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ShifTable: A Natural Remote Target-Selection Technique on Large Displays

Kibum Kim[1,2], Xiangshi Ren[1*] and Yang Gao[1]

[1]*Kochi University of Technology, 185 Miyanokuchi, Tosayamada-cho, Kami City, Kochi 782-8502, Japan*
[2]*Chuncheon National University of Education, Gongji Ro 126, Chuncheon 200-703, Gangwon-Do, Republic of Korea*
**Corresponding author: xsren@acm.org*

To simplify the selection of remote targets on large displays, a novel technique called ShifTable is presented in this paper. With ShifTable, users move a finger or a pen towards a desired target, and the whole screen carrying the target shifts faster in the opposite direction, towards the finger or pen. We conducted two experiments to compare ShifTable with unaided direct selection (baseline), Gesture Select and Pan. The results show that ShifTable was significantly faster than unaided direct selection and Gesture Select in selection time, and outperformed Gesture Select in error rate. In addition, elderly participants were able to copy-and-paste targets significantly faster with ShifTable than with Pan. Although ShifTable's simple operation allows users to easily and naturally select remote targets on a large display, we also found usability issues that need to be addressed for this intuitive technique to be more widely accepted by the elderly users.

RESEARCH HIGHLIGHTS

- Presents natural and simple remote target-selection interfaces for large vertical and horizontal displays.
- Describes user studies with elderly people who have no experience on large multi-touch displays.
- Articulates the features of ShifTable for the elderly users and presents an analysis of differences between ShifTable and other interfaces.

Keywords: interaction paradigms; pointing; gestural input; pen computing; tables and interactive surfaces; elderly/seniors

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1. INTRODUCTION

Large displays are becoming increasingly popular as commercial products. Researchers have paid a lot of attention to large screen interaction, focusing on issues like large-scale scientific data visualization (Ni *et al*., 2006) and mid-air pan-and-zoom techniques (Nancel *et al*., 2013). It is true that large displays can be operated from a distance by a mouse or a keyboard; however, there are many situations where users need to or prefer to manipulate icons at close range such as on large multi-touch tablets. Unlike interacting with desktop devices where all the objects are within the users' reach, users have to walk to select distant targets when working with large displays. Such inconvenience not only causes physical tiredness but also interrupts the users' workflow. To solve this problem, researchers have proposed two kinds of technique. One is interaction from a distance with an intermediate device (e.g. Aliakseyeu *et al*., 2006; Antle *et al*., 2011; Iannacci *et al*., 2011; Parker *et al*., 2005; Shoemaker *et al*., 2007). The other is interaction from a distance with no intermediate devices, as for example where targets are selected by using a ray-casting model, e.g. Banerjee *et al*. (2011) and Vogel and Balakrishnan (2005), while others select remote targets by bringing targets near to them, e.g. Baudisch *et al*. (2003), Bezerianos and Balakrishnan (2005) and Bragdon and Ko (2011). However, these techniques ignored two important features in practice; (i) selection with devices or gestures can be difficult to operate,

Figure 1. ShifTable: (**a**) the user draws an initial line with a finger or a pen to trigger the technique. (**b**) The user keeps moving the finger towards the desired target, and the screen shifts at a faster rate towards the finger. When it approaches, the target is selected by single tapping on it. (**c**) Then, the corresponding application is activated, and the screen returns automatically to its original position.

and users may prefer natural gestures to capture a target, and (ii) if a large display is wall-sized, users maybe not be able to select a target that is too far away for them to see it clearly.

In this paper, we present ShifTable, which is as easily performed as a natural 'reach' motion with the following process; (i) users draw an initial line with a finger or a pen in the general direction of the desired target to trigger ShifTable, (ii) they move the finger or the pen continuously towards a desired target, and the screen carrying the target shifts in the opposite direction of the finger or the pen, (iii) they select the target by single tapping on it, and after selection the screen returns automatically to its original position (Fig. 1).

2. RELATED WORK

We analyzed previous techniques for selecting remote targets on a large display. The existing techniques can be classified into two categories, interaction using devices and interaction without using any devices.

2.1. Interaction using devices

Several techniques allow users to use devices when interacting with large displays at a distance. For example, a laser pointer is a common device for remote interactions with large displays (Antle *et al.*, 2011; Iannacci *et al.*, 2011; Myers *et al.*, 2002). Bubble radar uses a tablet to control a large display with the aid of bubble cursor (Aliakseyeu *et al.*, 2006). On the other hand, a projector can be a mediator for interacting with large displays: shadow reaching is a shadow-based interaction, which applies a perspective projection to a shadow representation of a user, and the user interacts with the display via body positioning (Shoemaker *et al.*, 2007); TractorBeam is a hybrid point-touch input technique, allowing users to reach remote targets on a tabletop by casting a virtual beam (Parker *et al.*, 2005). ContHead lets users perform pointing actions with coarse pointing first using natural head movements, and then with precise pointing using a small pointing zone on the handheld device via finger gestures (Nancel *et al*., 2013).

Bragdon and Ko (2011) proposed Gesture Select, which overlays different marks on the targets. Users need firstly to identify the marks, and then draw the same gesture as a mark on the target to select it. However, this technique is not scalable when targets are too small or far away for users to identify the mark clearly. In addition, the complexity of different gestures may cause physical tiredness. Superflick gives a good summary of remote interaction techniques with large displays using devices (Reetz *et al.*, 2006).

2.2. Interaction without any devices

The need of additional devices is inconvenient for users when interacting with large displays, especially with horizontal displays. To avoid this limitation, many techniques have been developed to interact with large displays without using any devices. Some techniques are based on ray-casting models, while others bring targets near so users can select them.

2.2.1. *Based on ray-casting models*

Vogel and Balakrishnan (2005) proposed AirTap and Thumb-Trigger, unimanual pointing and clicking interactions on large displays from a distance. They pointed out that ray-casting was fast, but inaccurate. Jota *et al*. (2010) compared four pointing techniques—laser, arrow, image-plane and fixed-origin. Taking the user's line of sight (i.e. perspective) into consideration improved the accuracy of the task. Their work supported single-handed interactions. Pointable is an in-air, bimanual interaction, which is based on the user's perspective on the target (Banerjee *et al*., 2011). With Pointable, the cursor position is determined through a nose bridge and the index finger of the dominant hand; then the non-dominant hand is free to scale and to rotate the target. These techniques, based on ray-casting models with a line of sight, require users to stare at the desired target, and this may make the users tired.

2.2.2. *Bring targets near to users*

Drag-and-Pop/Pick (Baudisch *et al*., 2003) brings distant targets near to users by creating copy icons, and then users select and manipulate the copies to interact with the originals.

However, this technique can only bring a fixed number of targets nearer. Push-and-pop (Collomb *et al.*, 2005) brings more targets close to the user, which is effective for low target density. However, it may not work well when the targets are large and numerous, and when users have to re-find the desired target. Object pointing (OP) (Guiard *et al.*, 2004) skips empty spaces to interact with the screen so it can drastically reduce wasteful input information. Delphian Desktop (Asano *et al.*, 2005) constantly tracks the cursor location to predict the user's desired target, and then the user can either automatically or manually jump to the goal position according to the prediction. However, OP and Delphian Desktop were not evaluated on large displays.

