IMPROVING THE ACCURACY OF TOUCH SCREENS: AN EXPERIMENTAL EVALUATION OF THREE STRATEGIES

Richard L. Potter,[§] *Linda J. Weldon,*[†] *Ben Shneiderman*[§‡]

Human-Computer Interaction Laboratory
Center for Automation Research

[§]Department of Computer Science
[‡]Institute for Advanced Computer Studies
University of Maryland
College Park, Maryland 20742
and
[†]Department of Psychology
Essex Community College
Baltimore County, Maryland 21237

ABSTRACT

A study comparing the speed, accuracy, and user satisfaction of three different touch screen strategies was performed. The purpose of the experiment was to evaluate the merits of the more intricate touch strategies that are possible on touch screens that return a continuous stream of touch data. The results showed that a touch strategy providing continuous feedback until a selection was confirmed had fewer errors than other touch strategies. The implications of the results for touch screens containing small, densely-packed targets were discussed.

KEYWORDS: Touch screens, empirical studies, user interface, human-computer interaction.

INTRODUCTION

Reaching up and placing a finger on a touch screen at a selectable region seems simple and direct enough. However, peculiarities in both touch screen technology and human dexterity leave room for improvements in this simple touch screen strategy for some applications. For example, parallax between the touch screen surface and the display surface can cause users to misinterpret where their fingers are actually touching by a significant amount.

Touch screens are attractive because they enable quick learning and rapid performance, do not consume desk or other workspace, have no moving parts, and evoke high user satisfaction [2, 5, 6, 7]. However, widespread use of touch screens has been limited by the high error rates shown in many studies, lack of precision, fatigue in arm motion, and concern for screen smudging [4, 5].

Common touch screen applications include information kiosks at airports or shopping malls, educational games, and exhibits at museums and amusement parks. The simplicity of touch screen usage is attractive for novices and the durability of touch screens is favored by designers. Current touch screens have found little use for more frequent knowledgeable users, such as air traffic controllers or medical equipment operators, probably because of the annoyance of high error rates. However, we believe that it is possible to overcome this problem.

We believed that we could preserve the benefits of touch screens and reduce the disadvantages by providing continuous feedback of pointing position and enabling users to drag a cursor on the screen with their fingers, thus creating a "finger mouse." Users can adjust their initial touch until they arrive at the precise position desired. Selection is completed when the users lift their fingers from the screen or alternatively when the first valid target is encountered.

There are many possible strategies that can allow a user to select one of a set of displayed predefined areas. The user's intentions can be expressed in an infinite number of ways by changing the articulation of the touch. For example, the user could select an area in the center of the screen by pressing in the center. Alternatively, the selection could be made by tapping the center twice, followed by a circular motion around the center. Certainly most of the possible strategies will be impractical. Still, we are left with a multitude of imaginative practical strategies from which to choose.

The type of touch technology used can limit or expand the range of expression possible by the user. Some touch screens only register the initial impact with the screen so dragging the finger can not be interpreted as part of the interaction. Other touch screens can detect two different touch points while some average multiple simulateneous touches to derive only one point. Some touch screens can ever report the pressure the user is applying during different moments of the interaction.

The touch screen used for the present experiment was a MicroTouch screen which returns a succession of data records. Each record contains whether a finger is touching the screen, and whether the finger was lifted at that position. For the MicroTouch screen our range of interaction can be summarized by the location of the final touch, and the path taken in between. Only one touch can be tracked at one time. From this array of possibilities we designed and implemented three touch strategies: land-on, first-contact, and take-off.

The simplest strategy, *land-on*, uses only the initial touching of the touch screen for selection. If a selectable item is under the initial touch then it is selected, otherwise nothing is selected. All further contact with the touch screen is ignored until the finger is removed. Thus dragging the finger has no effect. The land-on strategy was meant to simulate technologies, such as piezo-electric, that do not provide continuous touch data.

The second strategy, *first-contact*, was designed to work basically the same as land-on but take advantage of the continuous stream of touch data provided by technologies such as those used in some capacitive touch screens. Users make selections by dragging their fingers to the desired item. The human-computer interaction is not limited to the initial impact with the touch screen. In this strategy it is not what position the user lands on that becomes selected, rather it is whatever selectable item the user first contacts. Of course if the user makes first contact with some undesired item before reaching the desired item, the undesired item will be selected.

