

Zoom Selector: A Pen-based Interaction Technique for Small Target Selection

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This paper describes the design and evaluation of a new selection technique, called Zoom Selector. Zoom Selector uses a circular zoom area to select a small target. It employs a pre-selection mechanism to activate the objects (e.g., icons) inside the zoom area. Zoom Selector relocates and enlarges these captured objects as sectors of a zoom pie according to their original locations. An empirical evaluation was performed to compare Zoom Selector with other four selection techniques. The evaluation results indicate that Zoom Selector helps a user easily select small target and reduces the cognitive burden of each target acquisition. This evaluation also provides clear evidence that Zoom Selector has a potential to greatly enhance the efficiency, accuracy, and usability of small target acquisition in mobile systems.

1. Introduction

Mobile computing, ubiquitous computing and pervasive computing have emerged as the most promising interactive computing metaphors for use in handheld devices, such as tablet computers, PDAs and mobile phones. These new computing and communication devices support personal information collection, presentation and distribution. Many of them are featured by stylus pens and small screens.

However, there is a paradox in the human interaction with these portable small computing devices. Light weights of these devices make them portable to be easily carried around, however, the portability restricts their accessible screen size to be smaller than on normal desktop computers. In a desktop display, the normal screen size of the monitor is 15–17" (about 381–431 mm) whereas the screen size of a tablet computer is about 8.5–10". The screen size of handheld devices is even smaller, at 3.6–3.8" for the smallest mobile phone.

Although the capacity of the screen size is much smaller on mobile devices, GUI (Graphic User Interface) elements such as pull-down menus, icons and application buttons are usually transferred to mobile interfaces with little change in design or layout. The most commonly used technique for target acquisition in the portable environment is still the click action used in the desktop environment, except

that the mouse is replaced by a pen. The pen click interaction is performed by perceiving the location of the target, pressing the tip of the pen directly on the target and quickly releasing. This process theoretically simulates the click action of the mouse.

This simple transfer of the desktop interface and interaction metaphor into the pen-based mobile computing environment has two drawbacks. In the first place, target acquisition technique using the desktop "click" metaphor is not well-suited to the physical features of portable pen-based devices. The tip of the pen is made of plastic and is equipped with a spring in the body of pen. The elasticity of the pen and the lack of friction on the LCD or tablet surface make it difficult to precisely position the pen tip. Also, pointing/selecting on a slippery surface would require far greater measurement of hand or muscle control if a steady pointing/selection is wanted to achieve. An unsteady hand, which results in less precisely pointing/selecting effort, would greatly reduce interaction efficiency. It also increases the cognitive effort required for successfully locating and selecting targets. Based on these observation, we considered it to be unreasonable to incorporate the normal click metaphor into the pen-based mobile computing environment.

Furthermore, the volume of information displayed on a small screen is constricted by the WIMP interface style. Obviously, fewer objects of standard size can be displayed on small screens. Therefore, small targets are difficult to select using the normal click selection action for reasons mentioned above. Also, the limitation of human eyesight makes the pen-based

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small target selection to be more difficult. Thus smaller screens permit fewer useable icons and much less information per screen.

The challenge is to solve the paradox between the benefits of smaller displays (e.g., portability) and their disadvantages (e.g., the corresponding loss of information and an inefficient target to screen size ratio). This situation suggests a need for a new interaction technique for target acquisition on mobile devices.

We seek to solve the conflict between limited screen size and information display requirements. This will enable users to interact with objects more easily and to promote the interaction advantages of pen-based devices. In this paper, we explore the interaction efficiency of a new selection technique called *Zoom Selector* for application to small target acquisition in small-sized pen-based computers.

2. Related Work

Many studies have reported on interaction techniques because of the universality of the target acquisition task. However, most of that research has focused on mice or touch screen devices^{1),5),10),15),17)}. Ren and Moriya (2000) is one of the few exceptions for pen-input systems¹⁶⁾.

Kabbash and Buxton (1995) proposed the “prince” technique which uses an area cursor to select a target, rather than the click method. They replaced the pointer cursor with a cursor that is larger than a normal activation area¹⁰⁾.

Worden, et al. (1997) made further extension by integrating the area cursor with sticky icons to enhance the performance of object selection tasks conducted by older adults¹⁸⁾. These studies provided some evidence that the area cursor is better than a regular cursor for some target acquisition tasks.