The Vacuum (Bezerianos and Balakrishnan, 2005) is a circular widget on the screen by which users bring remote targets near keeping spatial proportions, but in smaller scale. The Vacuum is scalable to large numbers of targets, but not to small targets because the smaller the targets become the harder they are to select. In addition, according to Bezerianos and Balakrishnan (2005), there was no significant difference in selection time between Vacuum, Drag-and-Pop/Pick, and unaided direct selection for single-target selection. Malacria *et al.* (2010) proposed CycloPan and CycloZoom+ for navigation. CycloPan pans large documents by the line of finger motion, and CycloZoom+ carries the region of interest into view by a circular finger motion. These two techniques were mainly conducted on navigation tasks, although the authors pointed out that they could also be used for many other interaction tasks.

On the other hand, Karlson and Bederson (2007) presented one-handed selection of targets, which were out of thumb reach on touchscreen-based mobile devices, while users were standing and walking. ThumbSpace, their object selection technique for one-handed thumb use on mobile devices, has promising implications and it could be easily applied to remote target selection on large displays (Karlson and Bederson, 2007, 2008).

In commercial applications, the common way to bring targets near to users is to use Pan or Scroll interfaces. Of all these techniques, Pan is the most similar technique to ShifTable. However, there are a couple of significant differences between them. First, with Pan, the movement speed of the targets is similar to the speed of the user's hand. So, if the desired target is located far away, users have to move the hand several times to reach it on a large display. In contrast, ShifTable provides faster movement of the targets than the movement of the user's hand. Second, the direction of the hand movement used to draw the target is the opposite for ShifTable, i.e., in ShifTable hand movement is towards the target. This feature has several advantages, which we will discuss later. Third, ShifTable supports an easy screen-reset method, and this feature is useful in some context such as a copy-and-paste task, which was tested in Experiment 2. The details of these differences are discussed in the discussion section later.

3. CHARACTERISTICS OF SHIFTABLE

ShifTable is designed for simple operation and natural 'reach' motion. We designed ShifTable according to the following goals:

- *Simple and easy*. The technique should be easily operated and it should minimize physical movement and fatigue. Ideally, it should be as simple as a regular pointing or clicking target-selection task.
- *Scalable to different conditions*. The technique should be effective in various conditions, such as small/large targets, near/far targets, and sparsely/densely dispersed targets.
- *Easily extended*. The technique should support not only the selection of remote targets but also extended manipulations such as copy, paste, delete and rename.
- *Flexible adjustment*. The technique's parameters should support flexible adjustment with minimal overhead. It should support timely modification of inaccurate operation without restarting the whole technique.

Compared with previous works, ShifTable has a number of potential advantages:

- With ShifTable, the screen will shift in the direction opposed to the movement of the user's finger or pen. This resembles a natural and subconscious movement to reach an object.
- Unlike Drag-and-Pop/Pick (Baudisch *et al.*, 2003) or Vacuum (Bezerianos and Balakrishnan, 2005), ShifTable does not drag a specific number of targets, but moves the whole screen with all the targets towards the user without shrinking the size of targets or the space between them. This helps users re-find the desired target by maintaining the target's relative positions. Therefore, ShifTable can work well for targets whether they are clustered together or evenly distributed.
- Unlike Vacuum (Bezerianos and Balakrishnan, 2005) or Gesture Select (Bragdon and Ko, 2011), ShifTable does not need any proxy target or complex gestures to select targets or to adjust the direction.
- Two steps of the remote target-selection interaction can be fluidly achieved: move the finger or pen towards the desired target, and then select the desired target when it comes near.
- When users attempt to access a target by motioning in a wrong direction, the direction can be adjusted flexibly and quickly just with a natural 'reach' motion.

4. DESIGN OF SHIFTABLE

The design of ShifTable includes the following parameters: initial line (l) to trigger ShifTable, speed ratio (α) to determine the movement speed of the screen, movement direction and its adjustment, how to select a target, and how to reset when there are mistakes. The following subsections discuss these design features.

4.1. Trigger

ShifTable is triggered by drawing an initial line in the direction of a target. For a target already within reach, it is best to directly select it. Therefore, our technique is triggered only for the targets that are beyond the user's reach. The length of the initial line (l) is set as the ratio of the average length of a sample of users' reaches (r) to the speed ratio (α):

$$l = \frac{r}{\alpha} \tag{1}$$

The interface will start to shift only when the initial drawing exceeds this length. Thus, a single drawing line gesture will not conflict with a drag gesture. Through pilot studies, we determined r as 14.2 in. and α as 5:1 (see Appendix). Therefore, the length of the initial line l was set as 2.84 in.

4.2. Speed ratio

The speed ratio is the speed of the screen divided by the speed of the user's hand, denoted by α:

$$\alpha = \frac{V_{\text{screen}}}{V_{\text{hand}}} \tag{2}$$

where V_{screen} is the movement speed of the screen, V_{hand} is the speed of the user's hand. To interact with targets that are far away, the movement speed of the screen should meet the following two requirements: (i) to ensure that the user can reach the target by moving a finger or a pen just a short distance, the movement speed of the screen should be faster than that of a finger or a pen; (ii) the speed of the screen movement should not be too fast for the user to react when stopping it. Through a pilot study, we determined α to be 5:1 in our experiment setting (see Appendix).

To make ShifTable adaptable to different sizes of display, inspired by Cao *et al*. (2008), the speed ratio can be adjusted by using multiple fingers on the larger display. We designed it so that the speed ratio would be increased when users drew the initial line with more fingers. For example, when one finger is used the speed ratio is 5:1, when two fingers are used the speed ratio is 6:1.

4.3. Moving direction and adjustment

With ShifTable, users can easily adjust the direction of a target by simply changing the direction of the hand. When the user's hand changes direction, the screen changes trajectory accordingly and immediately (Fig. 2). Hence, the user simply moves a finger or a pen towards the desired target wherever it is, and the target moves simultaneously at a faster speed towards the user's hand.

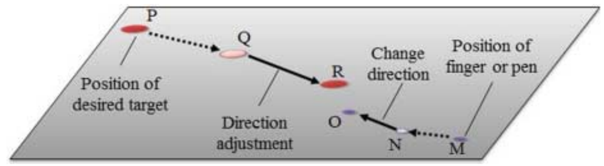

Figure 2. The user firstly moves the finger from M to N, and the round target, carried by the screen, moves from P to Q at the same time. Then the user adjusts the direction and moves the finger from N to O, and the target moves accordingly, from Q to R. Line MN is parallel to line PQ and line NO is parallel to line QR.

4.4. Target selection and reset

When the desired target comes near the user, selection can be accomplished by a single tap on it. Once the user performs the selection successfully, the screen immediately returns to its original position. If the selection fails (for example, via a mistake like tapping on the background instead), there will not be any reaction.

Users may want to undo the operation after drawing an initial line. We observed in pilot studies that users usually double tapped the background when they wanted to cancel. So, we implemented this approach; this allows users to undo their operation by double tapping on the background whenever they like. When users undo a current operation, the screen resets to its original position.

5. EXPERIMENT 1: COMPARISON WITH GESTURE SELECT

To evaluate the performance of ShifTable, we conducted an experiment to compare it with gesture select (which has proved to be the fastest remote target-selection technique on large displays, Bragdon and Ko, 2011) as well as with unaided direct selection, as a baseline. The simplified version of Gesture Select was implemented with '\$1 recognizer' (Wobbrock *et al*., 2007) for single target selection.

