Survey of Techniques to Increase Accuracy of Touch Screen Devices

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Abstract- *The objective of this project is to conduct exploratory research into the effort of increasing accurac on touch screen devices. Graphical password schemes have been proposed as a possible alternative to text-based schemes. Human can remember pictures better than text, thus may contribute to a more positive user experience. Graphical password techniques include recall-based click password (e.g. imposing background image so user can click on various locations on the image), and recognize-based selection password (e.g. selecting images or icons from an image pool).*

Keyword: Touch Screen Design, Human Computer Interactions, Touch Screen Device Accuracy

1 Introduction

Touch-Screen interface designs have attracted rising attention in recent years; devices such as ATM (automated teller machines), ticket machine, PDA (personal digital assistant), have been widely used in various occasions. Lately, Touch-Screen devices are technologically becoming more accurate, usable and popular in any size; such as smart phones, or Apple's iPad, iPhone, and iPod touch [1] etc. Media report estimates that Touch-Screen devices will account for more than 80 percent of mobile sales in North America by 2013[2, 3]. The worldwide market for Touch-Screen mobile devices will surpass 362.7 million units in 2010, a 96.8 percent increase from 2009 sales of 184.3 million units, according to Gartner, Inc. By 2013, Touch-Screen mobile devices will account for 58 percent of all mobile device sales worldwide and more than 80 percent in developed markets such as North America and Western Europe. [2] By 2013, Touch-Screen mobile devices will account for 58 percent of all mobile device sales worldwide and more than 80 percent in developed markets such as North America and Western Europe. [3]

One difficulty for interface design on mobile computers is lack of screen space caused by their small size. Small screens can easily become cluttered with information and widgets, which presents a difficult challenge for interface designers. [4] Small displays and multiple inputs require users to select menus and enter data with pinpoint accuracy. These challenges are especially exacerbated when a user is in motion. Human factors researchers propose improving Touch-Screen targets through a variety of design innovations. Areas of inquiry include changing graphical target size and location, employing mathematical models to expand the target area, minimizing errors with target-specific prompts, and basing outputs on gestures and user histories. [5]

This research involves building surveying existing works on improving accuracy for touch screen devices. In addition, we try to gain a more complete understanding on the following:

a. *Approaches of overcoming limitations of a touch screen computer for graphical password designs.*
Touch screens have special limitations such as: user's finger, hand and arm can obscure part of the screen; and the human finger as a pointing device has very low "resolution". It is also difficult to point at targets that are smaller than the users' finger width.
b. *The relationship between the background color, image choice and the accuracy of touch screen devices.*
When properly selected, we expect background image to positively increase the accuracy of touch screen devices. we define the complexity of an image is as a combinational quantitative measure of the number of objects presented, the number of major colors, and the familiarity of the image to users and other factors. Careful selected background images can enhance effective graphical password design

c. *The relationship between different types of gestures and accuracy*
Users can benefit from using different types of gestures for different purposes on touch screen devices. Although a large screen on a PC would provide more pixels, it allows less interactive methods. We anticipate different types of gestures would provide different user experiences, thus provide different types of accuracy.

2 The Survey

Recent work by Diller [5] studied various techniques to improve input areas of touch screen mobile devices; in this work, multiple approaches and studies were discussed. Our work differs from this work by having a more comprehensive discussion and classification of techniques to increase accuracy of touch screen devices. The intention of this work is to provide fellow researchers and practitioners in the field with a more complete guide to achieve more usable touch screen device designs.

In addition to analyzing properties of tabletop displays and summarizing existing text entry methods for tabletop use; Work by Go et al. [6] also proposed a new keyboard design. In addition to the new design, the work primarily discussed touch screen keyboard use for finger typing; the analysis is from five aspects: screen size, touch screen keyboard types, number of keys, typing devices, and technique. Our work will focus more on the precision of Touch-Screen input.