Potter, et al. (1988)’s study of selection strategies on touch screens suggested that more intricate selection strategies may aid target acquisition as the number of items increases and their size decreases¹⁵⁾. Their study indicated that the “take off” strategy is more accurate than the “first-contact” strategy when choosing the target from a group of objects.

Dulberg, et al. (1999) tried to use the flick gesture to not only reduce the cognitive burden required for precise targeting but also decrease the target acquisition and activation time⁵⁾.

To study the selection of extremely small targets (pixel level size), several interaction meth-

ods are proposed and studied^{1),17)}. For instance, Albinsson and Zhai (2003) found that different “interaction instruments” may be used according to different needs. The study of the techniques for pixel level target selection is helpful to explore the capability of the information space in the current ubiquitous mobile small screen devices.

Ren and Moriya (2000) compared pen-based selection techniques and their characteristics, and proved that the proposed “Slide Touch” selection technique is the best of the six techniques tested. Slide Touch is where the target is selected at the moment the pen-tip touches the target for the first time after landing on the screen surface. The experiment results show that it is particularly useful in the situations where the target is isolated or where targets are arranged sparsely¹⁶⁾.

Past literature have provided some useful, albeit limited suggestions for design of acquisition techniques to enhance the interaction usability and efficiency for small object selection. However, their recommendation have several limitations inherited from their original design assumptions about the usage context.

The work described in this paper aims to provide a technique that can precisely select a target from a group of objects, especially when these objects are arranged close together. Zoom Selector provides an alternative method for supporting small interface objects on small screens by using a transparent lens to zoom in on the object for selection. One specific innovative aspect in our work is that we also consider the inter-distance between small targets as one of the factors in evaluating the efficiency of the target acquiring techniques used on small screen devices. This has not been considered in any previous literature.

In this work, we compared Zoom Selector with several previously studied interaction techniques^{5),16),18)}.

In addition to the research results reported on the direct object targeting, some auxiliary methods were also proposed in previous work. Among them, zooming was demonstrated to be a powerful mechanism for interaction with multi-scale information spaces^{2),14)}. It is efficient as an intermediate step in pointing at the enlarged objects. In the context of abstracting the information structure, it has been employed to enable the user to explore the data spaces with different levels of information ab-

straction²⁾. Its information hierarchy feature is employed in the design of Zoom Selector to amplify the interface objects on the small screen. A transparent lens is used to select irregular object area by using different palettes³⁾. The use of transparent tools enables the user to continue to see the underlying application with minimum disturbance. Zoom Selector also uses a transparent circle (or lens) to select objects lying beneath the region. The circle sections are filled with color only when the user is approaching the target. This instance-zooming overcomes the disadvantage of constant zooming where the user loses the contextual global view of the task. This was mentioned as a major barrier to the use of zooming in small screen devices¹⁾.

3. Zoom Selector

We designed Zoom Selector as a kind of magnifying lens for target selection and compared its interaction efficiency on selecting objects in different sizes and different object layouts.

We found that there is often only one row of icons displayed in a PDA application because of its space shortage. Therefore, the number of icons that can be displayed on the screen is limited. In some cases, if more than one row of icons are displayed, there is little space left for displaying other information, such as text, pictures, etc. We found this to be true of mobile phone interfaces as well. Typical applications that can be found on PDAs and mobile phones include web-browsers, message editors, picture drawing, etc. Based on this observation, we designed Zoom Selector to enable small object selection. More icons can be arranged in both horizontal and vertical dimensions. More space can be left for displaying other information.

We considered that the selection of an interface object, such as an icon, can be divided into two processes. The first is the conceptual process to recognize the target object from a group of objects displayed within a certain interface area in a certain layout. The second process is to select the recognized target by directly clicking on it or locating it using alternative techniques. This process should be conducted based on the recognition of the target object or a rough area that may include the target icon. Of course, this step also can be used to further identify the target object if a rough area has been assumed to possibly include the target object, even if the action is cancelled without a selection.

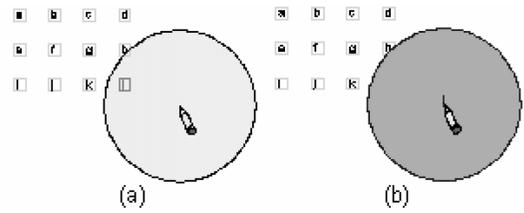


Fig. 1 A single object covered by Zoom Selector (a) will be realigned as in (b).

