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PAPER

How Are the Differences between Selection Strategies Affected by Changes in Target Size, Distance and Direction?

Xiangshi REN† *and* Shinji MORIYA†, *Members*

SUMMARY Fitt's law is commonly used to model target selection. But Fitts' law deals with only one kind of selection strategy. Our question is, do changes in target size, distance and direction to a target affect the differences in performance between target selection strategies? We performed the first empirical tests on a pen-based system to evaluate differences in performance between six selection strategies for selecting a target. Three target sizes, eight pen-movement-directions and three pen-movement-distances were applied to all six strategies. The results show that differences between selection strategies are affected by variations in target size but not by the other parameters (distance and direction).

key words: *pen-based systems, pen-input interfaces, target selection strategies, small targets, variations in differences*

1. Introduction

The era of mobile computing is here and pen-based systems are employed in many fields, especially portable applications. In portable pen-based systems, target selection, e.g. selection of menus, data (one character of the text or graphic segment, etc.), and ranges etc. are more often attempted than data input. In these small-sized pen-based systems, the target size decreases as the amount of information on the screen increases. The trade-off between the accessibility of targets and the amount of information presented is a fundamental problem in human-computer design.

In order to solve the problem, some leading studies have developed a variety of relatively efficient selection strategies for touchscreens [4], [8], [9]; mice [2], [12]; touchpads [3]; and 3D applications [13]. However, current target selection strategies on pen-based systems are mostly only imitations of selection techniques for mouse and touch-screen devices. Investigations which focus on differences between selection strategies on pen-based systems have not been conducted.

Moreover, traditional studies on selection strategies have not paid attention to various parameters. For example, Fitts' law [1] is commonly used to model target selection, but Fitts' law only describes the situation on the use of one kind of selection strategy. Furthermore, although Potter et al. [4] conducted an empirical experiment to compare three selection strategies for touchscreens, they only used one kind of target size (6.4 mm × 6.4 mm square). Finger-movement-distance and finger-movement-direction were not considered.

This paper looks at variables (target size, pen-movement-distance, and pen-movement direction) to describe their effect on the users' selection strategies. Three target sizes, three distances, and eight directions were studied to gauge their effect on target selection strategies for pen-based systems.

2. Tablet Structure and the Six Strategies

An electromagnetic tablet [11] was used in the experiment. When the pen-tip is within a given height above the tablet surface (1 cm), the computer can recognize the coordinates (x, y) of the pen-tip. Thus, even though the menu on the screen is 2 dimensional (2D), it can be highlighted or selected when the pen is above the tablet surface (within 1 cm). This means that the menu can be expressed as a 3 dimensional (3D) target.

The oval and the cylinder shown in Fig. 1 illustrate targets on the pen-based system screen. The oval shows that the target is a 2D target. The cylinder shows that the target is a 3D target. That is, the circle with a solid line is at the bottom of the 3D target.

Some responses will take place when the pen is in the cylinder. It is important to note that although the illustration in Fig. 1 shows circular targets, the shape of the target has no definitive bearing on this discussion.

The six strategies for selecting a target [6] in the experiment are as follows:

- Land-on1: the pen approaches from above. The target is selected only momentarily at the time the pen makes contact with the screen in the target area.
- Land-on2 is an extension of the Land-on1 strategy. Here also the target is selected when the pen touches it for the first time, but in this case the pen lands outside the target area before moving into it.
- Take-off1: the target is highlighted only while the pen is touching it. The selection is made at the moment the pen is taken off the target.

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†The authors are with the Department of Information and Communication Engineering, Tokyo Denki University, Tokyo, 101-8457 Japan.

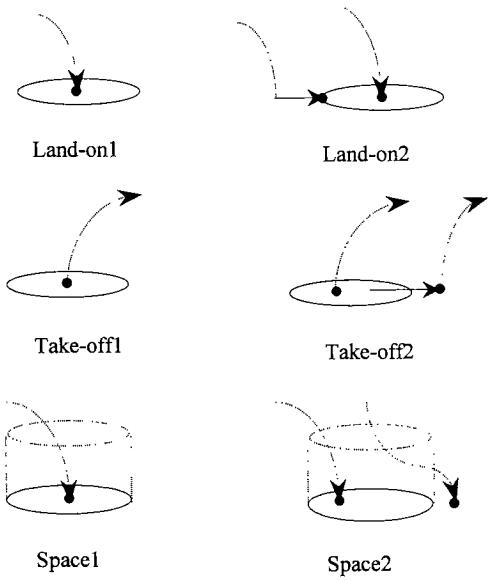

Fig. 1 The six strategies used in the experiment. The arrow shows the movement of the pen-tip. A dashed line arrow means the pen-tip is above the screen and a solid line arrow shows that the pen-tip is on the screen. The point shows where the target selection is made by the pen.