2.1 Touch Screen Precision

The Touch-Screen device size and the Touch-Screen's effective area affect the Touch-Screen keyboard design. The device sizes can be small, medium, or large. Small Touch-Screen devices[7], such as mobile and smart phones, Personal Digital Assistants (PDAs), and handheld computers, have a smaller Touch-Screen area and smaller onscreen objects. Even though manipulations on smaller devices primarily relied on stylus, finger use has become more popular in the research community since Apple's iPhone and iPod touch were released. Medium-size Touch-Screen devices include standard PCs and tablet PCs. Finally, large Touch-Screen devices contain table-top displays, wall-sized displays and projectors [8]. Recently, researchers started to examine text entry specifically for tabletop displays [9].

There are two types of keyboard: soft keyboard and gesture-based keyboard (menu based) [6]. Soft keyboards can have various keyboard layouts; and a gesture-based keyboard allows the user inputting a gesture, drawing a line without lifting up the finger or stylus.

The QWERTY layout is the standard for soft keyboards, but an alphabetical layout is used as a selection keyboard in some cases. These two layouts are suitable for walk-up-and-use scenarios. [9] Two typical cases for the number of keys include alphabetical (full-size) keyboards such as the 101 keyboard for standard PCs and the numerical 10-key pad for mobile phones. [6]

The work by Parhi et al. [7] is presented to determine optimal target sizes for one-handed thumb use of mobile handheld devices equipped with a touch screen using a two phase study. The study primarily focused on small sized screen. Phase 1 of this study is intended to determine size recommendation for widgets used for single-target tasks, such as activating buttons, radio buttons and checkboxes; while phase 2 is trying to evaluate required key sizes for widgets used for text or numeric entry. The study concluded that no key size smaller than 9.6mm would be recommended for serial tapping tasks, such as data or numeric entry. A 9.2 mm target size for discrete tasks would be sufficiently large for one-handed thumb use on touch screen devices.

Investigations by Sears, A., et al. [10] showed the effect keyboard size has on typing speed and error rates for touch screen keyboards using the lift-off strategy. A cursor appeared when users touched the screen and a key was selected when they lifted their finger from the screen. Four keyboard sizes were investigated ranging from 24.6 cm to 6.8 cm wide. Results indicated novice users can type approximately 10 words per minute on smallest keyboard and 20 words per minute on the largest. Experienced users improved to 21 words per minute on smallest keyboard and 32 words per minute.

Work by Colle and Hiszem estimates the smallest key size that would not degrade performance or user satisfaction. The results showed participants entry times were longer and errors were higher for smaller key sizes, but no significant differences were found between key sizes of 20-25mm. participants also preferred 20 mm keys to smaller keys, and they were indifferent between 20 and 25 mm keys. The work concludes a key size of 20 mm was found to be sufficiently large for land-on key entry. [11]

Three experiments conducted by Lee and Zhai focused on the operation of soft buttons (either using a stylus or fingers). The study showed button size affects performance, particularly when buttons are smaller than 10 mm. Styli can more accurately handle smaller buttons and they depend less on synthetic feedback than fingers do, but they can be lost easily and require an acquisition step that bare fingers do not. The two types of touch sensors explored, capacitive and resistive, afford very different behavior but only subtle performance difference. The first can be operated by fingers with very sensitive response, but is more error prone. [12]

Work by Brewster [4] describes a small pilot study and two formal experiments that investigate the usability of sonically-enhanced buttons of different sizes. An experimental interface was created that ran on a 3Com Palm III mobile computer and used a simple calculator-style interface to enter data. The buttons of the calculator were changed in size between 4x4, 8x8 and 16x16 pixels and used a range of different types of sound from basic to complex. Results showed that sounds significantly improved usability for both standard and small button sizes – more data could be entered with sonically-enhanced buttons and subjective workload reduced. More sophisticated sounds that presented more information about the state of the buttons were shown to be more effective than the standard Palm III sounds. The results showed that if sound was added to buttons then they could be reduced in size from 16x16 to 8x8 pixels without much loss in quantitative performance. This reduction in size, however, caused a significant increase in subjective workload. Results also showed that when a mobile device was used in more realistic situation (whilst walking outside) usability was significantly reduced (with increased workload and less data entered) than when used in a usability laboratory. These studies show that sound can be beneficial for usability and that care must be taken to do testing in realistic environments to get a good measure of mobile device usability.

