PAPER

Selection Strategies for Small Targets and the Smallest Maximum Target Size on Pen-Based Systems

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

SUMMARY An experiment is reported comparing six pen input strategies for selecting a small target using five diffenent sized targets (1, 3, 5, 7 and 9 dot diameter circles respectively, 0.36 mm per dot). The results showed that the best strategy, in terms of error rate, selection time and subjective preferences, was the "land-on2" strategy where the target is selected when the pen-tip touches the target for the first time after landing on the screen surface. Moreover, "the smallest maximum size" was determined to be 5 dots (1.8 mm). This was the largest size among the targets which had a significant main effect on error rate in the six strategies. These results are important for both researchers and designers of pen-based systems.
key words: *mobile computing, pen-based input, selection strategies, small targets, the smallest maximum size*

1. Introduction

There are two ways to study pointing devices. One is to compare different types of pointing devices. Representative examples are found in [1], [2]. Another is to compare different pointing/selection strategies with a particular pointing device so that the design of the interaction may be optimized. A few notable examples are found in [8], [15]. This paper is concerned with the latter.

There has been relatively little discussion (see [7], [8], [13]) on selection strategies with a particular device compared to the extensive literature which compares different poingting devices.

Among the studies which compare selection strategies with a particular device, there only are a few studies on pen-based input. There are a few notable exceptions, for example, [6], [14]. However, these studies used *indirect* pointing tablets that lie on the desktop, as opposed to those that are mounted right on the computer screen. Kato, Fukuda & Nakagawa [5] is one of a few exceptions. *Indirect* pointing tablets are hard to used in mobile systems, especially personal digital assistants (PDAs) because these systems require hand-sized small screens for ease of use, for example, when on the move.

In PDA systems with direct pen interfaces, target selection [e.g. selection of menus, data (one character of the text or graphic segment, etc.), and ranges etc.] is more often attempted than data input. The trade-off between the accessibility of targets and the amount of information presented on the screen is a fundamental problem in human-computer design. It is predicted that the target size will decrease as the amount of information on the screen increases.

In order to solve the problem, some leading studies have developed a variety of relatively efficient selection strategies for selecting a small target [4], [9], [11], [16]. However, current target selection strategies on pen-based systems are mostly only imitations of selection techniques for mouse and touch-screen devices.

This paper presents an experimental comparison of six pen input strategies for selecting a small target. It makes two main contributions. First, it shows that the best strategy, in terms of error rates, selection time and subjective preferences, was the "land-on2" strategy where the target is selected at the moment the pen-tip touches the target for the first time after landing on the screen surface. Second, it found that "the smallest maximum size" was determined to be 5 dots (1.8 mm). That was the largest size among the targets which had a significant main effect on error rate in the six strategies.

2. The Six Strategies and the Reason for Using Them

2.1 The Six Strategies

The six strategies are illustrated in Fig. 1. We used an electromagnetic tablet. When the pen-tip is within a given height above the tablet surface (1 cm), the coordinates (x, y) of the pen-tip are able to input data. 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 computer 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 (Fig. 1) shows circular targets, the shape of the target has no definitive bearing on this discussion.

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

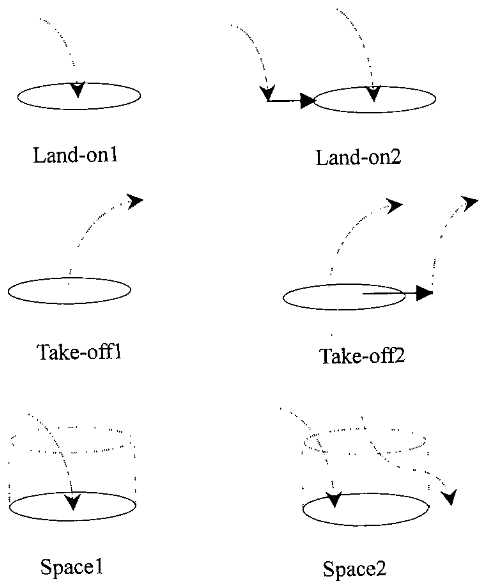

Fig. 1 Six strategies used by the experiment.

The arrows in Fig. 1 show the movement of the pen-tip. The dashed lines mean the pen-tip is above the screen and the solid lines show that the pen-tip is on the screen.

- 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.
- 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 initial 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.

