underneath the fingertip. The applications included text selection, scrolling, and drag and drop tactile widgets. However, the widgets investigated were mainly aimed at stylus as opposed to fingertip interaction. More importantly, the widgets in these research projects all originate from desktop designs.

Other forms of tactile feedback have also been investigated for use with mobile touchscreen devices. Moving away from widgets, Poupyrev [9] and Williamson *et. al* [11] have examined the use of tactile feedback for ambient information. By adding tactile feedback to gesture control, users can ‘feel’ how the information moves inside devices. Unlike previous research that focuses on tactile feedback for traditional interfaces, this is an example of an interaction technique specifically aimed at mobile touchscreens.

The work described in this paper was conducted to address the different interaction possibilities afforded by touchscreens in dynamic mobile environments. The aim of this research being to move away from conventional desktop designs and incorporate tactile feedback as a third dimension in touchscreen displays in order to fully accommodate the use of fingertips.

3. T-BAR INTERFACE WIDGETS

T-Bars are user interface widgets that take on the role of buttons, named as such because they are both tactile and have a visual representation shaped like the letter T, shown in a horizontal layout in Figure 1. Based on Poupyrev’s finding [9] that tactile feedback is most useful when used to enhance gestural interactions, we have designed an element where the fingertip is used to slide and activate, using tactile feedback to guide the user to a successful activation and make adjusting movements along the way. The slide movement is analysed and, if the length of the slide is above the threshold and the fingertip touches the top of the T-Bar, an activation event is triggered.

When touched, the length of the T-Bar feels like a round pipe. This sensation is created be leveraging a gradient of actuator intensities. Humans can discriminate a vast range of intensities of tactile stimulus. For example, given appropriate conditions, the palm of a hand can feel vibratory stimulus with an amplitude as low as 0.2 microns [3]. On a touchscreen mobile device with a 480x680 3.5” display, the T-Bar used is 30 pixels wide. Depending on which pixel row of the bar is touched, different levels of intensities are felt (created using different amplitude levels). Using an accelerometer board, the frequency and amplitude levels of the iPhone’s built-in vibrotactile actuator were measured showing a resonant frequency of 140Hz. Whilst the actuator has an intensity range on average of 0 - 6.5 microns, pilot studies have indicated that only levels above 1.5 microns are easily perceived in mobile situations, and differences in 0.3 microns can be distinguished easily. Therefore, the first five pixels of the bar have an intensity range of 4 - 6.5 microns using 0.5 micron increments, and the subsequent five are the same in reverse order (Figure 1). This configuration gives the bar a detectable bump, simulating a rounded pipe. Through the inclusion of tactile feedback, users can detect the bars and ‘feel’ their way along them. Changes in intensity of the tactile feedback allows users to detect when the fingertip begins to veer away from the bar, enabling them to maintain the fingertip’s position on the bar. In the top bar of the ‘T’, intensity ranges are mapped to a pipe perpendicular to the previous, but with a more abrupt bump. This acts as confirmation that the selection has been successful.

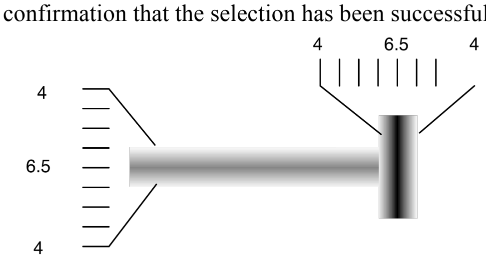

Figure 1: Visual representation of a T-Bar showing variations in tactile feedback intensity.

To activate a bar users must first place one finger on the bar (which can be located visually or by running the finger along the screen feeling the bumps), and then slide along it until the end is reached. The tactile feedback guides users’ fingertip movements, and acknowledges the activation of the bar using a strong bump at the end. If users feel the intensity of the vibration getting weaker whilst sliding, they can make appropriate adjustments to their gesture. For example, if it has become weaker move the finger more towards the direction where it feels stronger.

The T-Bar is also visually informative before and during interaction, with an animation of a glowing light in the direction of the required movement. As the bars will always be wider than the width of fingers, the user can still view large areas of the bar even whilst touching it.

4. T-BAR APPLICATIONS

In order to evaluate the effectiveness of the T-Bar as a new touchscreen user interface widget, two applications that make use of multiple T-Bars were created. Inspired by designs that attempt to deviate from the traditional desktop GUI paradigm, the prototype applications, File-o-Feel and Touch 'n' Twist, are explicitly tailored for mobile devices and fingertip interaction.