5.1. Participants

Nine subjects (aged 24–28 years, five males, four females and all right-handed) participated in the experiment. All participants had experience using the mouse, but none had previous experience with large multi-touch displays. They were paid around \$10 for their participation.

5.2. Apparatus

The experiment was conducted on a PQ Labs multi-touch table. It is a 52.3 in. (W) $\times$ 29.6 in. (H) large display with a resolution of 1920 $\times$ 1200 pixels. For the pen input modality, we used a grip touch pen, which weighed 7g and was 10 $\times$ 117 $\times$ 10 mm ($W \times H \times D$) in size. The experiment program was implemented using C# language and ran on an AMD Athlon X2 CPU with 2 GB of RAM. The experiment program used .Net framework for the implementation of the graphical interface, which provided a target, distracters and a start button. In addition, .Net frameworks support several library functions, which can detect various mouse inputs such as mouse button clicking, pressing and releasing, as well as mouse cursor movements. The recognition of finger or pen input was supported by PQ Labs multi-touch layer. So, the finger and pen input behaviors could map to mouse inputs for the control of the graphical interface that was used in the experiment.

5.3. Experimental design

A repeated-measures within-subject design was used, with independent variables: technique (unaided direct selection, Gesture Select, ShifTable), display orientation (horizontal, vertical), input modality (pen, finger), distracter count (9, 49), target position (left, right) and distance between the start button and the target (near, far). We conducted a pilot study with three different sizes for targets (43, 54, 72 pixels). However, target size produced no significant effect on selection time or error rate in ShifTable. So in the experiment we used just one size of 54 pixels (1.5 in.).

In the pilot studies, participants mentioned that ease of operation was very different when interaction changed from pen based to finger based. Tu *et al*. (2012) also pointed out that finger drawn gestures were quite different to pen drawn gestures in basic measures, including average speed. So, we took the input modalities into consideration. We also considered two positions for the desired target; these were left or right of the user. We chose two distracter counts, 9 and 49. We set distances between the start button and the target as 1440 and 1600 pixels and these were expressed as 'near' and 'far', respectively.

User performances were significantly affected when the orientation of a large display changed from horizontal to vertical in the pilot studies. Rogers and Lindley (2004) also pointed out a number of differences between interactions on horizontal displays and on vertical displays. Hence, we conducted the experiments and analyzed the results in the two display orientations separately; interaction on a horizontal display and interaction on a vertical display.

Each participant performed the entire experiment in one session of two hours, including a break coinciding with the change of display orientation. The experiment conditions were randomly ordered and counterbalanced using a Latin square. In summary, the experiment consisted of:

9 participants ×
2 display orientations (horizontal, vertical)×
3 techniques (unaided, Gesture Select, ShifTable)×
2 input modalities (pen, finger)×
2 distances (near, far)×
2 distracter counts (9, 49)×
2 positions of target (left, right)×
2 repetitions×
3 Blocks
= 5184 trials

5.4. Task and procedure

Participants were asked to first tap the start button and then chose the desired target among the distracter targets. The start button was used for controlling the distance from the user to the desired target. The distracter targets evenly surrounded the desired target in one to three layers based on the number of distractors. The closest layer of distracter targets was 1 in. away from the desired target and the farthest layer was 9 in. away. All the targets were circular in shape. The desired target was highlighted in Green. Participants had to successfully select the desired target before the trial ended. The result of each trial would be shown on the screen when the selection ended.

Before the experiment, participants were asked to do one training block for each technique. All participants took a 10 min break between blocks. They were asked to complete the selection as quickly and accurately as possible. It is notable that in the unaided direct selection condition, participants were asked to walk at their normal speed as they had done in the practice session.

After the experiment, participants were asked to fill in a questionnaire which consisted of seven questions regarding speed, accuracy, physical tiredness, ease of operation, ease of learning, satisfaction and desire to use on a 1–7 scale (1 = lowest preference and 7 = highest preference). They were also asked to state their feelings about the three techniques.

5.5. Performance measures

To evaluate the three techniques in two display orientations, we examined selection time, error rate and subjective preferences. For unaided direct selection, selection time was the time a user took to successfully select the desired target, including error correction. For Gesture Select and ShifTable, selection time was the time a user took to successfully select the desired target, including error correction, but not including the time of cancelation. With ShifTable, the user does not need to keep his finger on the screen and may lift the hand up in the middle of selection process without interrupting the selection process. Because of this, the user can operate ShifTable flexibly and can undo the operation by double tapping the background. For all three techniques, error rate was the percentage of trials where a wrong target was selected.

5.6. Results

Given that each participant performed three blocks in the experiment, we first check the learning effect to see if the

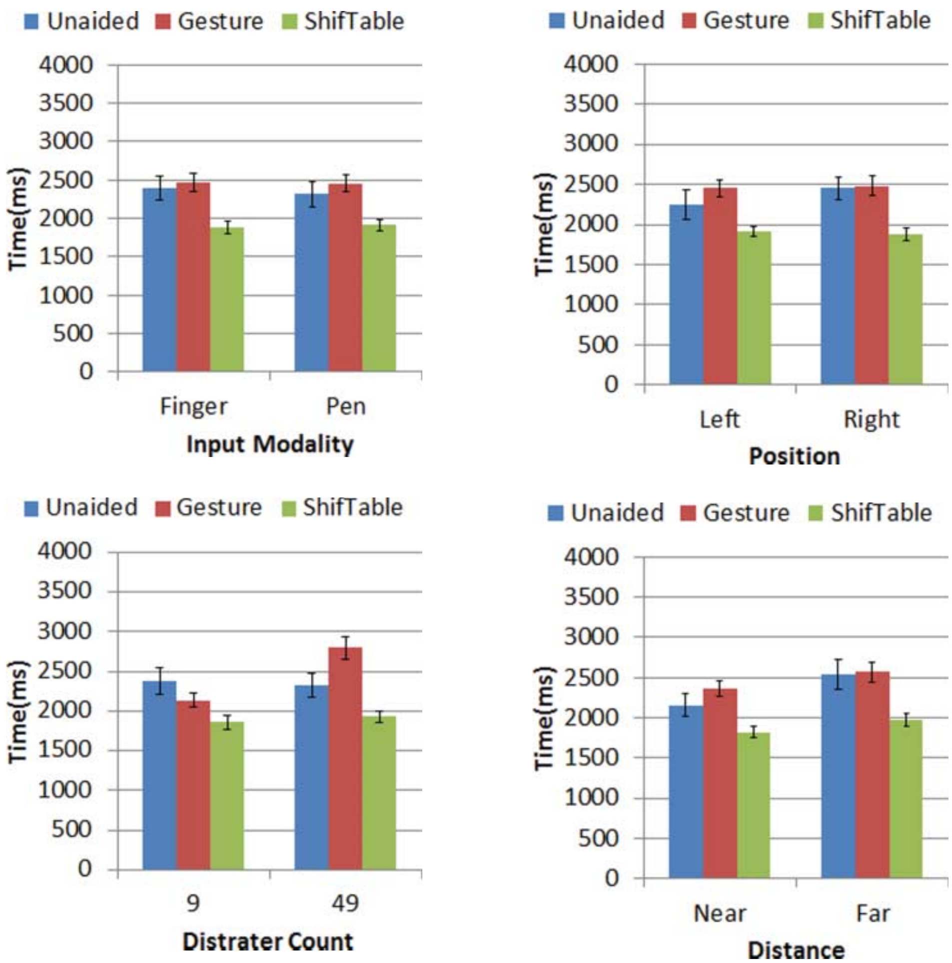

Figure 3. Input modality, position, distracter count and distance vs. selection time on a horizontal display.

data we collected had reached a level of stability. No learning effect was found among three blocks on selection time with interaction on a horizontal display, that is to say, blocks do not affect each other significantly. Therefore, all data from three blocks were applied to our analysis for interaction on a horizontal display. For interaction on a vertical display, there were significant differences between blocks 1 and 2, 1 and 3, but no significant difference was found between blocks 2 and 3, which shows an obvious learning effect after the trials of block 1. Thus we considered only data from blocks 2 and 3 to be stable data for the vertical display.