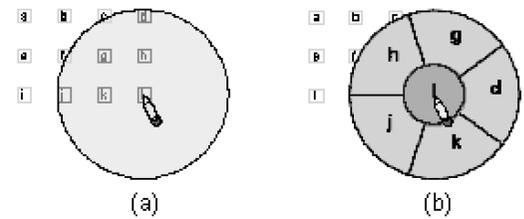


Fig. 2 When multiple objects are included in Zoom Selector area and one of them contains the pen tip (a), they will be realigned as in (b).

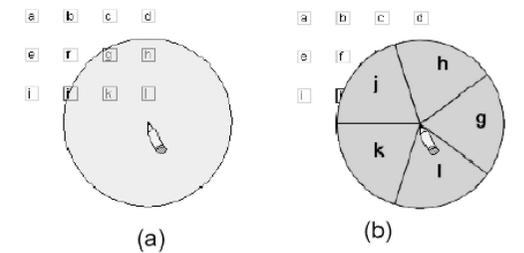


Fig. 3 When Zoom Selector covers multiple objects (a), it will redisplay these objects as in (b).

Our design mainly addresses the second process and tries to provide a selection interaction technique to improve the efficiency of physical selection of the target icon.

Zoom Selector is composed of a transparent round circle, an adjustable lens, with the pen tip at the center. The colored transparent circular cursor (35.6mm in diameter) is used to catch objects, as shown in **Figs. 1 (a), 2 (a), and 3 (a)**. This adjustable lens appears when the pen-tip touches the surface of the tablet or is less than 1 cm above the tablet screen surface. Through the translucent lens, it is easy to see how many objects are inside the pre-selection area and what each of them is. Their features, such as the size and the label, are dis-

We used an electromagnetic tablet in the experiments. This type of tablet can recognize the coordinates (x, y) of the pen-tip.

played recognizably, without being hidden or distorted. This step is called catching the target object.

Given the confidence that the target object is caught by the lens, the user can activate Zoom Selector to make a precise selection. Simply pressing the pen-tip, the display of Zoom Selector changes from the circular cursor to a pie menu. Pre-caught objects are relocated in this pie menu, with one object in each sector, as shown in Figs. 1 (b), 2 (b), and 3 (b). An object relocation strategy is applied to help the object recognition.

There are many ways to relocate enlarged icons. For instance, icons can be mapped according to their original locations, such as image-based magnification, or, they can be arranged according to the group to which the icon belongs, such as pie-arrangement. Image-based magnification is more intuitive and faster to find the target in the enlarged area because this approach preserves original relative positions of objects. Comparatively, the pie arrangement can be easier for pen-based directional control. In image-based magnification, the user must stop at the target region to control both distance and orientation of the moving, while, in pie-arrangement, the user only needs to care about the orientation. To the most, using the image-based magnification approach to enlarge the area covered by the lens may distort the shape of the objects. It may inevitably result in a certain amount of demagnification to compensate for the loss of display area¹¹⁾. For these reasons, we choose the pie-arrangement, over the image-based magnification, to enlarge the small screen objects in our design of Zoom Selector.

Pie arrangement in Zoom Selector is further enhanced by a strategy, which is called the shortest-distance strategy. This strategy is designed to relocate the objects that are captured by the lens according to the distance from the location of the pen-tip to the location of the icon. Assuming that the location of the pen-tip is the user's focus point, if the object is closer to the focus point before the pen-tip is pressed, it will be relocated onto the position that is also closer to the focus point after pressing. We thought this shortest-distance approach may reduce the cognitive load of the user and would enable the user to find and hit the correct target.

The shortest-distance approach does have

some drawbacks. We found that locating the central object onto the central section in the pie will reduce the user's cognitive load, but, when we tried to keep same relocation strategy on the other rounded objects, users may lose their location orientation.

To improve users' perception efficiency yet help them keep their location orientation, we made a tradeoff design in this work. We considered there can be two types of situation that objects are captured, depending on the distribution of the captured objects. One can be the case that the distribution of objects shows strong inclination on the target that users may desire. We can call this "inclined capturing". Examples can be that there is only one object captured by the circle lens (Fig. 1), or there are more than one objects captured, within which there is only one object that has the strongest possibility to be the desired target (Fig. 2). Another type of object capturing can be the case that there are more than one objects captured, and none of them is obviously inclined as the target. We can call it "non-inclined capturing". An example can be the situation shown in Fig. 3.