3 Efforts to Improve Touch-Screen Input Precision

3.1 Tactile Feedback

Many researchers have shown the benefits of tactile feedback for touch screen widgets in all metrics: performance, usability and user experience [13-20]. Koskinen et. al, [20] showed people perceive some tactile feedbacks more pleasant than others when virtual buttons are pressed with fingers on a touch screen.

3.2 Add Sound to Improve Precision

The results from Brewster [4] showed that if sound was added to buttons then they could be reduced in size from 16x16 to 8x8 pixels without much loss in quantitative performance. This reduction in size, however, caused a significant increase in subjective workload.
Early portable computers used either a joystick or trackball as the pointing device. This changed in 1994 when Apple Computer, Inc. [1] introduced the PowerBook 500 series of notebook computers, the first commercial computer with a built-in touchpad as a pointing device[21]. Since then, numerous notebook computer manufacturers also adopted this technology. Today, the trackball is all but extinct in notebook computers. Joystick usage is also down, with IBM and Toshiba remaining as the key players. The touchpad is now the predominant pointing technology for notebook computers. [22]

Being direct between control and display, touch screens also have special limitations. First, the user's finger, hand and arm can obscure part of the screen. Second, the human finger as a pointing device has very low "resolution". It is difficult to point at targets that are smaller than the finger width. These limitations have been realized and tackled before, mostly notably by Sears, Shneiderman and colleagues [10, 23]. Their basic technique, called *Take-Off*, provides a cursor above the user's finger tip with a fixed offset when touching the screen. The user drags the cursor to a desired target and lifts the finger (takes off) to select the target objects. They achieved considerable success with this technique for targets between finger size and 4 pixels. For very small targets (1 and 2 pixel targets), however, users tended to make a large amount of errors with *Take-Off*. To handle small targets, Potter and colleagues [24] used techniques relying on the system's knowledge of target locations, which essentially avoided the need of precise pointing. However, there are many situations where the system cannot know what objects are users' targets. Instead of using a bare finger, in some cases the user may use a stylus (pen) to interact with touch screens. A stylus is a much "sharper" pointer than a finger tip, but its resolution may still not be as good as a mouse cursor. Ren and Moriya investigated different strategies for handling small targets and reported that 1.8 mm (5 pixels) was a crucial limit beyond which special needs arise. [25]

This work [25] also proposed several techniques to improve bare hand pointing on touch screens. The goal is to design techniques allowing users to precisely point at single pixels without resolving to zoom. User studies proved "precision-handle" have promising attributes considering speed, accuracy and comfort. "Precision-handle" is done by using a handle with a smaller scaled tip for increased precision. The handle can stretch or shrink as the user manipulates it. [25] The user studies indicate that the bandwidth of the unsupported index finger is approximately 3.0 bits/s while the wrist and forearm have bandwidths of about 4.1 bits/s. [26]

Subjects attempted to recognize simple line drawings of common objects using either touch or vision. [27]
The author proposed three strategies in this paper:
1. land-on: uses initial touch of the touch screen for selection
2. First contact: user makes selections by dragging their fingers to the desired item.
3. take off: when user make contact with the touch screen, a cursor (<+>) will appear to assist the user, after dragging the cursor, when user is satisfied with its placement, they confirm the selection by removing their finger from the touch screen.