5.6.1. *Interaction on a horizontal display*

For three interaction techniques on a horizontal display, we analyzed performance in terms of selection time, error rate and subjective preferences. A repeated-measure five-way ANOVA (analysis of variance) was used with the following factors: technique, input modality, distance, distractor count, and target positions.

5.6.1.1. Selection time The results of selection time on a horizontal display are presented in Fig. 3. Technique had a significant main effect on selection time ($F(2,16) = 8.26$, $P < 0.01$), as did position ($F(1,8) = 8.89$, $P < 0.05$), distance ($F(1,8) = 25.66$, $P = 0.01$) and distracter count ($F(1,8) = 41.75$, $P < 0.001$). There was also a significant technique × target position interaction ($F(2,16) = 5.09$, $P = 0.05$) and a technique × distracter count interaction ($F(2,16) = 49.86$, $P < 0.001$).

Post hoc analysis with Bonferroni correction indicated that ShifTable significantly outperformed Gesture Select ($P = 0.001$) and unaided direct selection ($P = 0.007$) for all conditions. The input modality had no significant effect on the three techniques. The selection time of ShifTable increased just 2% from finger-based interaction to pen-based interaction. Position had no significant effect on the selection time of ShifTable or Gesture Select. However, it had a significant effect on unaided direct selection ($P < 0.05$). Distracter count had no significant effect on the selection time of ShifTable. Gesture

Select, however, was significantly affected by the distracter count ($P < 0.001$), increasing 30.8% from 9 to 49. Unaided direct selection was not affected by the distracter count. ShifTable was significantly affected by distance ($F(1,8) = 17.92$, $P < 0.01$), increasing 7.96% from near to far targets, as were Gesture Select 8.5% ($P < 0.01$) and unaided direct selection 17.94% ($P < 0.001$).

5.6.1.2. Error rate Unaided direct selection had a mean error rate of 0.001%, while Gesture Select had a mean error rate of 5.6%, and ShifTable had a mean error rate of 0.2%. The Shapiro–Wilk test showed that error data were not normally distributed and the Friedman test was used to analyze the results of error rate. This indicated that there was a significant difference in overall error rates depending on which technique was used, $\chi^2(2) = 58.7$, $P < 0.001$. Post hoc Wilcoxon signed-rank analysis with Bonferroni correction indicated that there were significant error reductions in unaided direct selection vs. Gesture Select ($Z = -5.19$, $P < 0.001$) and in ShifTable vs. Gesture Select ($Z = -4.95$, $P < 0.001$). However, there was no significant error reduction in unaided direct selection vs. ShifTable.

Distracter count also had a significant main effect on error rate, $\chi^2(1) = 9.1$, $P < 0.003$. Nine distractors had a mean error rate of 0.9% and forty-nine distractors had a mean error rate of 2.9%. However, input modality, distance and target position had no significant effect on error rate.

5.6.1.3. Subjective preferences Fig. 4 shows the subjective ratings for the three techniques on a horizontal display. These ratings were based on the average value of the answers given by the subjects to seven questions. A Friedman test indicated that there was a statistically significant difference in perceived overall ratings on all seven questions, $\chi^2(2) = 8.7$, $P < 0.05$. ShifTable was rated the highest regarding ease of operation,

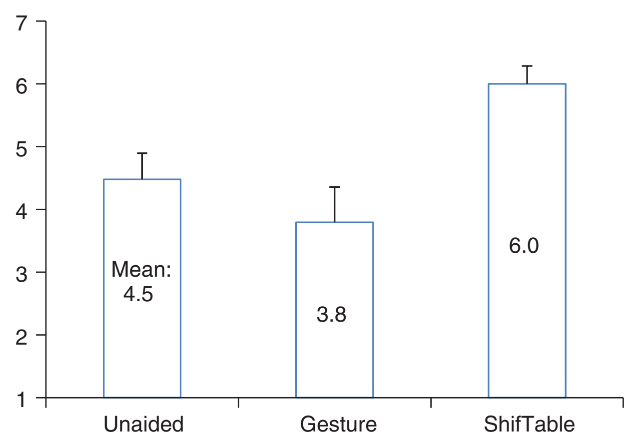

Figure 4. Subjective evaluation for the three techniques on a horizontal display based on seven questions (1 = lowest preference, 7 = highest preference).

satisfaction, desire to use and lack of physical tiredness. Gesture Select was rated the lowest for accuracy and for ease of operation. Post hoc analysis with Wilcoxon signed-rank test using Bonferroni correction indicated that there were significant differences in ShifTable vs. Gesture Select ($Z = -2.67$, $P = 0.008$) but not in ShifTable vs. unaided direct selection. There was no significant difference between unaided direct selection and Gesture Select.

5.6.2. Interaction on a vertical display

To compare the three interaction techniques on a vertical display, we analyzed performance in terms of selection time, error rate and subjective preferences. A repeated-measure five-way ANOVA was used with the factors of technique, input modality, distance, distractor count and target position.

5.6.2.1. Selection time The results regarding selection time on a vertical display are presented in Fig. 5. Technique had a significant main effect on selection time ($F(2,16) = 11.08$, $P < 0.01$), as did distracter count ($F(1,8) = 32.14$, $P < 0.001$), and distance ($F(1,8) = 34.12$, $P < 0.001$). There was also a significant technique × target position interaction ($F(2,16) = 16.98$, $P < 0.001$) and a technique × distracter count interaction ($F(2,16) = 38.59$, $P < 0.001$).

Post hoc analysis with Bonferroni correction indicated that ShifTable significantly outperformed Gesture Select for all conditions ($P < 0.01$) but not unaided direct selection ($P = 0.068$). ShifTable was significantly affected by input modality ($F(1,8) = 8.27$, $P < 0.05$), increasing 8.59% from pen-based interaction to finger-based interaction. Gesture Select and unaided direct selection were not significantly affected by input modality. ShifTable was significantly affected by position ($F(1,8) = 9.33$, $P < 0.05$), increasing 6.41% from right to left, so were unaided direct selection ($F(1,8) = 5.55$, $P < 0.05$), increasing 5.91% from left to right and Gesture Select ($F(1,8) = 7.02$, $P < 0.05$), increasing 5.24% from left to right. ShifTable was significantly affected by distracter count ($F(1,8) = 15.15$, $P < 0.01$), increasing 5.82% from 9 to 49, so was Gesture Select ($F(1,8) = 39.63$, $P < 0.001$), increasing 29.11% from 9 to 49. Unaided direct selection was not affected by distracter count. There was a significant effect from distance for ShifTable ($F(1,8) = 10.12$, $P < 0.05$), increasing 8.92% from near to far targets; and unaided direct selection ($F(1,8) = 27.00$, $P < 0.01$), increasing 22.00% from near to far. Gesture Select was not significantly affected by distance.