The third strategy, *take-off*, was designed to utilize the continuous stream of touch data and give more user feedback. Whenever users make contact with the touch screen, a cursor (in the form of a plus sign < + >) appears slightly above their fingers so that the specific position of selection is known. As long as users keep their fingers in contact with the screen, no selection will be made. After dragging the cursor, when the users are satisfied with its placement, they confirm the selection by removing their finger from the touch screen.

We tried to make each strategy perform at its best. For the land-on strategy and to a lesser extent first-contact strategy, the accuracy of the initial touch was deemed important. The cursor was placed directly below the finger so that the users would not have to judge some arbitrary biasing. However for the take-off strategy a slight bias, placing the cursor about 1/2 inch above the finger, was employed. In this case the users need a clear view of the cursor. Users can easily adjust the position of the cursor with the take-off strategy so any inaccuracies of the initial contact caused by the bias can be easily corrected. In all three strategies if the finger is removed and no item has been selected, the cursor remains visible at the point on the screen where the finger last positioned it.

In addition to the cursor considerations, take-off received other minor enhancements to take advantage of its unique qualities. Since the cursor traveled within character boundaries, there existed positions where minute shifts of the finger would cause the cursor to jump back and forth by an entire character. Cursor stabilization was added so that users could better keep the cursor in one place while deciding if its placement was desirable. There also existed an interval from the time the user placed the cursor on the desired item to the time the user's finger was released. This introduced the ability to highlight the entire item by inverse video during this time. This highlighting gave the user even more feedback as to what would be selected should the finger be removed from the touch screen.

A related experiment used an infra-red touch screen that could register multiple touches [3]. Seven touch strategies were tested in the experiment. The subjects were to select from 60 targets which were 3/4 inch square and displayed in a grid that was six high by ten wide. One of the strategies tested was similar to the take-off strategy and another was similar to the first-contact strategy in the present experiment. There were no significant differences between these two particular strategies in task completion time or number of errors. We also have recently become aware of other attempts to create a take-off strategy [1].

The characteristics of the touch strategies we used in this experiment are:

1. Land-On:
- cursor is directly under the finger
- only the position of the first impact with the screen is used
- a selection is made upon first impact if a target exists at that location

2. First-Contact:
- cursor is directly under the finger
- all position data is used until the first contact with any target
- a selection is made upon first contact with any target

3. Take-Off:
- cursor is about 1/2 inch above the finger
- all position data is used throughout selection
- a selection is made upon release if a target exists at that cursor location
- jitter stabilization of cursor for when finger is on character boundaries
- entire item is highlighted when cursor appears on top of it

The characteristics of the cursor are:

- a plus sign < + >
- moves on character boundaries in discrete jumps
- flashes so that both the cursor and the character it appears on, alternate to remain visible

Our experiment investigated how well people use and accept these more intricate touch strategies. Performance was measured in terms of speed and number of incorrect selections. The task the subjects had to complete required searching for two letter state abbreviations from a group of 50 on the screen. Thus the subjects experienced some cognitive load in making each selection; the task was easy but required concentration.

METHOD

Subjects. Twenty-four people volunteered to participate in the study. Subjects were informed of the measures that would be taken. Each subject was run individually, in an experimental session that typically lasted for approximately 20 minutes. A post-experiment questionnaire about the subjects' computer experience revealed a range from no experience to over nine years of experience, with a median of four years of experience. Because of the location of the experiment, most of the subjects who volunteered were computer science students.

Equipment. In all cases, the touch screen strategies were implemented using a MicroTouch screen mounted on an IBM PC-AT with an Enhanced Graphics Adapter and color display. This touch screen uses conductive glass technology that provides continuous touch information to the computer. Software was written to create the three different touch strategies for use in selecting items from the array on the display.

Design and Procedure. Touch strategy was a within-subjects variable. Each subject was tested on all three of the strategies that were implemented. Each subject had 5 practice trials followed by 15 test trials for each condition. The experimental conditions were counterbalanced across subjects. In each trial, the subject pressed the spacebar on the keyboard which controlled the presentation of the message informing the subject of the target for the trial. The subject would then touch the target on the screen and receive feedback on the item touched. If an error was made, the subject was directed to try again. The response time for each selection was recorded automatically. Following the experiment, subjects received a post-experiment questionnaire that asked for background information, their subjective evaluation of the touch strategies, and additional comments.