4.1 Hardware

There are currently several commercially available touchscreen mobile devices. The T-Bar can be implemented on any mobile touchscreen device incorporating a standard vibrotactile actuator. We decided to implement the T-Bar on the Apple iPhone because it has a large screen allowing large sliding gestures, a standard vibration unit and multi-touch capabilities. As T-Bars have been designed for touch interfaces and these increasingly support multi-touch functionality, both example T-Bar applications allow users to simultaneously use multiple fingers, rather than just one.

4.2 File-o-Feel

File-o-Feel is a prototype T-Bar list interface based on the traditional file-o-fax/rolodex concept of a scrollable tab-divided collection of information. Most mobile UIs present catalogues of information in large scrollable lists; if there is a large amount of content to be displayed in the list, each index heading can be extremely small and difficult to select with the fingertip. Furthermore, the finger may cover the index text, making rapid lookup difficult or impossible. This type of interface was chosen because it is typical of many mobile applications containing lists of items; for example, lists of songs in music players, emails in mail applications and contacts in address books. File-o-Feel (Figure 2) is designed to utilise a vertical row of T-Bars. The horizontal edges of a vertical list of items can be felt, and by sliding along the edge the item may be opened to fill the display.

Earlier work by Cockburn and Brewster [1] on menu-selection tasks with tactile feedback showed that excessive feedback or 'noise' can damage interaction by interfering with the acquisition of neighbouring targets and the results suggest that each item in the menu should be more than 7 pixels apart. Therefore, in File-o-Feel, a 60 pixel gap has been included between each T-Bar.

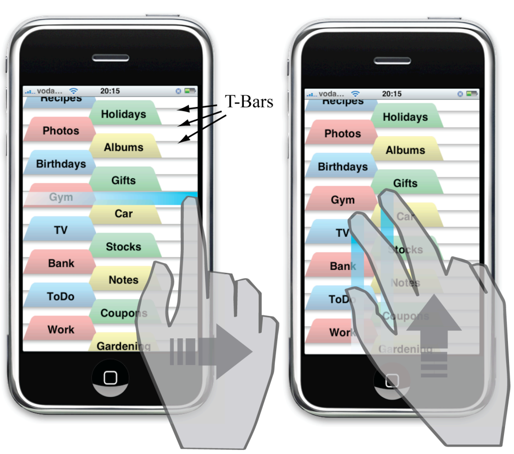

Figure 2: Left hand side shows File-o-Feel interface with T-Bar rows and left-to-right gesture. Right hand side shows two-finger gesture required to scroll through the list.

Through multi-touch, File-o-Feel can operate in two different modes, selection mode and scrolling mode. Scrolling mode is activated when the user places two fingers on the screen. File-o-Feel allows users to quickly scroll through the list of information using two fingers, whilst 'feeling' and interacting with the T-Bars can be accomplished with one finger in selection mode. This technique eliminates the need for traditional scrollbars, whilst continuing to support the requirement for lists longer than the height of the screen, and also preventing problems that can occur with touchscreen lists when users intends to scroll but their touch triggers a selection event instead. In File-o-Feel the user can touch anywhere on the list whilst using two fingers without selecting anything, because 'feel' or selection mode is disabled. Then, using one finger, users can slide along the T-Bar of the item they wish to select. Here they will feel another tactile bump to indicate that the item has been selected successfully. Whilst traditional UIs have the concept of focus we deliberately ignore it. For example, if a button is pressed in a traditional interface only that button can receive movement events until the press is released once more. The concept of focus is not used in our interface so that users may begin by selecting one item via its T-Bar and then move their finger to another T-Bar, without lifting it off the display.

4.3 Touch 'n' Twist

To explore the wide design space for tactile displays using T-Bars, our second example interaction, Touch 'n' Twist, is based on a baggage carousel concept, where items enter and leave the screen like a conveyor belt. It applies T-Bars to a semi-circular display with corresponding icons for each item at the end of each T-Bar (Figure 3). The Touch 'n' Twist interface is used to display an application launcher that can be used as a convenient access point for mobile device application software, such as Internet browsers, email applications, phone books and messengers.

Once again, Touch 'n' Twist operates in two modes, scrolling mode and selection mode. When two fingers are applied to the display, scrolling mode is activated and the circular display of applications can be rotated. Selection mode is activated when one finger touches the display, allowing users to run a finger along the T-Bar attached the application they wish to launch. As the user does this, the changes in intensity can be felt as the fingertip moves over the bar until the end is reached, then a tactile click is presented indicating that the application has been selected.