- Take-off2 is an extension of the Take-off1 strategy. The target is highlighted only while the pen is in contact with it, however the selection is made when the pen is removed from any point on the screen either inside or outside the target area.
- Space1: the pen approaches from above. The target is highlighted while the pen is within the 1 cm high cylinder above the target. Selection is made at the moment the pen makes contact with the target area (i.e. inside the bottom circle).
- Space2 is an extension of the Space1 strategy. The target is highlighted while the pen is within the 1 cm high cylinder above the target. After highlighting, the selection is made when the pen makes contact with any point on the screen either inside or outside the target area.

The Land-on1 and Take-off1 strategies are already in common use. The Land-on2 strategy corresponds to the *first-contact* strategy [4]. The Take-off2, Space1 and Space2 strategies were new strategies designed for this experiment.

The main factors affecting our choice of these six strategies were the six conditions created by the pen parameters [5]. They are: contact with the screen, removal from the screen, contact inside the target, contact outside the target, target highlighted and target not highlighted.

Contact and removal of the pen were treated as movements between the 2D plane and 3D space. Pen contact involves a movement from 3D to 2D, while removal involves a movement from 2D to 3D. These changes were considered to be suitable conditions for a subject to affect and confirm the moment of target selection. The strategies in which selection was made by contact with the screen were the Land-on1, Land-on2, Space1 and Space2 strategies. The strategies in which selection was made by removal from the screen were the Take-off1 and Take-off2 strategies. These conditions exist in both 2D targets and 3D targets. Here, the Land-on1, Land-on2, Take-off1 and Take-off2 strategies can be used for 2D target selection. The Space1 and Space2 strategies were used for 3D target selection assuming that the pen was approaching the target from above.

We considered the movement of the pen into and out of the target (2D or 3D) from the perspective of the user's eyes and ears. When the pen moved into or out of the target, users could confirm whether or not the target was highlighted. Those strategies in which selection was made by contact within the target area were the Land-on1, Take-off1 and Space1 strategies. On the other hand, those strategies in which selection was made by contact either inside or outside the target were the Land-on2, Take-off2 and Space2 strategies.

Those strategies in which selection was made when the pen was removed from the surface of the target or from above the target after visual confirmation, were the Take-off1, Take-off2, Space1 and Space2 strategies. Those strategies in which visual confirmation was not possible were the Land-on1 and Land-on2 strategies.

3. Method

3.1 Subjects

Twenty-one subjects (17 male, 4 female; all right-handed, university students), were tested for the experiment. Their ages ranged from twenty-one to twenty-three years. Ten had had previous experience with pen-input systems, while the others had had no experience.

3.2 Equipment

The hardware used in this experiment was: a tablet-cum-display (HD-640A, WACOM Corp.), a stylus pen (SP-200A, WACOM Corp.), and a personal computer (PC9801-DA, NEC Corp.). The space resolution of the tablet input is 0.05 mm/point. The height of the liquid crystal screen was 144.0 mm and the width was 230.4 mm. The liquid crystal display resolution was 400 dots high and 640 dots wide. 1 dot was about 0.36 mm. The pen/screen contact area was 1.40 mm in diameter.

3.3 Procedure

First the experiment was explained to each subject and then each of them had 20 practice trials immediately before the experiment started.

A message "Select a target as quickly and accurately as possible using the strategy" was displayed on the screen of the experimental tool when the experiment started.

When a target was being selected using any one of the strategies, the steps were as follows:

(a) Initial position: a circular initial position was displayed at the center of the screen. The initial position was the place where the pen was pointed immediately before beginning the selection procedure. The subject had been told which strategy he/she was to use and how many trails he/she had to do.