Land-on1 and Take-off1 strategies are already in common use. The Land-on2 strategy corresponds to the *first-contact* strategy [8]. However, the Take-off2, Space1 and Space2 strategies were new strategies designed for this experiment.

2.2 Characteristics of the Six Strategies and their Classification, and Reasons for the Determination of those Six Strategies

What characteristics do these various strategies have? What criteria were used to select the six strategies used here? Regarding the above questions, we concentrated on the six conditions created by the pen parameters. They are: contact with the screen, remove from the screen, contact inside the target, contact outside the target, target highlighted and target not highlighted.

Targets exist both as planes (2D) and as solid bodies (3D). Here, the 2D strategies are the Land-on1, Land-on2, Take-off1 and Take-off2 strategies. The 3D strategies are the Space1 and Space2 strategies.

Contact and removal of the pen were considered 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 the subject to recognize and confirm the moment of target selection. The strategies in which selection was made by contact with the screen (Land-on1, Land-on2, Space1 and Space2 strategies) were named On strategies. The strategies in which selection was made by removal from the screen (Take-off1 and Take-off2 strategies) were named Off strategies. Where the target existed on the 2D plane, both the On and Off strategies were deployed. Where the target existed in 3D space, only the On strategies were used, assuming that the pen was approaching the target from above.

We considered the movement of the pen into and out of the target 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 named In strategies (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 named In-Out strategies (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 named 2Stage strategies (the Take-off1, Take-off2, Space1 and Space2 strategy). Those strategies in which visual confirmation was not possible were named 1Stage strategies (Land-on1 and Land-on2 strategies).

3. Method

3.1 Subjects

Nineteen subjects (14 male, 5 female; 18 right-handed, 1 left-handed), all university students, were tested for the experiment. Their ages ranged from twenty-one to twenty-three years old. Seven people 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 Co.), a stylus pen (SP-200A, WACOM Co.), and a personal computer (PC9801-DA, NEC Co.). The space resolution of the tablet input was 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 Design

Figure 2 shows the eight possible target positions.

Size of target: all the targets were circular. To examine the relationship between target size and the six strategies we used five target sizes (1, 3, 5, 7 and 9 dot diameter circles) in all trials.

Distance to target: the distance to the target was the radius of a circle in which the center point was the initial position. The distance of 131 dots (4.70 cm) was determined by a preliminary experiment. This was the average distance that ten subjects could extend the pen to the target.

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

3.4 Procedure

Before beginning the test session, we explained the experiment to each subject and they each had 20 practice trials.

To examine potential differences in performance when the tablet was laid on a desk top (i.e. on-desk conditions) and when the tablet could not be laid on a desk top (i.e. off-desk conditions), ten of nineteen subjects were asked to hold the tablet on their laps or in any position they found comfortable. They were not allowed to put the tablet on the desk.

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.

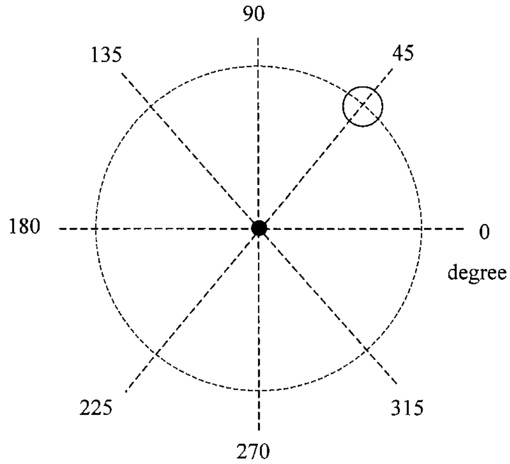

Fig. 2 An example of target arrangement. •: Initial position, ○: Position of a target display.

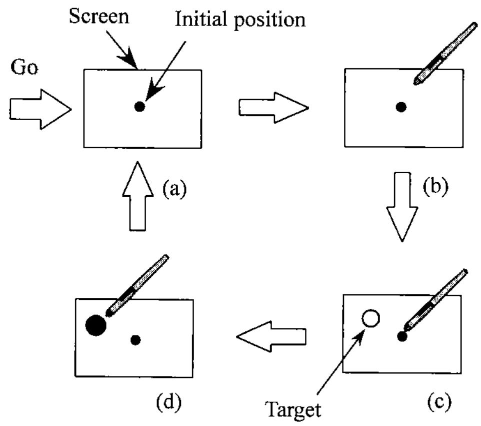

Fig. 3 Steps in selecting a target. (a) Initial position, (b) Pointing at the initial position, (c) Display of a target, (d) Target selection.