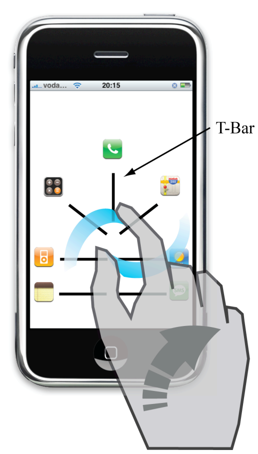

Figure 3: The Twist 'n' Touch interface with rows of T-Bars at angles on a carousel used with a twist pinch gesture to rotate through T-Bar items.

Twist 'n' Touch is not restricted to functioning solely as an application launcher, any piece of information could be attached to the circle of T-Bars. The purpose of this example was to examine the use of a circular interface and users' abilities to use T-Bars at different orientations e.g. on diagonal trajectories.

5. INITIAL EVALUATIONS

Initial pilot evaluations with six experienced touchscreen mobile device users have yielded interesting results. Users appeared to grasp the concept of T-Bars quickly, and found the swiping gesture to be simple to achieve after some practice. Every user commented that the tactile feedback on the T-Bars enabled them to keep their fingers on the line more easily. However, the changes in intensity across the T-Bar were not as easily distinguished as we had hoped. Four of the six users did not notice any intensity changes, suggesting that a greater difference is needed to create the illusion of a rounded bar. For example, 1.5 to 6.5 microns instead of 4 to 6.5 microns, with intervals of 1 micron. Furthermore, the 'click' at the end of the T-Bar should occur earlier, further away from the edge of the screen, as many users had lifted their fingers off the screen during their swipe gesture before reaching the absolute edge. This suggests that the T-Bar needs to be moved further from the edge of the screen, or the tail of the 'T' should be made shorter.

In File-o-Feel it took an average of two attempts for users to establish the multi-touch technique for scrolling the list and the single touch for T-Bars. Some users commented that the two-column list was unusual and that the inner column labels were covering the outer item T-Bars. However, we adjusted the code so that the T-Bar for inner items could still be felt. It is placed transparently on top of labels so the visual display is not obscured. Users commented that "it feels as though I am flicking through files with my fingers like in a normal filing cabinet", although some said "I sometimes forget to switch from two fingers to one" indicating that some sort of reminder or hint, perhaps graphical, is required to inform users that multi-touch is available.

Twist 'n' Touch users were not accustomed to making diagonal swiping gestures but soon grasped the concept. Some of the comments included "I feel like I can start anywhere on the screen and still manage to select the correct item by feeling around the display", "the T-Bar means I don't have to be so accurate with my target selection, so long as I eventually feel the line, I can select the item I need" and "I found myself using the visual display at first to help locate the T-Bars and then I could look away from the screen and just wait to feel the big vibrating click to let me know I had selected an item". This indicates that less visual attention may be required from mobile users when using T-Bars.

6. CONCLUSION

To summarise, T-Bars are finger-based touchscreen widgets designed to replace traditional GUI buttons. Changes in intensity of tactile feedback along the T-Bar create the sensation of a rounded shape and help to guide the user's finger along the bar as an item is selected. T-Bars take advantage of the new interaction opportunities made possible by touchscreen displays and are designed to enhance mobile interfaces by eliminating occlusion issues, making full use of the available screen space and reducing the load placed on the visual modality. T-Bars have the potential to be integrated into numerous finger-based interfaces and can be created using the standard, built-in vibration motors commonly found in commercially available mobile devices.

The two interfaces discussed – File-o-Feel and Touch 'n' Twist – highlight the versatility of the T-Bar widget and that T-Bars can be included in many different finger-based applications. Furthermore, both interfaces exploit the capabilities of touchscreen devices and fingertip interaction without relying on traditional desktop concepts.

Given the promising outcomes from the pilot studies, the next stage of this research will involve a full-scale quantitative study to evaluate T-Bars in lab and mobile settings. In addition, we plan to investigate an assortment of intensity gradients for T-Bars. For example, cone shaped gradients could perhaps be used to inform users of the distance remaining before an item is selected. We also encourage those interested to try the interactions and give feedback on our open-source iPhone haptic prototypes, through the project website (http://iphone-haptics.googlecode.com).

7. ACKNOWLEDGEMENTS

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