5.6.2.2. Error rate Unaided direct selection had a mean error rate of 0.001%, while Gesture Select had a mean error rate of 9.5% and ShifTable had a mean error rate of 0.7%. The Shapiro–Wilk test showed that error data were not normally distributed. The box-plot in Fig. 6 shows the spread of the error rates. The Friedman test was used to analyze the error rate data. It indicated that there was a significant difference in

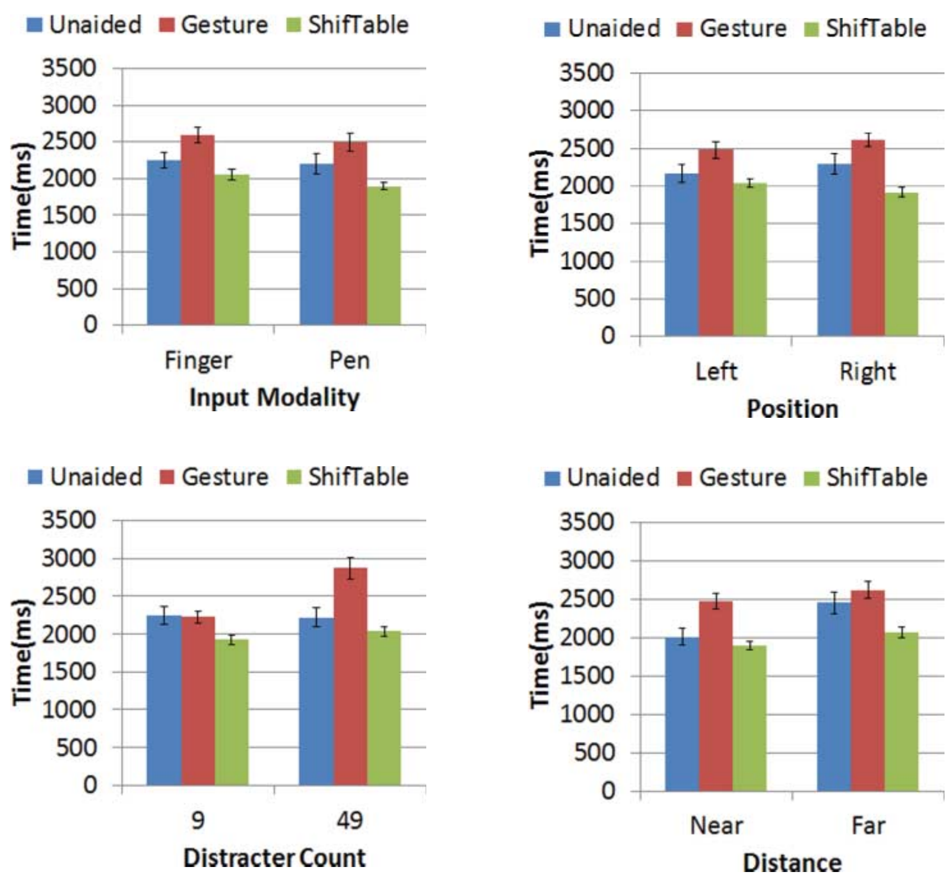

Figure 5. Input modality, position, distracter count and distance vs. selection time on a vertical display.

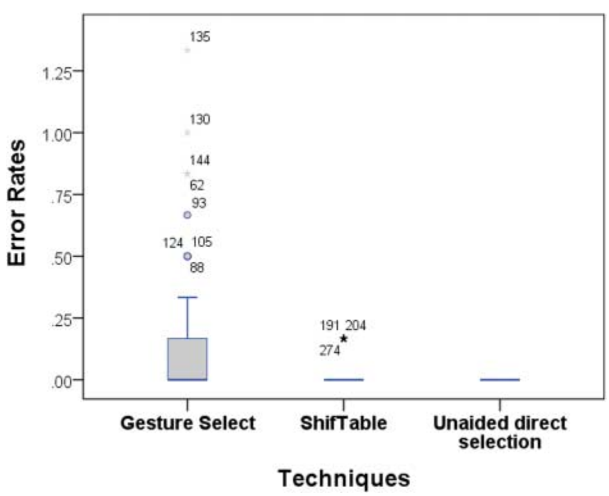

Figure 6. The box-plot for the spread of the error data on a vertical display.

overall error rates depending on which technique was used, $\chi^2(2) = 71.4$, $P < 0.001$. Post hoc analysis with Wilcoxon signed-rank test using Bonferroni correction showed that there were significant error reductions in ShifTble vs. Gesture Select ($Z = -5.48$, $P < 0.001$), in unaided direct selection vs. Gesture Select ($Z = -5.82$, $P < 0.001$), and in unaided direct selection vs. ShifTable ($Z = -2.45$, $P = 0.014$).

Distracter counts had a significant main effect on error rate, $\chi^2(1) = 8.1$, $P < 0.005$. Nine distractors had a mean error rate of 1.9% and 49 distractors had a mean error rate of 5.2%. Target positions also had a significant main effect on error rate, $\chi^2(1) = 6.1$, $P < 0.02$. Left target position had a mean error rate of 2.2% and right target position had a mean error rate of 4.9%. However, input modality and distance had no significant effect on error rate.

5.6.2.3. Subjective preferences A Friedman test indicated that there was a statistically significant difference in perceived overall ratings on all seven questions, $\chi^2(2) = 9.7$, $P = 0.008$. ShifTable was rated the highest regarding ease of operation, satisfaction, desire to use and lack of physical tiredness. Unaided direct selection was rated the highest regarding accuracy and was rated as the easiest to learn. Gesture Select was rated the lowest for accuracy and for ease of operation. Post hoc analysis with Wilcoxon signed-rank test using Bonferroni correction indicated that ShifTable significantly outperformed Gesture Select ($Z = -2.67$,

$P = 0.008$) in preferences but did not outperform unaided direct selection. There was no significant difference between unaided direct selection and Gesture Select.

5.7. Discussion

ShifTable significantly outperformed both unaided direct selection and Gesture Select in selection time on a large horizontal display and it outperformed Gesture Select on a vertical display. ShifTable's simplicity in operation might enable users to complete the task faster than with the more complex Gesture Select. It is notable that all nine participants in Experiment 1 chose ShifTable as the easiest technique to operate on both horizontal and vertical displays. The simplicity of ShifTable also led to higher accuracy in task completion: ShifTable had much lower error rates (0.2% for horizontal and 0.7% for vertical) than those of Gesture Select (5.6% for horizontal and 9.5% for vertical). For unaided direct selection, participants physically walked around the display and selected the target on a horizontal display. Hence, the selection time for unaided direct selection (2351 ms) on a horizontal display was significantly longer than for selection time using ShifTable (1894 ms).