For cases that are inclined capturing, we use the shortest-distance strategy to relocate the object that is closest to the focus point, which is strongly inclined to be the desired target, onto the central section, see Figs. 1 (b) and 2 (b). For the cases that are non-inclined capturing, we get objects' original location sequence from left to right and top to bottom. Objects are rearranged, following their location sequence, to the sections of the pie from the middle of the 0° horizontal line in a counter clockwise direction. For example, in Fig. 2 (a), there are 12 buttons on the screen. The pie captures six of them, which are buttons *d*, *g*, *h*, *j*, *k*, and *l* (from the left to the right, from the top to the bottom). The button *l* is under the focus point, whereas the other five are not. When Zoom Selector is invoked, the button *l* is relocated onto the center circle of the pie (this object is highly possible to be the target). The other five are relocated onto the other five pie sectors, from the middle of the 0° horizontal line in a counter clockwise direction (these objects are not obviously inclined.). A similar example is shown in Fig. 3. In this case, no object is inclined to be the target, and therefore, five captured objects are rearranged as non-inclined captured objects. The different relocating strategies for inclined/non-

inclined objects enable us not only taking advantage of short-distance to reduce the user's cognitive burden, but also alleviating the lose of object orientation caused by object rearrangement.

Once the user presses the pen-tip, three different object layouts may be displayed on the activated lens of Zoom Selector according to the different context of the covered objects. Figure 1 (b) depicts the layout case when only one object is caught by the adjustable lens. Figure 2 (b) displays the instance where multiple objects are captured, and there is a object located precisely under the user's pen-tip. Figure 3 (b) shows multiple objects being caught where no specific object is under the precise location of the pen-tip. If there is no object covered by Zoom Selector, the adjustable lens will not be activated. With an enlarged object pie, the user can easily recognize the target object. The user can drag the pen to the desired pie sector (i.e., the target object) and then release the pen to finalize the selection. The user can also give up a selection by releasing the pen outside the selector.

Generally, when the user wants to choose a target, he/she can move Zoom Selector to the area that includes the target, then press the pen to activate Zoom Selector, and finally select the target he/she wants to acquire.

4. Experiment

4.1 Subjects

Sixteen volunteers (10 males and 6 females) served as subjects in the experiment. All of them were right-handed, and had professional experience using the mouse. Eight of them had some previous experience using the pen, but rarely used the pen in everyday life.

4.2 Apparatus

The experiments were performed on a Pentium IV 1.5 G PC running Microsoft Windows 2000 professional. A Wacom tablet with a stylus pen and a Samsung 17" monitor in SVGA mode (1024 × 768) were connected to the PC.

4.3 Design

The details of the design are shown in Tables 1–4. The design parameters of screen size, target size and object layout were chosen based on a survey of real interaction situations. We had investigated the interfaces of tablet computers⁸⁾, PDAs^{4),6),9),12)}, and the interfaces of mobile phones, such as Motorola 2688, Nokia 8810, and Panasonic GT90.

Table 1 Screen environment.

Desktop	368 × 259 mm (1024 × 720 pixels)
Tablet	180 × 216 mm (500 × 600 pixels)
Mobile	79 × 108 mm (220 × 300 pixels)

Table 2 Target size.

Small	0.70 mm	Smallest object size possible (3 pixels)
	1.06 mm	The smaller size (5 pixels)
Middle	2.11 mm	The size of the object icon in the toolbar (10 pixels)
Large	5.30 mm	The size of a toolbar icon in the application (25 pixels)
	6.77 mm	The size of an object icon in the desktop (32 pixels)

Table 3 Object layout.

1	One single object (i.e., target) displayed on the screen
2 × 2 Compact	Four object icons are displayed compactly, in 2 rows and 2 columns, separated only by a thin dividing line.
2 × 2 Inter-spaced	Four object icons are displayed with a space, in 2 rows and 2 columns, whose width is the same as the size of an object icon.
3 × 4 Compact	Twelve object icons are displayed compactly, in 3 rows and 4 columns, separated only by a thin dividing line.
3 × 4 Inter-spaced	Twelve object icons are displayed with a space, in 3 rows and 4 columns, whose width is the same as the size of an object icon.