User studies showed the take off strategy had a significantly higher rating of satisfaction; it also showed less errors. [24] The work proposed a pointing technique, which is called *Shift* that is designed to address these issues. When the user touches the screen, Shift creates a callout showing a copy of the occluded screen area and places it in a non-occluded location. [28]

The study by Sears et. al [23]explored touch screen keyboards using high precision touch screen strategies. The work demonstrates touch screen keyboards provided slower speed compare to traditional keyboard. Touch-Screen keyboards may be useful when limited text entry is needed or keyboard is awkward. [23]

Many other works[29] also reconfirmed the fat finger problem through user study. The work also presented two devices that exploit the new model in order to improve touch accuracy. RidgePad prototype extracts posture and user ID from the user's fingerprint during each touch interaction. In a user study, it achieved 1.8 times higher accuracy than a simulated capacitive baseline condition. [29]

The work by Karlson et. al [30] involves the study of a new software based interaction technique called "Thumb Space", which provides general one-handed thumb operation of Touch-Screen based mobile devices. The process includes a few major steps:

1. Defining the ThumbSpace, in this phase, user drag the thumb to define a rectangular shape that user will be comfortable with tapping.
2. Guess, aim and lift. The guess phase requires user to make an initial guess about the sub region with his thumb corresponds to the intended target, and touch the sub-region. in the aim phase, user rolls or drags his thumb to make object cursor animate to the closest displace space object. Finally, user confirms the selection by lifting his thumb.
The user studies showed the ThumbSpace design improves accuracy for selecting targets that are out of thumb reach, and makes users as effective at selecting small targets as large targets. [30]

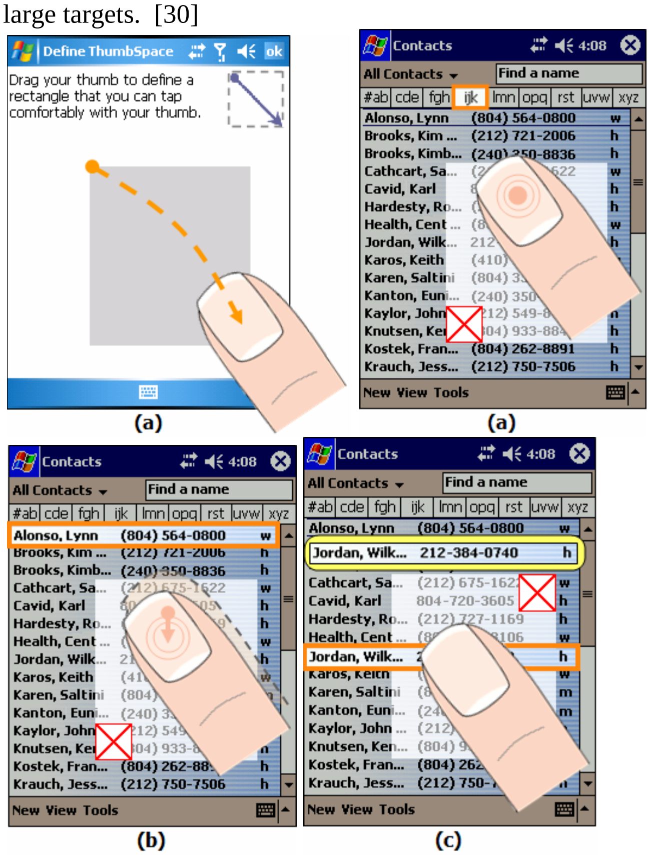

Figure1 : Defining the ThumbSpace. Selecting objects with ThumbSpace. Assuming the user wants to select the first name in the list, he first (a) *guesses* the location of the ThumbSpace proxy for 'Alonso'; (b) the initial ThumbSpace point of contact maps to 'ijk' so the user *aims* for the intended target by dragging his thumb downward. The user confirms the selection by lifting his thumb, or cancels the selection by dragging his thumb to the X before lifting; (c) ThumbSpace occlusion correction. [30]

This user study later conducted about "Thumb Space" [31] was performed on different target size, position and different hand use under walking or standing positions. With a few limitations such as study environment, control of walking pace etc, the conclusions are as follow:
1. Preferred vs. non-preferred hand: about a third of the users sometimes use their non-preferred hand to dial their mobile phones; this finding is different from the use of a mouse, pen or stylus.
2. Standing vs. walking: with limited space of walking (with no real world physical obstacles), the studies suggested walking by itself does not affect performance.
3. Target position and size: the largest target size of 11.5mm in this study generated a 95% accuracy rate. While positions on the left and right edge were not preferred, these provided accuracy rates about 10 percent than those int he middle. Such result confirms that when participants perceived a task to be more difficult and uncomfortable they took longer to thumb tab and were able to be more accurate. [31]

