CS-TR-2268
CAR-TR-450

Revised January 1989

High Precision Touchscreens: Design Strategies and Comparisons with a Mouse

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Abstract

Three studies were conducted comparing speed of performance, error rates, and user preference ratings for three selection devices. The devices tested were a touchscreen, a touchscreen with stabilization (stabilization software filters and smooths raw data from hardware), and a mouse. The task was the selection of rectangular targets 1, 4, 16, and 32 pixels per side (0.4x0.6, 1.7x2.2, 6.9x9.0, 13.8x17.9 mm respectively). Touchscreen users were able to point at single pixel targets, thereby countering widespread expectations of poor touchscreen resolution. The results show no difference in performance between the mouse and touchscreen for targets ranging from 32 to 4 pixels per side. In addition, stabilization significantly reduced the error rates for the touchscreen when selecting small targets. These results imply that touchscreens, when properly used, have attractive advantages in selecting targets as small as 4 pixels per size (approximately one-quarter of the size of a single character). A variant of Fitts' Law is proposed to predict touchscreen pointing times. Ideas for future research are also presented.

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To appear in the International Journal of Man Machine Studies

Int. J. Man–Machine Studies (1991) **34**, 593–613

High precision touchscreens: design strategies and comparisons with a mouse

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(Received 4 August 1989 and accepted in revised form 29 January 1990)

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Introduction

OVERVIEW

Many pointing devices are available for use with computers, but none are as natural to use as the touchscreen. Pointing at an item or touching it, is one of the most natural ways to select it. Touchscreens allow the software designer to take advantage of this convenient selection method by having the users simply touch the item they are interested in.

Touchscreens are easy to learn to use, require no additional work space, have no moving parts, and are very durable (Pickering, 1986; Shneiderman, 1987; Stone, 1987; Muratore, 1987; Potter, Weldon & Shneiderman, 1988). Durability has made touchscreens popular in many applications, including kiosks at airports, shopping malls, amusement parks and home automation. Even with these positive features, the touchscreen's reputation for a lack of precision, high error rates, arm fatigue, and smudging the screen have resulted in limited use (Pickering, 1986; Shneiderman, 1987). Current touchscreen implementations do not include tasks requiring high resolution or tasks that are performed by frequent or experienced users. An adequate reduction in error rates, combined with the speed of the touchscreen may help expand this relatively limited use.

PREVIOUS EXPERIMENTS

Many studies have compared touchscreens with other selection devices for various tasks. Our summary motivates our experiments. First, studies that compared the

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touchscreen with other selection devices are reviewed. Then several studies that explored the use of alternative selection strategies, an error reduction method we employ, will also be summarized.

Muratore (1987) did an extensive literature survey, reviewing 14 studies that compared various cursor control devices. Her interpretation of these results implies that the touchscreen was the fastest but least accurate of the devices studied. Hall, Cunningham, Roache and Cox (1988) investigated the effects of various factors on touchscreen performance. The display was an IBM InfoWindow color terminal with a piezoelectric touchscreen using the land-on selection strategy forcing the selection at the location of the initial touch. Feedback was not provided about the accuracy of selections. They reported that accuracy varied from 66·7% for targets 10 mm per side, to 99·2% for targets 26 mm per side, and that accuracy was maximized once targets were approximately 26 mm per side. Ostroff and Shneiderman (1988) compared a touchscreen, mouse, number keys and arrow keys. The touchscreen was a Carroll Touch infra-red touchscreen using the land-on strategy. The study involved selecting words from an interactive encyclopedia (Hyperties™).† The results were similar to those of most other studies comparing the touchscreen and the mouse, indicating that the touchscreen was faster. They found no significant difference between error rates for the mouse and the touchscreen. This finding may be due in part to the relatively large size of the targets used and the rapid but awkward form of the jump mouse. (A jump mouse moves the cursor from one target to the next, skipping the space between them.) Ahlstrom and Lenman (1987) compared a conductive touchscreen using the land-on strategy and mouse for the selection of a six character word from a list of words. This study indicated that the touchscreen was faster, but resulted in much higher error rates. Karat, McDonald and Anderson (1986) compared a touchscreen, mouse and keyboard for selection tasks. The touchscreen used was an Elographics analog membrane touchscreen using the land-on strategy. The task involved selecting items from a menu in a calendar program and a telephone directory. Some tasks also involved a typing sub-task. The results indicated that the touchscreen was the preferred device for the task without the typing sub-task, while the keyboard was preferred when the sub-task was included. The touchscreen was the fastest for both tasks.

These studies have been limited to relatively large targets for selection tasks, but they do give some insight into the potential use of touchscreens. It is clear that a touchscreen can be used for rapidly selecting relatively large targets. Unfortunately, most of these studies also indicate that error rates were significantly higher for touchscreens. There are two explanations that may account for the majority of these errors, the inability of the touchscreens used in these studies to provide precise information about the location of a touch, and inadequate selection strategies for the tasks studied.