(b) Touching the initial position: the subject touched the initial position with the pen.

(c) Display of a target: the target was then displayed with size and position changed at random. These parameters (target sizes, positions) were randomly selected by the computer. Targets of a particular size were never displayed in the same position twice. The distances between the initial position and the target were 39, 131 or 160 dots, randomly selected by the computer.

(d) Target selection: the subject then received a message on the screen to indicate whether he/she had made a successful selection or not.

(e) The subject then repeated (a) to (d) above.

(f) End of selection: a message indicating the end of the experiment was displayed when the subject had completed the task.

The strategies were not mixed. In a given trial each subject used only one strategy.

3.4 Design and Data Processing

Figure 2 shows an example of the display of a target.

- Size of target: all the targets for the experiment were circular. Circular targets were used so that the distance between the initial position and the edge of all targets on each radius remained constant in all directions. To examine the relationship between target size and strategy, three target sizes of 3, 5 and 9 dots (1.1 mm, 1.8 mm and 3.2 mm diameter circles) were used in all trials.

- Pen-movement-distance: the distance to the target was the radius of a circle in which the center point was the initial position. To examine the relationship between distance and strategy, the distances of 39, 131 and 160 dots (14.0, 47.2 and 57.6 mm) were determined by a preliminary experiment†.

- Pen-movement-direction: eight directions were used. They were at 0, 45, 90, 135, 180, 225, 270 and 315 degrees from the initial position.

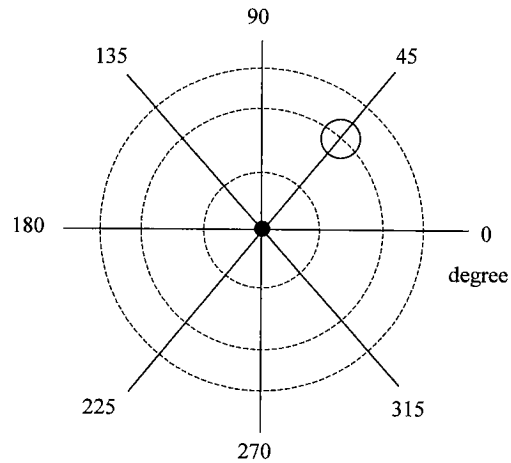

Fig. 2 An example of the display of a target. The black point (center •) is the initial position. The small circle (○) shows one of the twenty-four possible positions for the display of a target. The dotted line shows the pen-movement-distances from the initial position to the target. The solid line indicates the eight pen-movement directions to the target from the initial position.

The subject performed a total of 92 trials for each strategy. These consisted of 20 practice trials and 72 test trials (= 3 target sizes × 3 distances × 8 directions).

A break was taken at the end of each strategy trial. Whenever the subject felt tired he/she was allowed to take a rest. Each subject completed 432 test trials (= 6 strategies × 72). In each strategy 1512 test trials (= 21 subjects × 72) were completed. The order for the six strategies was different for each of the twenty-one subjects.

The data for each strategy was recorded automatically as follows:

(1) Presence or absence of error when a target was selected. (One selection was a continuous operation from the moment the pen touched the initial position until the removal of the pen from the tablet surface.) Feedback to the subject indicated whether the selection was successful or not. In either case, the subject could not cancel the selection.

†Distances of 39 dots and 131 dots were the average values used by ten subjects in a preliminary experiment. When their wrists were in a fired condition 39 dots was the radius of the circular which could be drawn by the subjects; 131 dots was the radius of the circular arc which was the maximum finger-movement-distance. The outside circle radius of 160 dots was determined according to the size limitations (height) of the tablet screen. It was also a distance by which the wrist could be moved.

Table 1 F value (ANOVA, F(5, 120), $p < 0.0001$) compared the six strategies regarding error rate and selection time in each target size, distance.

	Target size (dots)			Distance (dots)		
	3	5	9	39	131	160
Error rate	24.7	9.99	0.65†	15.2	16.3	16.5
Selection time	9.75	6.85	5.22††	7.33	10.3	10.1

†$p > 0.05$, ††$p < 0.001$

Table 2 F value (ANOVA, F(5, 120), $p < 0.0001$) compared the six strategies regarding error rate and selection time in each direction.