When working on a horizontal display selection time on ShifTable was significantly affected only by target distance. On the other hand, when working on a vertical display, ShifTable was significantly affected by input modality, distracter count and position. This could be explained by the participants' feedback which indicated that working on a vertical display caused more friction and discomfort than working on a horizontal display, especially when using fingers to drag on the vertical display, which magnified the effect of input modality, distracter count and position. It is obvious that different input modalities (pen or finger) can produce different friction when interacting with touch-based displays. Compared with operating a horizontal display with the fingers, the use of fingers on a vertical display was more inconvenient and caused more tiredness. We reasonably believe that techniques requiring one direction movements and with less fatigue, like ShifTable, are more suitable than techniques requiring multi-direction movements, like Gesture Select, on such displays.

6. EXPERIMENT 2: ELDERLY USER STUDY

To explore the ease of operation of ShifTable in practice, we conducted another experiment. It was different from Experiment 1 in several respects. First, we conducted Experiment 2 with only elderly participants so we could focus on testing whether ShifTable would be easy enough to operate. Second, Experiment 2 was conducted only on a horizontal display with pen input. Our pilot studies showed that the elderly participants could not work for long periods, and operating with a finger on a vertical display caused discomfort to them. Thus, we decided to decrease the levels of the display orientation factor and the input modality factor used in Experiment 1, respectively. Third, we compared ShifTable with Pan in Experiment 2. Elderly participants had difficulty completing the task with Gesture Select in the pilot studies. In addition, Pan is widely used as a remote target-selection technique in commercial products. Thus, we were interested to compare ShifTable with Pan. Fourth, to examine a real-world usage scenario for ShifTable, we adopted the context of copying and pasting targets on a large display, as a task in Experiment 2.

6.1. Participants

All nine elderly participants, recruited from a local community, were right-handed. Four were females. Their ages ranged from 65 to 84 years. The median was 73 years of age and the average height was 158 cm. None of the participants had experience using tabletop computers, while three of them had experience using PCs. They were paid $30 for the half-day visit.

6.2. Apparatus

The equipment was the same as for Experiment 1. In addition, we slightly modified the experiment program which was used in Experiment 1 for the copy-and-paste task in Experiment 2: (i) A source object was copied by clicking on it and the copied object was pasted to the target by selecting the destination target. (ii) By double-clicking the background, the screen returned to its original position on the ShifTable mode. These interactions could be implemented by modifying mouse functions in Windows library, based on the current position of the mouse cursor.

6.3. Experimental design

We used a repeated-measures within-subject design with five factors: repeated blocks, technique (Pan, ShifTable), direction of a source to copy and a target to paste (left–right, right–left), distracter count (9, 49) and distance between the source and the target (near, far). Therefore, the experiment consisted of:

9 participants ×
2 techniques (Pan, ShifTable) ×
1 display orientation (horizontal) ×
1 input modality (pen) ×
2 distances (near, far) ×
2 distractor counts (9, 49) ×
2 positions of source and target (left–right, right–left) ×
2 repetitions ×
3 Blocks
= 864 trials.

The order of conditions was randomized and counterbalanced using a Latin square within a block. Each participant performed the entire experiment in one session of one hour, including breaks between blocks.

6.4. Task and procedure

We tested a copy-and-paste task on the large horizontal display. Participants were asked to first tap the start button, and then it would display a source with distracters and a target. The distracters evenly surrounded the source in one to three layers based on the number of distractors. The closest layer of distracters was 1 in. away from the source and the farthest layer was 9 in. away (Fig. 7). The source was first selected to be copied, and then the destination was selected for the source to be pasted to. The source and the target was located diagonally opposite to each other (e.g. top-left and bottom-right). Thus, when the source was selected by a pen using Pan or ShifTable, the target would move out of the display. To get the target back on the display, participants moved the pen again in the opposite direction in the Pan condition, or they could double tap on the background to have the screen return to its original position in the ShifTable condition. Then, participants needed to select the target to paste. The source, target and distractors were all circular in shape and they changed color from green to red with a successful selection.

Before the experiment, participants were asked to practice 20 trials for each Pan and ShifTable technique. They were asked to complete the task as quickly and accurately as possible. During the experiment, all participants took a 10-min break between blocks. After the experiment, participants were asked to fill in questionnaires, which consisted of seven questions regarding speed, accuracy, physical tiredness, ease of operation, ease of learning, satisfaction and desire to use. At the end, there were also open-questions regarding their experience during the experiment.

6.5. Performance measures

We examined copy-and-paste time, error rate, and subjective preferences to evaluate the performances of Pan and ShifTable with the elderly participants. Copy-and-paste time was the time participants took to successfully select the desired source and the target destination for copying and pasting, with any error corrections. Error rate was the percentage of trials where the wrong source or target was selected.

6.6. Results

A repeated-measure five-way ANOVA was used with the following factors: target-selection technique, distractor count, target distance, target position and block number.

6.6.1. Copy-and-paste time

Repeating the tasks in three blocks helped the participants improve their task completion time overall ($F(2, 16) = 4.02$, $P < 0.05$). The mean copy-and-paste times were 9624 ms (Standard Error (SE) = 654 ms) for the first block, 9130 ms (SE = 827 ms) for the second block and 8686 ms (SE = 693 ms) for the third block.

The remote target-selection technique had a significant effect on the mean copy-and-paste times ($F(1, 8) = 23.73$, $P < 0.01$). Fig. 8 shows the mean copy-and-paste times for ShifTable and Pan techniques. The overall mean copy-and-paste times were 8038 ms (SE = 579 ms) for ShifTable, and 10 256 ms (SE = 870 ms) for Pan.

The positions of the source to copy and the target to paste had a significant effect on the mean copy-and-paste times ($F(1, 8) = 126.32$, $P < 0.001$). The overall mean copy-and-paste times were 9679 ms (SE = 703 ms) for the combination of the left source and the right target positions, and 8615 ms (SE = 706 ms) for the combination of the right source and the left target positions. Neither distractor count nor target distance had a significant effect on the copy-and-paste completion time.

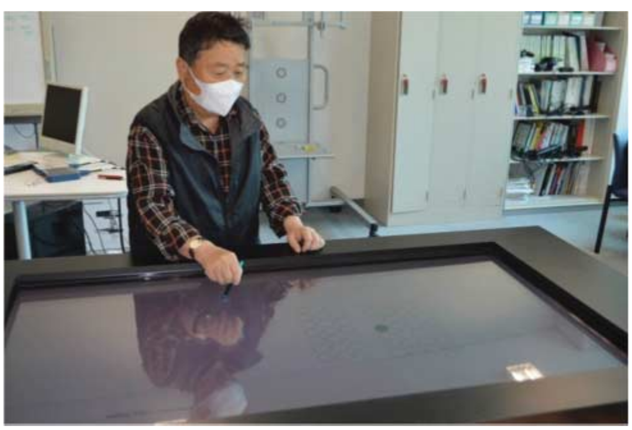

Figure 7. An elderly user selects a target on the horizontal display using ShifTable.