Figure 3 shows a typical display which would appear when a target was being selected using any one of the strategies.

(a) Initial position: a circular initial position was displayed at the center of the screen. The initial position was the place where the pen would be 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) Pointing at the initial position: the subject pointed to the initial position with the pen.

(c) Display of a target: the target was displayed with the size and direction changed at random (See Sect. 3.3). The parameters of the target (position and size) were randomly selected by the computer. Targets of a particular size were never displayed in the same position twice. The distance between the initial position to the target was constant at 131 dots.

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

(e) The subject then repeated (a) and (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.

The subject had a total of 60 trials for each strategy. These consisted of 20 practice trials and 40 test trials (= 5 target sizes × 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 240 test trials (= 6 strategies × 40). In each strategy 760 test trials (= 19 subjects × 40) were completed. The order for the six strategies was different for each of the nineteen subjects.

The data for each strategy were recorded automatically as follows:

(i) Presence or absence of error when a target was selected: one selection was a continuous operation from the approach of the pen to the target 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.

(ii) Position and size of the target displayed.

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

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

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

3.5 Subjective Evaluation

The subjects were questioned about their preferences after they ended each trial. "For the strategy tested just now, how do you rate P? Please answer on a 1-to-9 scale (123456789)." P consisted of six subquestions regarding selection accuracy, selection speed, selection ease, learning ease, satisfaction and desire to use.

4. Results

To determine the effect, in all six strategies, of target size on error rates, selection times and subject preferences, an ANOVA (analysis of variance) with repeated measures was performed.

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 Error Rates

The error rates for each of the six strategies is shown in Fig. 4. There was a significant difference for the six strategies, $F(5,108) = 9.76$, $p < 0.01$. This means that the difference in error rates was due to the difference in the various strategy operations. The error rates for the Land-on2 strategy were the lowest among the six strategies (see Fig. 4). But there was no significant difference in the total numbers of errors for the five target sizes (1, 3, 5, 7 and 9 dots) for the Land-on2, Take-off2 and Space2 strategies in the In-Out strategy group, $F(2,54) = 0.19$. The error rates for these three strategies did not differ for target sizes of 1, 3 and 5 dots, $F(2,54) = 0.07$.

To investigate why there was a significant difference for the six strategies, analyses were conducted between each of four strategy groups. The results showed that there were no significant differences ($p < 0.05$) between the On and Off strategies, or between 2D and 3D strategies, or between 1Stage and 2Stage strategies. However, there was a significant difference between the In and In-Out strategies, $F(1,36) = 18.1$, $p < .001$. When the average values of In and In-Out strategies were compared, the In strategies produced a 31% error rate and the In-out strategies produced a 14% error rates. Figure 5 shows that the In-Out strategies had lower error rates than the In strategies in every target size (1, 3, 5, 7 and 9 dots).

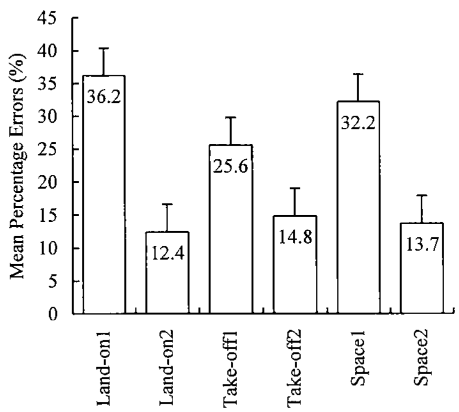

Fig. 4 The mean error rates for each strategy for all sizes. The vertical lines show the standard error.

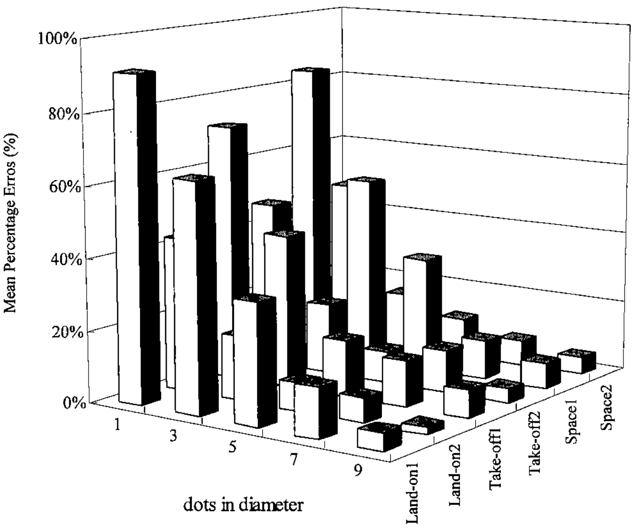

Fig. 5 Mean error rates per target size for the In strategies and the In-Out strategies.