The experiment used a four factor, mixed factorial design with repeated measures. The within subjects variables that constituted the task type were the screen environment (Table 1), target size (Table 2), object layout (Table 3), and the type of selection technique (Table 4). Selection time, error score, and subjective preferences were the dependent variables.

4.4 Procedure

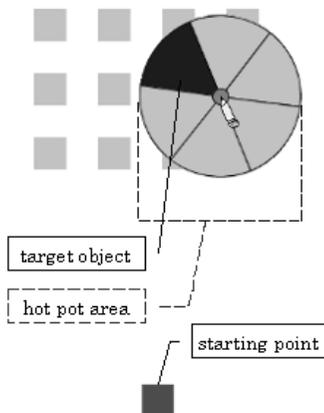
First, all of the selection techniques were explained to the subjects. Then, each subject had 30 minutes to practice. Those who had no experience using the pen were given an extra 10 minutes in addition to their assigned training time.

After finishing the orientation trials, subjects were told to do the real trials. The experiment was separated into three parts, one for each type of the three screen environments (see Table 1).

At the beginning of each part, a list of the five techniques was displayed. Once one tech-

Table 4 Selection technique.

Normal Click	Like the mouse, the pen moves to the object. When the hotspot of the cursor is on the object, the tip of the pen is pressed on the screen and quickly released.
Slide Touch	The target is selected when the pen touches it for the first time; in this case the pen initially lands outside the target area before moving into it.
Flick Gesture	The left mouse button is briefly pressed and held while the mouse is quickly moved a short distance.
Area Cursor	Area cursor has a larger hotspot than normal activation area, of the same size as the area cursor; this serves as the point of activation for the cursor.
Zoom Selector	The pen moves into the area of the objects and is pressed. Pre-selected objects are displayed on the activated Zoom Selector (35.6 mm in diameter). The pen-tip is then moved to the desired enlarged target sector and released to fulfill the selection.

**Fig. 4** A screen shot of the experiment.

nique was indicated, the subject would begin to do a succession of trials. Each trial combined one target size and one arrangement of objects. For each technique a total of 5×5 trials were completed. This represents a random combination of 5 target sizes and 5 target arrangements selected randomly by the computer.

A screen shot of the experiment using Zoom Selector is shown in **Fig. 4**. The start point was located at the center of the bottom of the interface. To begin the trial the subject was instructed to point at the start point so that all the subjects' trails began at the same point. The size of the hotspot is the double size of the object plus the interspaced distance between two objects, which is also the diameter of Zoom Selector.

The steps for selecting a target were as follows:

- (1) The beginning point was display at the center of the bottom of the interface.
- (2) The subject touched the initial position with the pen. Once the beginning point was selected, the trial had begun. The time recorder embedded in the application recorded the trial times.
- (3) A group of icons were displayed in the center of the top of the screen, one of which was the target icon. The target icon was blue, all of the rest were gray.
- (4) The subject attempted to select the target.
- (5) The object that the subject selected was turned to red, even if the subject made a wrong selection.
- (6) Once the subject selected the target correctly, a message box was displayed to the subject indicating that the trial had been completed successfully.
- (7) The subject then repeated (1) through (6) above.

The selection times for the trials were recorded. During the trials, subjects made some unsuccessful selection attempts. The times for error interactions were recorded as error scores. For example, if the user made 4 error selections before completing the selection of a 3 pixel target with a 2×2 object layout on the tablet screen size using the normal click, the error score in that situation would be 4.

At the end of the trials for each technique, a questionnaire regarding subjective preferences was presented. The subjects were asked to input a preference value for each selection interaction according to their experience in the trials. The range of preference values was 1 (lowest preference) to 10 (highest preference). One digital decimal place was allowed.

Each subject completed a total of 125 trials in each screen environment. The sum of the trials in each screen environment was the combination of the five selection techniques, five target sizes and five object layouts ($5 \times 5 \times 5$). Each subject therefore completed 375 trials (125×3). All subjects completed all of the trials. After finishing the experiment, we had a set of trial data consisting of 16×375 items. In addition, each subject supplied 15 preference values, 5 for each screen environment. The analysis of subjective preferences was based on 16×15 values.