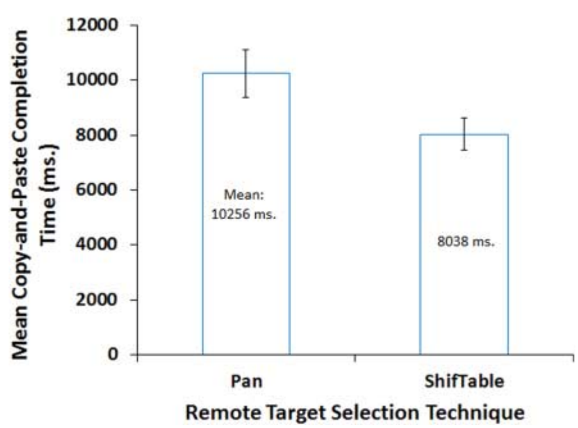

Figure 8. Mean copy-and-paste completion time for two remote target selection techniques.

6.6.2. Error rate

There were only two trials in which participants were not able to select the target correctly, and these were under the ShifTable condition. The Friedman test indicated that none of the following factors had any significant statistical effect on overall error rate: target-selection technique, distractor count, target distance, target position, and block factors.

6.6.3. Subjective preferences

A Friedman test indicated that there was a statistically significant difference in perceived overall easiness to learn, depending on which technique was used, $\chi^2(1) = 8.0$, $P < 0.01$. Pan was preferred above ShifTable. We could not find any significant differences for the other questions, such as ease of operation, desire to use, accuracy, speed, tiredness or overall satisfaction.

6.7. Discussion

In the following subsections, we discuss ShifTable vs. Pan and the features of ShifTable for the elderly users.

6.7.1. ShifTable vs. Pan

Pan is one of the most available techniques for accessing remote targets on large displays. With pan, users first stretch out their hand as far as they can towards the target, and then they touch the screen and drag it near to themselves. The screen moves towards the user at the same speed as the hand. After the selection, users manually send the screen to its original position. A keystroke level analysis of the selection time (T) by Pan can be expressed, $T = n \times (T_s + T_m) + T_p$. T_s is the time user's stretch out the hand to a target, T_m is the time the screen moves to the user, which is at the same speed as the user's hand, and T_p is the time taken to pick the target. If the target is located too far away, there will be n repetitions for T_s and T_m.

On the other hand, the selection time T' of ShifTable can be expressed as the following equation, $T' = T'_s + T'_m + T'_p$. Where T'_s is the initial trigger time which is achieved by drawing a line, T'_m is the time taken to move the hand towards a target and T'_p is the time taken to pick the target. T'_s depends on the time the user takes to draw an initial line to trigger the technique. Usually, the initial line is short; in our experiment it is only 2.84 in. Thus, it is reasonable that T'_s will not be longer than T_s. With ShifTable, the screen will shift to the user faster than the speed of the user's hand. With Pan, the screen moves to the user at the same speed as the user's hand. In addition, with Pan, we observed that participants often needed to remove the pen from the screen, move it in the air, and reposition it on the screen again to drag the target because they pulled the hand back to achieve the required target movement. With ShifTable, however, the pen kept continuous contact with the screen. So, T'_m is much smaller than T_m. T'_p and T_p, both depend on the action of picking the target and there is no significant difference between them. Therefore, ShifTable generally outperforms Pan in selection time.

As participants mentioned, with ShifTable it is easier for users to control the direction of the screen movement, since they just need to move the pen towards the target wherever it is. For Pan, in a large display, participants often had a hard time seeing both the target and the pen simultaneously, which makes it difficult to monitor both target movement and pen movement at the same time.

During Experiment 2, moving the screen back to its original position after selecting the source in order to access the target which had disappeared out of the display area was a challenge with Pan. Because participants could not see the approach of the missing target, the execution with Pan was not always optimal. Participants often used pan like a two directional scroll movement (i.e. horizontal scrolling first and then vertical scrolling), instead of a simple and direct diagonal movement to access the missing target. By contrast, in ShifTable, participants could easily return the screen to its original position by simple double tapping on the background, and they could select the target where the source was to be pasted.

6.7.2. Features of ShifTable for the elderly users

Unlike Drag-and-pop/pick (Baudisch *et al.*, 2003), Vacuum (Bezerianos and Balakrishnan, 2005) and Gesture Select (Bragdon and Ko, 2011), ShifTable neither put additional icons or proxies on the display nor did it require complex gestures to interact with a large display. Rather, a user reaches towards the target with a finger or a pen, and then the whole screen moves towards the user so that the target can be easily selected. Thus, ShifTable's simple one step gesture, like a natural 'reach' motion, reduces the elderly users' cognitive load and fatigue.

Before conducting Experiment 2, we did informal pilot studies of ShifTable, Gesture Select and unaided direct selection for elderly participants. When the elderly participants carried out the selection tasks in our pilot studies, we specifically observed the following aspects of the interactions as they relate to the elderly; time spent acquiring each technique, tiredness shown in performing each technique, speed and accuracy of selection. During the unaided direct selection condition, all the elderly quickly acquired the technique. It was easy for them to correctly select desired targets at first, but they showed tiredness after doing the task for a while and the speed of selection slowed down. During the Gesture Select condition, the elderly came to understand the technique quite slowly. Even after 10 training trials, they still often made mistakes and failed the task. The elderly mentioned that it was difficult and uncomfortable for them to maintain awareness and to draw gesture marks. It was more difficult for them to use a finger than to use a pen. One participant was unable to perform the Gesture Select task with fingers. Most participants mentioned they felt tired doing such tasks. Speed and accuracy were both low. By contrast, in the ShifTable condition, participants acquired the technique within the first three training trials. They quickly and accurately finished all the tasks without too much tiredness. Regarding the degree of physical tiredness participants indicated that ShifTable caused less tiredness than the multi-gesture technique Gesture Select, and the walking involved in unaided direct selection.

In Experiment 2, we investigated the appropriateness of ShifTable for supporting the elderly user selection of multiple targets, where desired targets were far from each other. With double tapping, participants could easily reset the screen to select another target, which was distant in the opposite direction. However, the limitation of this approach was that elderly participants could not double tap fast enough from time to time. Furthermore, most of the elderly participants had never used a PC or a mouse, and they were not familiar with the concept of double-clicking. This was one reason why we got a low subjective preference in our questionnaire about easiness to learn, when ShifTable was compared with Pan. This lead us to a general usability guideline for touch gesture interfaces for elderly users: it is advisable to avoid repeating delicate kinetic gestures for elderly users.

In addition, we found the location of a target had a significant effect on the task completion time in Experiment 2. When elderly participants needed to approach the targets on the opposite side to their dominant hand, it took more time. This suggested how the items should be arranged on an interactive large display i.e., in support of easy access by elderly users.

With considerable progress in display technologies and interaction techniques, we are observing increasing affordability and availability of large interactive displays in our everyday lives. The rapid growth of such large public displays allows us to access a variety of information in diverse places and the contents are now much more interactive. However, the proliferation of large interactive displays also creates great challenges for elderly people, who require easy and intuitive access to displays. For example, they would like to interact with public supermarket displays that can guide him towards specific sections for food or clothing. Our work suggests simple but successful interfaces that can be utilized by elderly people. Future work will include conducting an additional *in situ* experiment with more participants to fully validate the value of our design.