Schildbach and Rukzio [32] used three moderately different target sizes—6.74 mm, 8.18 mm and 9.50 mm in width—per Apple's iPhone Human Interface Guidelines. To extend the real-world environment and determine the impact target size had on cognitive functioning, they asked participants to interact with the device while walking along a pre-determined course. 4 Results showed that increasing target size by up to 40 percent—i.e., from 6.74 x 6.74 mm to 9.5 x 9.5 mm—had a significant impact on decreasing error rates and mitigating the cognitive load demands of walking. Users slowed their normal walking pace when they encountered small targets, and essentially switched focuses from navigating through their environment toward interacting with their Touch-Screen devices. The researchers noted that such a change of attention outside of a controlled experiment might put users at a higher than normal risk for accidents. Therefore, they proposed creating a "walking mode" that presented larger input targets when the user was in motion. Their suggestion attempts to address the balancing act that designers face when trying to optimize a mobile device's Touch-Screen interface: large targets are not always optimal when display space is at a premium, even when they convey significant advantages to users. This complication called for some researchers to investigate mathematical alternatives to interpreting target selection.

Strategy	Details
Land-on 1	Target selected when stylus hits it
Land-on 2	Similar to Land-on 1, but this time the stylus must start outside the target and then move into it
Take-off 1	Target is highlighted when stylus is touching it, selection is made when pen is taken off the target
Take-off 2	Similar to Take-off 1, but the target is selected when the stylus is removed from any point on the screen (either inside or outside the target area)
Space 1	Pen approaches from above, target highlights when stylus is within 1 cm above the target. Selection occurs as soon as the stylus lands on the target
Space 2	Similar to Space 1, except that the selection is made when the pen lands anywhere on the screen (either inside or outside the target area)

Table 1: Selection strategies from Ren *et al.* [33].

In Ren *et al.'s* experiments [34], participants had to select individual targets that appeared in different locations on screen as fast as possible. Their results showed that the Land-on 2 strategy gave the best balance between speed of selection and error rate. This strategy has some problems in real situations as, if there were many targets close together, one might inadvertently select the wrong one by moving over it on the way to the target required. Not all of these strategies are currently implemented on mobile devices (for example, the space strategies relied on an electromagnetic tablet which could sense the stylus when it was above the surface – no current mobile computers work in this way). Many mobile devices implement just the Land-on 1 or Take-off 1 strategies (in the work described below the Take-off 1 strategy was used as the 3Com Palm III only provides this technique).

Some researchers have claimed that the current touch screen technology would not allow high resolution selection, saying that selection of a single character with a touch screen would be slow if it is even possible (Sherr, 1988; Greenstein & Arnaut, 1988). Others have blamed the size of the human finger for the lack of precision, claiming that the size of the user's finger limits the size of selectable regions (Beringer, 1985; Sherr, 1988; Greenstein & Arnaut, 1988). Previous studies have made no attempt at evaluating a touch screen for high resolution tasks, restricting targets to relatively large sizes ranging from a square that is 0.25 inches per side, to targets that were approximately 1.0 x 1.6 inches. In addition, many of these studies have indicated that touch screens result in significantly higher error rates than many other selection devices, including the mouse [24].

4 Conclusion

Touch screen devices represents exciting new frontiers in research and technologies. Touch screen devices are ubiquitous: they encompass portable audio and video players, digital cameras, tablet PCs and PDAs, as well as cell phones and smart phones. A Sept. 2006 *Cellular News* story [35] estimated that there are more than 2.5 billion mobile phones worldwide. In the upcoming decade, we do believe by improving touch screen devices accuracy, user experiences on touch screen devices will be dramatically improved.

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