Materials. The experimental array on the selection screen consisted of the two-letter postal abbreviations for 50 states arranged in the middle

Select CT from the items below.

AK	HI	ME	NJ	SD
AL	IA	MI	NM	TN
AR	ID	MN	NV	TX
AZ	IL	MO	NY	UT
CA	IN	MS	OH	VA
CO	KS	MT	OK	VT
CT	KY	NC	OR	WA
DE	LA	ND	PA	WI
FL	MA	NE	RI	WV
GA	MD	NH	SC	WY

Figure 1. The screen format, showing the experimental array and the target being requested.

of the screen. The abbreviations were listed in alphabetical order in 10 rows of 5 columns with two blank spaces between each column. The targets were approximately 1/4 square inch in area. A prompt line at the top of the selection screen displayed an abbreviation for the user to touch in the experimental array. Figure 1 shows the format of the screen. If the user touched the wrong item, an error message appeared in the prompt line. A message line appeared at the bottom of the selection screen showing the state name corresponding to the item selected.

RESULTS

Analyses were conducted for the performance measures that were collected during the experiment and for the ratings made by the subjects on the subjective evaluation questionnaire that was given at the conclusion of the experiment. Analyses of variance with repeated measures were used in the evaluation of the performance and subjective evaluation data that were collected.

Performance. The two performance measures were the time from the presentation of the target item until the correct target was selected and the errors that were made by the subjects.

Time. The item selection times for the 15 trials were divided into 3 blocks of 5 trials. The blocks represented the beginning trials, the middle trials, and the final trials. The analysis was a 3 (strategy) x 3 (block) x 6 (order) analysis of variance with repeated measures on the first two factors. There was a significant main effect for strategy, $\underline{F}$ (2,36) = 10.41, $\underline{p} < .001$. A post hoc analysis showed that the overall mean time for the first-contact strategy (16.93 sec) was significantly faster than the take-off strategy (20.92 sec). The mean performance time for the land-on strategy (17.73 sec) did not differ significantly from the other two strategies.

There was also a significant main effect for block, $\underline{F}$ (2,36) = 23.82, $\underline{p} < .001$, which reflected a significant difference between the beginning block of trials (20.20 sec) and the middle and final trials. The performance times decreased significantly after the first block of trials. The times for the middle and final blocks did not differ from each other (18.03 and 17.35 sec, respectively).

There was no significant interaction between strategies and blocks of trials. Although there was a main effect for order, $\underline{F}$ (2,18) = 2.84, $\underline{p}<.05$ attributable to the difference between the fastest and slowest counterbalancing orders, there were no interactions between order and the other factors.

Errors. Two types of errors were identified. One type of error occurred when a subject selected a wrong target. A second type of error occurred when the subject touched a blank part of the screen. The analysis showed a significant main effect for strategy, $\underline{F}$ (2,36) = 7.64, $\underline{p}$ <.002. A post hoc comparison of the means showed that there were significantly fewer errors with the take-off strategy (mean = 2.25) than with either the land-on strategy (mean = 5.08) or the first-contact strategy (mean = 4.08).

There was a significant main effect for type of error, $\underline{F}$ (1,18) = 19.89, $\underline{p}$ <.001, attributable to the greater number of wrong target errors (mean = 2.49) than blank space errors (mean = 1.32).

There was also a significant interaction between strategy and type of error, $\underline{F}$ (2,36) = 6.40, $\underline{p}<.004$. Figure 2 shows the mean error rates for the three strategies for each type of error. The take-off strategy had significantly fewer wrong target errors (mean = 1.08) than the first-contact and land-on strategies (with means for wrong targets of 3.29 and 3.08, respectively). The land-on and first contact strategies did not differ significantly from each other in terms of number of wrong target errors. Within the first-contact strategy, there were significantly more wrong target errors than blank space errors. The post hoc analysis showed that the first-contact and land-on wrong target errors were also significantly greater than the mean number of blank space errors for both first-contact and take-off strategies (0.79 and 1.17, respectively).

There were no order effects.