5. Result

We applied an ANOVA with repeated measures to analyze performance in terms of selection time, error score, and subjective preferences. Post hoc analysis was performed with Tukey's Honestly Significant Difference (HSD) test.

5.1 Selection Times

The analysis showed that there were significant differences within the five selection techniques in terms of selection time, $F(5, 5995) = 92.41$, $p < 0.001$. The selection time for Zoom Selector was the shortest (mean = 1,380 ms).

The post hoc Tukey HSD test showed that performance with Zoom Selector was faster than with Normal Click, Slide Touch, and Flick Gesture ($p < 0.05$). Selection by Area Cursor was faster than the Normal Click, Slide Touch and Flick Gesture techniques. The analysis results also showed that there was no significant difference between Normal Click, Slide Touch and Flick Gesture.

5.2 Error Scores

The analysis of mean error scores showed that there were significant differences among the five selection techniques, $F(4, 5995) = 88.81$, $p < 0.001$. The mean error score for the Normal Click technique was the highest (0.80). Zoom Selector had the lowest scores (mean = 0.17).

The post hoc Tukey HSD also showed the mean error score of Zoom Selector and Area Cursor were significantly lower than those of Normal Click, Flick Gesture, and Slide Touch. There was no significant difference between Zoom Selector and Area Cursor.

5.3 Subjective Preferences

There was a significant difference between the five selection techniques in subjective preference, $F(4, 235) = 64.09$, $p < 0.001$. Zoom Selector ranked first (mean = 8.47), followed by Area Cursor (mean = 7.78), Slide Touch (7.06), Flick Gesture (5.72) and Normal Click (5.63).

The post hoc Tukey HSD test also revealed that the mean subjective preference for Zoom Selector was significantly higher than for the other four techniques.

5.4 Comparing Performance in Different Interaction Contexts

We also performed a detailed analysis of the efficiencies of the selection techniques in three interaction contexts: (1) screen sizes; (2) object sizes; and (3) object layouts.

(1) *Screen Sizes.* The distances between ob-

jects varied with different screen sizes. Through analysis of the selection performance on different screen sizes, we were able to look closer at the efficiency of the selection techniques.

Analysis showed that significant differences were found between the five selection techniques on three screen size respectively (Desktop size: in selection time, $F(4, 1995) = 26.03$, in mean error score, $F(4, 1995) = 23.10$, both $p < 0.001$; Tablet size: in selection time, $F(4, 1995) = 55.25$, in error score, $F(4, 1995) = 42.58$, both $p < 0.001$; Mobile size: in selection time, $F(4, 1995) = 39.57$, in error score, $F(4, 1995) = 30.90$, both $p < 0.001$)

Performance times of Zoom Selector in all three screen contexts were the fastest (Desktop: 1694.71, Tablet: 1333.79, Mobile: 1,112.66 ms) and the most accurate (Desktop: 0.19, Tablet: 0.18, Mobile: 0.14 ms) among the five selection techniques.

The results revealed that zooming and relocating small objects into larger zoomed sectors gave Zoom Selector a significant advantage in selection time and accuracy especially in the small screen environment.

(2) *Target Sizes.* The mean selection time and mean error score of using five selection techniques to select objects with five different sizes are shown in **Fig. 5** and **Fig. 6** respectively.

From Fig. 5, selecting a 3 pixel (0.70 mm) object is the most difficult. The corresponding mean selection time was the longest. The selection of 32 pixel objects was faster than the selection of objects with the other four target sizes. This result demonstrated Fitts' law, which says that the index of difficulty for target acquisition rises as the width of the target decreases⁷⁾.

The analysis of selection techniques with respect to selection time for 3, 5, 10, 25, and 32 pixels showed that there were significant differences, $F(4, 1195) = 52.05, 33.68, 28.10, 17.41,$ and 40.83 , all $p < 0.001$. The post hoc Tukey HSD tests revealed that when the size of the target object is 3 or 5 pixels, Zoom Selector performed significantly better than the other four selection techniques. Also, from the bar chart, it can be seen that the performance of using Zoom Selector to choose the object is stable when the size of the object varies from small (3 pixel object) to large (32 pixels).