However, when all six strategies were compared, there were significant differences in error rate, in terms of the target sizes of 1, 3 and 5 dots. On the other hand, there were no significant differences in 7 or 9 dots between the six strategies ($p < 0.05$).

4.2 Selection Times

The selection time for each of the six strategies is shown in Fig. 6. There was a significant difference between the six strategies, $F(5, 108) = 3.17$, $p < 0.05$. This means selection times varied according to the strategy used. This indicates that the strategies influenced the selection times.

We investigated the cause of the significant differences in the six strategies. Comparisons between each of the four strategy groups showed there were significant differences between the On and Off strategies, $F(1, 36) = 242.9$, $p < 0.0001$, and between the 1Stage and 2Stage strategies, $F(1, 36) = 8.37$, $p < 0.01$. There were no significant differences between the 2D and 3D strategies, or between the In and In-Out strategies ($p < 0.05$). The average times of the On and Off strategies and the 1Stage and 2Stage strategies, showed that the On strategies (1.26 s) were faster than the Off strategies (2.41 s) and 1Stage strategies (1.13 s) were faster than 2Stage strategies (1.46 s).

There were significant differences for every target size (1 dot, $p < 0.05$; 3, 5, 7 and 9 dots, $p < 0.01$). The differences in selection times caused by variations in the target size were constant.

4.3 Subject Preferences

The analysis of the questionnaire showed a significant main effect on subject preferences for each of the six strategies, $F(5, 30) = 258.5$, $p < 0.0001$. In addition there was a significant difference in subject preferences between the In and In-Out groups of strategies, $F(1, 10) = 803.1$, $p < 0.0001$. This agreed with the test results. Moreover, among three of the strategies (Land-on2, Take-off2 and Space2 strategies) there was also a significant difference in preferences, $F(2, 15) = 7.90$, $p < 0.01$. Rated on a scale of 1-to-9 the Land-on2 strategy was the most preferred (mean = 8.0).

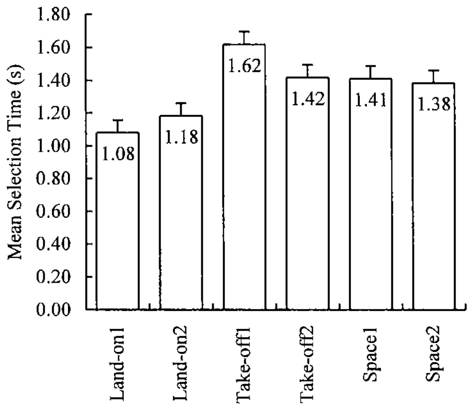

Fig. 6 The mean selection time for each strategy for all sizes. The vertical lines show the standard error.

5. Discussion

Of the six strategies, the Land-on1 and Take-off1 strategies are used most often. However, according to our results, we found the Land-on2 strategy was the most effective for selection of a small target.

As for selection time, a significant difference appeared between 1Stage and 2Stage strategies, and between On and Off strategies. This difference did not depend on target size or pen-movement-direction (180 and 315 degrees were excluded). On strategies were selected faster than Off strategies. 1Stage strategies were selected faster than 2Stage strategies. Therefore we can say that of the six strategies tested, Land-on1 and Land-on2 strategies were the fastest in selection times. This is because they are both On strategies and 1Stage strategies. In addition, the Land-on2 strategy had lower error rates. Thus we have determined that the Land-on2 strategy was the best strategy for selection of a small target in terms of selection time and error rates. In addition, there was no significant difference in selection times between the Land-on1 and Land-on2 strategies, $F(1, 36) = 0.53$. Furthermore the subjects also rated the Land-on2 strategy most highly.

Comparisons of each classified group revealed a significant difference in error rates between the In and the In-Out strategies. This implies that differences in error rates were independent of target size (1, 3 and 5 dots) and pen-movement-directions for these strategy groups. We concluded that the In-Out strategy group was the most effective for selecting a small target.