The inability of the touchscreen hardware to provide precise information may be due to a lack of resolution or the result of multiple pixel locations, possibly as many as 20 or more, being returned for a touch in a single location. While research by touchscreen manufacturers has dramatically increased the resolution of touchscreens, the problem of returning multiple pixel locations for a single touch remains.

† Hyperties is a trademark of Cognetics Corporation.

The extent to which this is a problem depends on both the touchscreen technology and manufacturer. Carroll Touch has published a Touch Handbook which provides a brief review of current touchscreen technologies including resolution, response time, and environmental resistance (Carroll Touch, 1989). Stabilization of the touchscreen will allow a single touch to result in the selection of a single pixel, possibly resulting in a significant reduction in errors, primarily for small targets. Ideally stabilization would be accomplished at the hardware level, but can also be done in software. Our studies will use software stabilization to filter and smooth raw data from the touchscreen hardware. Stabilization is an important idea that can be applied to many technologies including touchscreens, data gloves and light pens, but has never been tested with touchscreens.

Many alternative selection strategies have been suggested to help reduce errors including take-off, first-contact, land-on, and others requiring a second touch. The land-on strategy uses the location of the initial touch for the selection. If the initial touch corresponds to a selectable region, that region is selected, otherwise no selection is made. The first-contact strategy results in the selection of the first selectable region the finger comes into contact with. With this strategy the users move their fingers on the screen until a selectable region is touched, this region is then selected and the appropriate process is initiated. Once again, all additional contact is ignored until the finger is removed from the screen. The take-off strategy allows users to place their fingers on the screen and move to the desired region on the screen before a selection is made. A cursor is placed slightly above the users fingers when they touch the screen indicating the exact location of where a selection would be made. Users can then drag the cursor to the desired region, and lift their fingers from the screen to select it. A selection is made only if there is a selectable region under the cursor when users lift their fingers.

Several studies have been conducted to compare alternate selection strategies. The results indicate that some strategies may be promising for a wide range of tasks, and a significant reduction in error rates is possible (Murphy, 1987; Potter *et al.*, 1988; Potter, Berman & Shneiderman, 1989). Murphy (1987) compared seven selection strategies. He conducted an experiment that involved selecting targets that were 19 mm^2 from a matrix of 60 targets. His results indicated few significant differences among the selection strategies, making it difficult to promote any single strategy as the best with respect to either selection time or error rates for this target size.

Researchers at the University of Maryland Human–Computer Interaction Laboratory have performed two experiments comparing the land-on, first contact and take-off strategies. The first experiment involved the selection of a two character state abbreviation from a 5×10 matrix. This study indicated that the first-contact strategy was the fastest, while the take-off strategy produced the fewest errors. The second experiment involved the traversal of a hypertext database by selecting highlighted words. There were no significant differences in the time needed to perform the task, while the first-contact and take-off strategies produced fewer errors than land-on (Potter *et al.*, 1988; Potter *et al.*, 1989).

These experiments indicate that first-contact may be the fastest selection strategy, while the results pertaining to error rates did not consistently favor one strategy over the others. While these studies do provide a comparison of the selection strategies, they do not indicate how well a touchscreen using these strategies will perform compared with other selection devices.

Some researchers have claimed that the current touchscreen technology would not allow high-resolution selection, saying that selection of a single character with a touchscreen would be slow even if it were 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 touchscreen for high resolution tasks, restricting targets to relatively large sizes ranging from a square that is 6·4 mm per side, to targets that were approximately 25·4 × 40·6 mm. In addition, many of these studies have indicated that touchscreens result in significantly higher error rates than many other selection devices, including the mouse. Our experiments studied the selection of small targets with the touchscreen as compared with the mouse. We also studied the effects that stabilization and the use of an alternative selection strategy have on these selections. Error rates and selection speed were measured. User preference data were also collected.

Experiment one: stabilized touchscreen, non-stabilized touchscreen, and mouse

INTRODUCTION

The main purpose of the first experiment was to provide the comparison of a touchscreen with a mouse, using an improved selection strategy for high resolution tasks. The secondary purpose was to investigate the effect stabilization has on speed of performance, error rates and user preference for selection tasks when using a touchscreen.

Due to the difficulty involved in modifying hardware, stabilization was accomplished using software that filters and smooths raw data from the touchscreen hardware. These results should generalize to stabilization performed by either hardware or software.

The first step was to determine which selection strategy should be tested. To do this, we must understand the requirements of the task being evaluated. A typical high resolution task may be the selection of the start and stop points for a line in a graphics package, or possibly the selection of a character in a word processing program. Since it is difficult to touch a single character accurately, let alone a single pixel on the first attempt, the land-on strategy is not adequate. In addition, many high resolution tasks involve the selection of targets that are not defined before the selection is made, such as the starting point of a line which makes the first-contact strategy inappropriate. On the other hand, the take-off strategy provides continuous feedback about cursor location, allowing the user to position the cursor before a selection is made by lifting the finger. This makes take-off the best candidate for many high resolution tasks.

PILOT STUDY RESULTS

A pilot study helped determine that the original target sizes (16, 8, 4 and 2 pixels per side) were inappropriate. We decided that a larger range of target sizes would

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