The analysis showed that the five selection techniques had significant effects on selection accuracy in each of five target size contexts. $F(4, 1195) = 35.10, 17.05, 19.67, 24.77,$ and

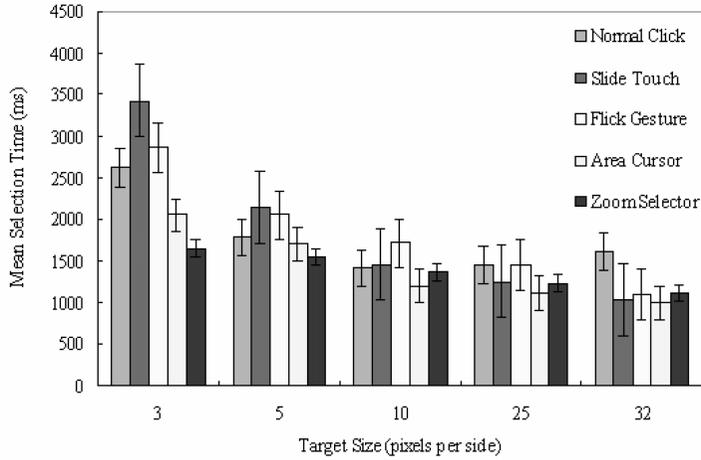


Fig. 5 Mean selection times in terms of five selection techniques with five target sizes.

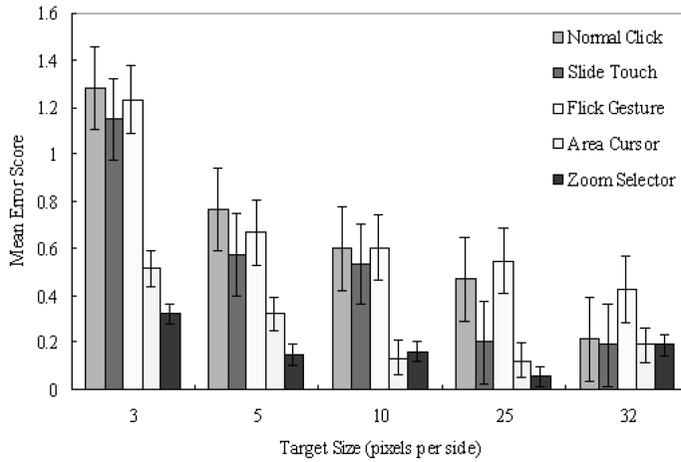


Fig. 6 Mean error scores of five selection techniques with five target sizes.

42.38, all $p < 0.001$. Selection using Zoom Selector revealed the fewest mistakes in 3, 5, 25, and 32 pixel targets. The distribution of targets in the circle section helps the user more easily achieve the acquisition of the target. When selecting the target size of 25 pixels, the effectiveness of using Zoom Selector reaches the peak (the error score was 0.05, which was one thirteenth of the value of using normal click technique).

(3) *Object Layouts.* Results of the analyses revealed that there were no significant differences between the target layouts in both selection time, $F(4, 5995) = 1.32$, and error score, $F(4, 5995) = 0.24$. It means that the variations in object layout would not affect the efficiency and accuracy of selection significantly. This agrees with Ren and Moriya

(2000), i.e., pen-movement-distance and pen-movement-direction do not affect selection techniques significantly¹⁶).

6. Discussion

(1) *Overcoming touch surface slipperiness and pen-tip vibration due to hand shake.*

From our experimental results, it can be seen that Zoom Selector and Area Cursor outperformed the other three techniques in both selection times and error scores.

The interactive characteristics of pen devices and experimental design features cause this increased performance. When contrasted with the normal click of a mouse, the unsteadiness of the pen-tip can make the press and click action inaccurate. This unsteadiness makes it difficult for users to hit a precise point on a small

screen. According to our observation, it is very common that the pen-tip often makes contact within a larger range near the target because of the touch screen slipperiness and the pen-tip vibration. Therefore, allowing some tolerance on the location of the pen-tip and providing an approximate adjustment for the hand movement to approach the target from surrounding areas would greatly reduce the risk of missing the object. This can explain that the lower error rate of using Zoom Selector and Area Cursor since both of them do not require for precisely object acquisition. They support much more imprecise actions compared with the Normal Click, or Flick Gesture techniques. Area Cursor uses its hotspot area to select the objects. Zoom Selector uses the pre-selection and object zooming to overcome the effects of the unsteadiness of the pen-tip and the human hand. When a group of objects are captured by the transparent circular cursor, the objects that are located inside the pre-selection area of Zoom Selector are activated, and then the pen-tip can be moved toward the target object gradually until it is under the cursor. The mean selection time and the error score for the selection of 3, 5, and 10 pixel targets reveals that the usage of pre-selection and selection areas results in more efficient and accurate selection than when using Normal Click and Flick Gesture, which require more effort to perceive the precise location of object.