	Direction (degrees)							
	0	45	90	135	180	225	270	315
Error rate	13.3	13.0	10.6	10.1	12.3	11.8	13.5	16.6
Selection time	10.2	8.22	7.66	6.51	5.34†	5.86	6.67	7.44

†$p < 0.001$

(2) Position and size of the target displayed.

(3) The time lapsed between display of the target and the moment when the pen contacted the screen.

(4) The time lapsed between contact with the target and removal from the screen.

(5) The time lapsed between contact with the screen and contact with the target.

These times were measured to an accuracy of 10 ms using a special program.

Data as defined in item (3) was recorded for the Land-on1, Space1 and Space2 strategies. Data as defined in item (5) above was recorded for the Land-on2 strategy. Data as defined in item (4) above was recorded for the Take-off1 and Take-off2 strategies.

4. Results and Discussion

In evaluating the results, we performed an analysis of variance (ANOVA) on the selection times, error rates, and subject preferences. The purpose of this analysis was to test how the target sizes, pen-movement-distances and pen-movement-directions affect the differences among the six selection strategies. Error rates were determined by dividing the number of errors by the total number of selection attempts. Selection time was the time required to select the target correctly.

4.1 The Three Variables: Target Size, Distance, and Direction

Analyses were conducted to determine the significant differences between the six strategies in terms of each target size, each pen-movement-distance (see Table 1) and each pen-movement-direction (see Table 2).

Target size

Figure 3 shows the error rates for each of the six strategies according to each target size. There were significant differences in error rates between the six strategies in each of the target sizes of 3 and 5 dots. On the other hand, there was no significant difference in error rates between the six strategies for the target size 9 dots. The significant differences in error rates between the six strategies were changed by changing the target sizes. In other words, the error rates were influenced by the selection strategies when the targets were small.

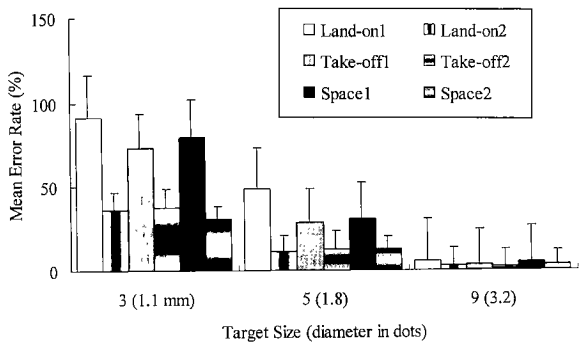

Fig. 3 Means (with standard error bars) for the error rates for each of the six strategies and each target size.

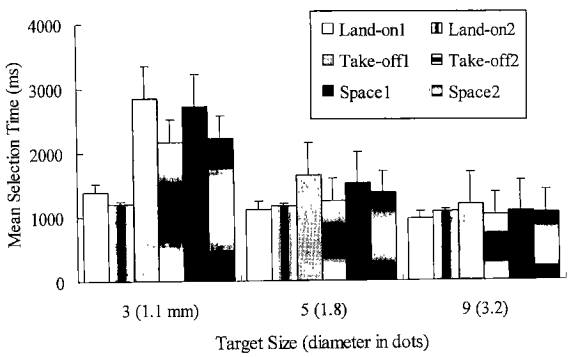

Fig. 4 Means for the selection times for each of the six strategies and each target size.

Figure 4 shows the selection times for each of the six strategies according to each target size. Significant

differences in selection time between the six strategies were found in each target size, 3, 5 and 9 dots. This means that significant differences in selection time between the six strategies did not change even when the target size was changed.

Overall, these results are important factors in the design of selection strategies for small targets in pen-based systems.

Pen-movement-distance and Pen-movement-direction

There were significant differences in error rate and selection time between the six strategies for each distance, 39, 131 and 160 dots (see Table 1).

Significant differences in error rate and selection time were observed between the six strategies for each direction (see Table 2).

It was shown that there were significant differences between the six strategies in both selection time and error rate caused by each of the pen-movement-distances and each of the pen-movement-directions. This means that there were significant differences even when the distances or directions were changed. Significant differences remained in all directions and all distances.

These results offer designers hints. The influence of pen-movement-distance and pen-movement-direction on pen-based input strategy design should be considered in this light.