Subjective Evaluation. After the timed trials on the three strategies, the subjects were asked to rate the strategies on the dimensions of ease of learning, awkwardness, and satisfaction. The analysis showed a significant interaction between strategies and rating dimension, $\underline{F}$ (4,72) = 4.71, $\underline{p}<.002$. A post hoc analysis of the interaction showed that the take-off strategy had a significantly higher rating of satisfaction (mean = 6.75) than the land-on

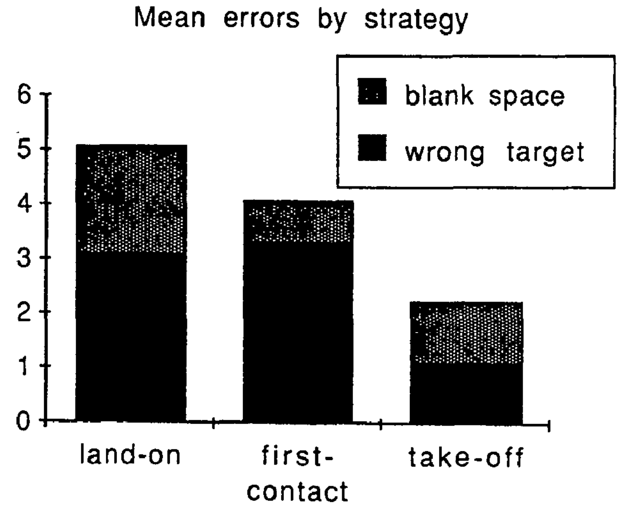

Figure 2. Mean error rates for selecting wrong targets and blank spaces for three touch strategies.

strategy (mean = 5.63), but not the first-contact strategy (mean = 5.96). The remaining meaningful comparisons reflected the overall ratings of the ease of learning the touch screen for all three strategies.

DISCUSSION

We were pleased to find that we could develop a touch screen strategy that produced statistically significantly lower error rates than commonly applied strategies. Our enthusiasm for the take-off approach was tempered by the recognition that this more intricate strategy did indeed take significantly longer. We were encouraged by the learning curve for take-off and would like to see if with more than 15 trials the time differences with other strategies would continue to decrease. The take-off strategy produced significantly fewer errors thereby reducing one of the severe problems with touch screens. We believe that ideas gained from this experiment will lead to refinements that will have still fewer errors.

The subjective reactions confirmed the impression that more intricate strategies with continuous feedback and confirmation are acceptable to users. Comments and our observations reminded us that there are still many design issues that strongly effect performance and satisfaction, such as the placement of the cursor (plus sign) or the stability of the feedback.

Subjects sometimes took great exception to the location of the cursor when using the take-off strategy. They believed that the cursor should be directly under the finger. The drag feature of take-off was used by subjects differently. Some subjects waited until they located the target on the screen and then placed their finger close to the target and made slight adjustments. Other subjects placed their finger on the screen immediately and then proceeded to drag, sometimes letting their finger help in the search. This flexibility probably helped take-off obtain its favorable user satisfaction rating.

Since in this experiment the items were small and densely spaced, there was little difference between the way the subjects used land-on and first-contact. The users noted this in their written comments and verbally during the performance of the experiment. It was common to see subjects using first-contact miss a target slightly and then jiggle their finger to make the selection. Had the subjects been using land-on, the jiggle would have been ignored and the subjects would have had to remove their finger and then replace it on the screen. Even with simple strategies, the continuous stream of touch data is beneficial.

Watching the subjects during the experiment suggested possibilities that could improve each of the three strategies. Subjects using take-off sometimes lifted their finger at such an angle that the cursor moved before their finger lost contact with the screen. This observation would suggest the software should ignore any sudden motion that occurs just before the finger is released. Also, subjects using take-off would sometimes not make solid contact with the screen as they dragged the cursor to the desired item. Thus some of these skips caused unintentional selections. The MicroTouch screen requires extremely minimal contact with screen surface so one would expect this problem to be more noticeable on a membrane technology touch screen. Perhaps some sort of filtering is possible that would minimize this effect.

Certainly there are situations where simple strategies are the best choice. An application requiring just a few large items on the screen at one time may not benefit greatly from the take-off strategy. However it is reassuring to know that as the number of items increases and their size decreases, more intricate touch screen strategies can be designed that have low error rates and high user satisfaction.

NOTE

The success of the take-off strategy coupled with the positive comments of visitors and experimental participants is encouraging. University officials are seeking to patent the take-off strategy with the multiple refinements that have been developed.

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