In Potter, et al. (1988)'s experiment, it has been shown that the take-off technique produced more accuracy compared with the first-contact (similar to Slide Touch)¹⁵. Conversely, Slide-Touch is better than Take-Off (similar to the take-off technique) in Ren and Moriya (2000)'s experiment¹⁶. First, in Potter, et al. (1988)'s experiment, the techniques were designed for finger (touch-screen). The finger has less vibration than the pen-tip. Also, they designed the target as a large two capital letter size object (1/4 square inch) so the target can be verified at that cursor location before a selection is made upon release. However, precisely selecting a pixel-level object using the take-off technique becomes very difficult in pen-based situations because the hand vibration and the slipperiness of the touch surface. This can also explain why the Slide Touch technique achieves a lower error rate than the Take-Off technique when choosing a pixel (0.36 mm diameter circle) or small pixel objects by pen in Ren and Moriya

(2000)'s experiment. However, when choosing an object from a layout of densely displayed objects, the Slide Touch technique may have trouble. There is a risk of choosing a wrong object instead of missing the object. Zoom Selector provides the zooming function to enlarge the captured objects. This provides the user with the ability to make sure the target is under the pen-tip before releasing it to make the selection. This minimizes the effect of vibration of the hand/pen-tip, or/and the slipperiness of the touch surface. Zoom Selector can prevent the user from choosing the wrong object and improve the selection accuracy.

(2) *Overcoming the limitations of smaller target sizes.*

Zoom Selector pre-selects the filtered objects inside the circular pre-selection area, relocates the objects based on their relative original locations, and zooms them out to the large pie sectors.

Because of this pre-selection strategy, the user only needs to position the pen in the general area of the target. There is no requirement to precisely hit the target. This greatly reduces the user's cognitive load. Once the center of Zoom Selector has been identified, the objects activated in the zoom area are relocated according to their original locations by applying the shortest-distance strategy we described in Section 3. Each object is located in a circular pie sector that is an equal division of the 'pie' based on the total number of activated objects. When the user presses the pen-tip, it is very easy for the user to see where the target is. In the experiment, we have shown that the use of Zoom Selector to select the small target sizes, 3 and 5 pixels is more efficient than the other methods.

The zoom mechanism makes objects appear larger, so that the user can easily recognize and distinguish the desired target from others. In our experiment, Zoom Selector magnified the objects by 5–10 times. The zoom technique makes the acquisition of small targets easy, and reduces the user's cognitive load when selecting.

Furthermore, the high preference value for Zoom Selector showed that it was the preferred target selection technique among subjects. Informal discussion with subjects also revealed that it took less effort to select small targets using Zoom Selector because a zoomed display of the objects made locating them much easier. It also can be seen that by zooming the objects the cognitive effort to perceive and select small

targets is greatly reduced.

7. Conclusion

We described the design and evaluation of a new selection technique, *Zoom Selector*. Our results show *Zoom Selector* outperforms the normal click method when used for small target acquisition. It is faster and more precise. The method of pre-selection, relocation and zooming of small objects into a large pie sector helps the user recognize and select the target more easily, and greatly reduces cognitive load in the selection interaction.

Our empirical evaluation and comparison of *Zoom Selector* with the other four selection techniques provides clear evidence that *Zoom Selector* shows a potential to greatly enhance the efficiency and accuracy of small target acquisition in mobile systems using a stylus pen. It could also be an efficient selection interaction metaphor to apply to PDAs or mobile phones.

We believe that the results of our work uncovered several basic principals that are applicable directly toward the design of interaction techniques for small target acquisition or for use with small screen devices.

Future work includes 1) doing a comparison of using image-based magnification and pie-arrangement for target acquisition, especially for small objects, and 2) improving the method of relocation and the presentation of activated objects in the zoom area according to the target distance from the center of *Zoom Selector* center by use of a new optimizing algorithm, rather than locating the objects in equal pie sectors in *Zoom Selector*.

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