4.2 Subject Preferences

The subjects were questioned about their preferences after they finished testing each strategy. The first question was: "For the strategy tested just now, when selecting T, how do you rate P? Please answer on a 1-to-5 scale (1 2 3 4 5)†." "T" means large or small targets as tested in the particular trial. "P" consisted of the six subquestions regarding selection accuracy, selection speed, selection ease, learning ease, satisfaction and desire to use. The questions (P) were asked of both large and small target sizes in each strategy. The second question was: "Which direction was most comfortable for selecting the targets in the strategy?" The subject marked his/her preferences on Fig. 2.

Significant main effects were seen among the six strategies regardless of target size (large target, $F(5,30) = 14.8$, $p < 0.0001$, and small target, $F(5,30) = 58.1$, $p < 0.0001$). This was based on the average value of the answers given by the subjects to the twelve questions.

The Land-on2 strategy and the Take-off2 strategy were rated highly for large targets. Furthermore, the Land-on2 strategy was most preferred (mean = 3.08) for small targets.

The smallest radius (39 dots) and the medium radius (131 dots) were the most popular pen-movement-distances. These radii were determined by a preliminary experiment. They were ones in which the movements of the hand were minimal. Nevertheless significant differences in the six strategies were observed. There was also a significant difference between the six strategies at the maximum outside radius of 160 dots.

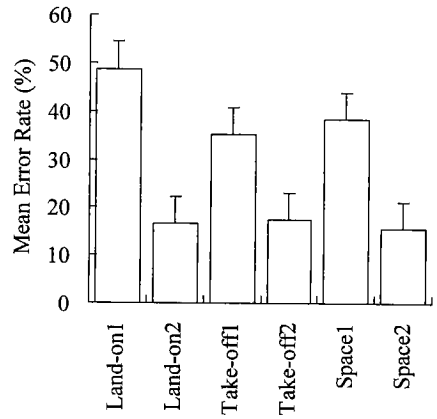

Fig. 5 Means for error rate for each strategy.

Regarding the pen-movement-directions, the vectors of 135, 180 and 225 degrees were preferred by most of the subjects. We assumed that the reason for this was that these vectors were on the left side of the initial position and they could be easily seen by these right-handed subjects.

4.3 Analysis for the Best Strategy of the Six

There was a significant difference in error rates between the six strategies, $F(5,120) = 17.8$ ($p < 0.0001$). This means that the error rate was influenced by the differences between the strategies. Figure 5 shows the mean error rates for each of the six strategies. The Land-on2, Take-off2 and Space2 strategies show lower error rates (16.6%, 17.4% and 15.5%) than the other three (Land-on1, Take-off1 and Space1).

However, there was no significant difference in error rates between these three (the Land-on2, Take-off2 and Space2 strategies), $F(2, 60) = 0.08$.

There was a significant difference in selection time between the six strategies, $F(5,120) = 10.8$ ($p < 0.0001$). From this we have concluded that the selection time was influenced by the particular strategy, i.e. selection time changed according to the strategy being applied. Figure 6 shows the average selection times for each of the six strategies. The Land-on2 strategy was the fastest of the six strategies (mean = 0.98 s). However, there was a significant difference between the Land-on2, Take-off2 and Space2 strategies, $F(2, 60) = 19.8$ ($p < 0.0001$).

Overall, based on analyses above, the Land-on2 strategy was the best strategy of the six.

†In the scale of 1 to 5, 1 = least preferred and 5 = most preferred.

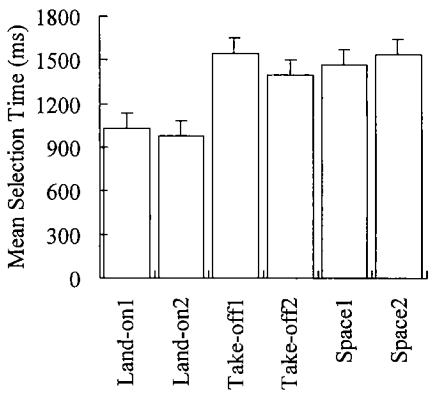

Fig. 6 Means for selection time for each strategy.