Regarding error rates, there was no significant difference in the results when the targets were large (7 or 9 dot). On the other hand, there were significant differences for the six strategies when the target sizes were small (1, 3 and 5 dots). The reason for this lies in the difference between the In and In-Out strategies. The In strategies were adequate when choosing large targets because there was no strain on the subject. When choosing a small target, the selection was not accurate using the In strategies only, thus the In-Out strategies were more effective, for example, where targets could be selected by directly pressing the target with the pen. In the case of a small target, it was necessary for the subjects to confirm visually whether or not the pen was inside the target area while either making contact or taking off. Using the In strategies, selection is completed at the moment of contact or take off. On the other hand, the In-Out strategies do not require visual confirmation of the pen position vis-a-vis the target. When selecting a small target with the In-Out strategies, one can direct the pen from a point on the surface of the target after landing on the screen, even if it is impossible to place the pen directly inside the target (as in the Land-on2 strategy). In the case of the Take-off2 strategy, selection was achieved even if a parallax on hand-movement occurred. In the questionnaire subjects overwhelmingly preferred the In-Out strategies. From this it is clear that the In-Out group of strategies is superior.

We have observed the following concerning the strategies of selecting a small target. When a small target on the 2D tablet surface is used (e.g. a pressure perception type tablet like ZAURUS, SHARP Co.), it is possible to conclude: if there are no other targets near a small target (e.g. a point or width of a line with 1 to 5 dots on a graphic screen or a small icon on a small pen-input system), the Land-on2 and Take-off2 strategies in the In-Out group are most effective for selecting the target. The Land-on2 strategy is especially effective when selection speed is considered.

When selecting target sizes of more than 5 dots, the selection performance became identical even when using different strategies. We concluded that 5 dots (1.80 mm circle in diameter) was the largest size among the targets, in which there was a significant main effect on error rates for the six strategies. We called this "the smallest maximum size". Therefore, 5 dots was the smallest maximum value from the experimental results.

In Fitts' law [3], $ID = \log_2(2D/W)$, ID is an abbreviation of *Index of Difficulty* of pointing, D is the distance, and W is the width of the target. If D is a constant, $ID_1 = \log_2(2D/W_1)$, $ID_2 = \log_2(2D/W_2), \ldots, W_1, W_2, \ldots > 5$ dots, then, as far as our results are concerned, there are no significant differences among $ID_1, ID_2, \ldots, ID_n$. In other words, when selecting target sizes of more than 5 dots, differences in the ID (error rates) due to target size will disappear. Thus, we clarified the boundary value of the target size which controlled the difficulty in using strategies. When a target is less than 5 dots, the strategy should be designed in line with our findings. This work defines values by which not only pen-based devices but also other devices may be researched.

No significant differences in error rates ($F(1,17) = 0.25$) and selection times ($F(1,17) = 1.38$, $p < 0.05$.) due to the different conditions associated with on-desk and off-desk use of the tablet were observed. This was because subjects using the tablet in off-desk conditions completed the 240 test trials with the tablet on their laps. This was the subjects' preferred off desk position. Other conditions (e.g. subjects standing) could be the subject of further research and analysis.

In this experiment, we focused on the selection of a single target. We will attempt to compare the six strategies in multi-target environments in future studies. It has been reported elsewhere that differences in the target shapes influence the selection time [12]. Here, circular targets were used so that the distance which the pen travels to the edge of a target remained constant in all directions. It is necessary to examine other target shapes in order to compare them with the results pertaining to circular targets used in this experiment. It is also necessary to investigate the relationships between strategies and target shapes and to find strategies which are suitable for specific shapes. Attention should be given to whether or not those shapes change the smallest maximum size of a target area.

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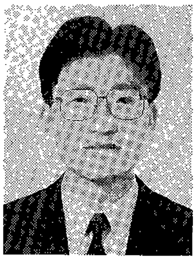
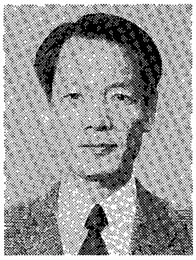


Xiangshi Ren was born in Changchun, China in 1965. He received a B.E. degree in electrical and communication engineering, M.E. and Ph.D. degrees in information and communication engineering from Tokyo Denki University, Japan, in 1991, 1993 and 1996 respectively. He is currently an assistant lecturer 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, and 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.