5. Conclusion and General Discussion

5.1 The Effects of Variables on Selection Strategies

This paper represents the first empirical tests of the effects of target size, distance, and direction to a target on the differences between selection strategies for pen-based systems.

The experiment showed that when target size decreased (1.1 mm and 1.8 mm diameter circles in our experiment), differences between selection strategies appeared; conversely, differences between selection strategies disappear when target sizes were increased beyond a certain size. We also showed that the differences between selection strategies were not influenced by distance to the target or direction to the target. These findings show that differences between selection strategies are affected by variations in target size, however, not by the other parameters (distance and direction).

These results have implications for designers and design issues. They contribute to the body of information about how changes in various parameters can affect the quality of selection. An understanding of human limitations, the parameters of selection strategies and the integration of human motor skills with computer devices is vital to the progress of human-computer interaction research.

5.2 The Best Strategy of the Six

The best strategy of the six strategies tested was the Land-on2 strategy. This result is the same as the result obtained in another empirical study [6]. We have verified again that the Land-on2 strategy is the most effective of the six strategies for selecting a small target.

5.3 Characteristics of Strategies for Selecting a Small Target

In the case of the target size of 9 dots no significant difference in error rate between the six strategies was observed. However, as the amount of information displayed on the screen is increasing, users have to select smaller targets because the width and height of screens is limited. This tendency is especially obvious in portable pen-based systems, in particular, personal digital assistants (PDAs), personal information managers (PIMs), and other pocket-sized pen-based applications.

When the screen is a 2D surface, and where other targets exist near the target, the Land-on1 and Take-off1 strategies can be used. For instance, the Take-off1 strategy is the same as for the familiar mouse technique. Here the selection is decided when the pen contacts the surface of the screen and, after visual confirmation, is moved into the target area. However, hand/eye coordination is essential when using the Land-on1 and Take-off1 strategies. For the Take-off1 strategy the pen must be within the target (that is, "catching" the target) when the pen is removed from the screen. In the Land-on1 strategy the pen approaches the screen and target area and it is in the target area only momentarily.

In situations where other targets do not exist near the target, and also in situations where other targets do not exist near one side of the target (e.g. the upper part), the Land-on2 and Take-off2 strategies are useful. For instance, in the Land-on2 strategy, contact with the target may be affected after landing on the screen outside the target area. However, in the Land-on2 strategy, selection is affected on contact with the target area thus making visual confirmation essential since the first target contacted will be selected. In this situation the Take-off2 strategy can be used because selection does not depend on the point of removal from the screen. Therefore the pen may, for example, pass through the target which will not be selected until the pen is removed from any point on the screen.

When using an electronic-tablet [11], a target on the screen can be designed as a 3D target. Thus the Space1 and Space2 strategies may be used in the same situation. In the Space1 and Space2 strategies the pen can affect the target before it makes contact with the screen, e.g., highlighting before screen contact.

6. Future Work

The selection of a single target was used in the experiment. A comparison of the six strategies in multi-target environments will be discussed in a future study. It has been reported elsewhere that differences in the target shapes influence the selection time [10]. The results obtained with circular targets will be compared with results to be obtained using other target shapes. It is also necessary to investigate the relationships between strategies and target shapes and to find strategies which are suitable for specific shapes.

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Xiangshi Ren was born in Changchun, China in 1965. He received a B.E. degree in electrical and communication engineering, M.E. and Ph.D. degrees in information and communication engineering from Tokyo Denki University, Japan, in 1991, 1993 and 1996 respectively. He is currently an assistant lecturer at Tokyo Denki University. His research interests include all aspects of human-computer interaction, in particular, pen-based input interactions, user interface evaluation, and multimodal interactions. He is a member of IPSJ, SIGHI of SICE, all in Japan, and the British HCI Group.

Shinji Moriya was born in Nagano, Japan in 1944. He received his Ph.D. degree from Tokyo Denki University in 1980. He was Visiting Associate Professor in the State University of New York at Buffalo in 1981 and in the University of Illinois at Urbana-Champaign in 1982, and Visiting Professor in the Yunnan Polytechnic University in China in 1994. He is currently professor of Tokyo Denki University. His research interests include pen-based and/or speech-input interactions, and evaluation and modelling of human-computer interactions. He is a member of IPSJ, SICE, Television Society of Japan, ACM and IEEE.