7. CONCLUSION

In this paper, we proposed ShifTable, a simple technique for remote target selection on large displays. In the design of ShifTable, we took the impact of easy and natural gestures into consideration, and made the technique as simple as possible. We conducted two experiments, for young and for elderly users. The results showed that ShifTable outperformed Gesture Select and Pan. Overall, ShifTable has clear advantages over existing interaction techniques on large displays with regard to remote target-selection time and error rates. The findings of our two experiments will serve as an initial step towards designing easily accessible technologies for elderly users in their interaction with large displays.

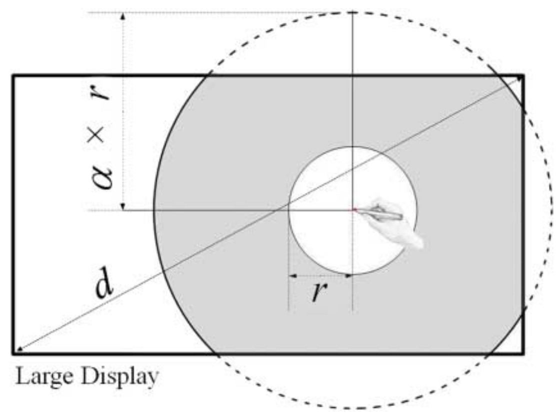

Figure 9. Shaded section represents the area where targets can be acquired; *r* is the average longest distance (i.e., 14.2 in.) of user's reach.

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REFERENCES

Aliakseyeu, D., Nacenta, M. A., Subramanian, S. and Gutwin, C. (2006) Bubble Radar: Efficient Pen-based Interaction. In Proc. AVI 2006, ACM Press, pp. 19–26.

Antle, A.N., Bevans, A., Tanenbaum, J., Seaborn, K. and Wang, S. (2011) Futura: design for collaborative learning and game play on a multi-touch digital tabletop. In Proc. TEI'11, ACM Press, pp. 93–100.

Asano, T., Sharlin, E., Kitamura, Y., Takashima, K. and Kishino, F. (2005) Predictive Interaction Using the Delphian Desktop. In Proc. UIST'05, ACM Press, pp. 133–141.

Banerjee, A., Burstyn, J., Girouard, A. and Vertegaal, R. (2011) Pointable: An In-air Pointing Technique to Manipulate Out-of-reach Targets on Tabletops. In Proc. ITS'11, ACM Press, pp. 11–20.

Baudisch, P., Cutrell, E., Czerwinski, M., Robbins, D.C., Tandler, P., Bederson, B.B. and Zierlinger, A. (2003) Drag-and-pop and Drag-and-pick: Techniques for Accessing Remote Screen Content on Touch- and Pen-operated Systems. In INTERACT'03, IOS Press, pp. 57–63.

Bezerianos, A. and Balakrishnan, R. (2005) The Vacuum: Facilitating the Manipulation of Distant Objects. In Proc. CHI'05, ACM Press, pp. 361–370.

Bragdon, A. and Ko, H.S. (2011) Gesture Select: Acquiring Remote Targets on Large Displays Without Pointing. In Proc. CHI'11, ACM Press, pp. 187–196.

Cao, X., Wilson, A., Balakrishnan, R., Hinckley, K. and Hudson, S. (2008) Shapetouch: Leveraging Contact Shape on Interactive Surfaces. In 3rd IEEE Int. Workshop on Horizontal Interactive Human Computer Systems, pp. 129–136.

Collomb, M., Baudisch, P. and Lee, B. (2005) Improving Drag-and-drop on Wall-size Displays. In Proc. GI'05, Canadian Human–Computer Communications Society, pp. 25–32.

Guiard, Y., Blanch, R. and Beaudouin-Lafon, M. (2004) Object Pointing: A Complement to Bitmap Pointing in GUIs. In Proc. GI'04, Canadian Human-Computer Communications Society, pp. 9–16.

Iannacci, F., Turnquist, E., Avrahami, D. and Patel, S.N. (2011) The Haptic Laser: Multi-sensation Tactile Feedback for at-a-Distance Physical Space Perception and Interaction. In Proc. CHI'11, ACM Press, pp. 2047–2050.

Jota, R., Nacenta, M.A., Jorge, J.A., Carpendale, S. and Greenberg, S. (2010) A Comparison of Ray Pointing Techniques for Very Large Displays. In Proc. GI'10, Canadian Information Processing Society, pp. 269–276.

Karlson, A.K. and Bederson, B.B. (2007) ThumbSpace: Generalized One-handed Input for Touchscreen-based Mobile Devices. In Proc. Interact'07, Springer, 324–338.

Karlson, A. K. and Bederson, B.B. (2008) One-handed Touchscreen Input for Legacy Applications. In Proc. CHI'08, ACM Press, pp. 1399–1408.

Malacria, S., Lecolinet, E. and Guiard, Y. (2010) Clutch-free Panning and Integrated Pan-zoom Control on Touch-sensitive Surfaces: The Cyclostar Approach. In Proc. CHI'10, ACM Press, pp. 2615–2624.

Myers, B.A., Bhatnagar, R., Nichols, J., Peck, C.H., Kong, D., Miller, R. and Long, A.C. (2002) Interacting at a distance: measuring the performance of laser pointers and other devices. In Proc. CHI'02, ACM Press, pp. 33–40.

Nancel, M., Chapuis, O., Pietriga, E., Yang, X.D., Irani, P.P. and Beaudouin-Lafon, M. (2013) High-precision Pointing on Large Wall Displays Using Small Handheld Devices. In Proc. CHI'13, ACM Press, pp. 831–840.

Nancel, M., Wagner, J., Pietriga, E., Chapuis, O. and Mackay, W. (2011) Mid-air Pan-and-zoom on Wall-sized Displays. In Proc. CHI'11, ACM Press, pp. 177–186.

Ni, T., Schmidt, G.S., Staadt, O.G., Livingston, M.A., Ball, R. and May, R. (2006) A survey of large high-resolution display technologies, techniques, and applications. In Proc. VR'06, IEEE Comput. Soc., pp. 223–236.

Parker, J.K., Mandryk, R.L. and Inkpen, K.M. (2005) Tractorbeam: Seamless Integration of Local and Remote Pointing for Tabletop Displays. In Proc. GI'05, Canadian Human–Computer Communications Society, pp. 33–40.

Reetz, A., Gutwin, C., Stach, T., Nacenta, M. and Subramanian, S. (2006) Superflick: A Natural and Efficient Technique for Long-distance Object Placement on Digital Tables. In Proc. GI'06, Canadian Information Processing Society, pp. 163–170.

Rogers, Y. and Lindley, S. (2004) Collaborating around vertical and horizontal large interactive displays: which way is best? Interact. Comput., 16, 1133–1152.

Shoemaker, G., Tang, A. and Booth, K.S. (2007) Shadow Reaching: A New Perspective on Interaction for Large Displays. In Proc. UIST'07, ACM Press, pp. 53–56.

Tu, H., Ren, X. and Zhai, S. (2012) A Comparative Evaluation of Finger and Pen Stroke Gestures. In Proc. CHI'12, ACM Press, pp. 1287–1296.

Vogel, D. and Balakrishnan, R. (2005) Distant Freehand Pointing and Clicking on Very Large, High Resolution Displays. In Proc. UIST'05, ACM Press, pp. 33–42.

Wobbrock, J.O., Wilson, A.D. and Li, Y. (2007) Gestures Without Libraries, Toolkits or Training: A $1 Recognizer for User Interface Prototypes. In Proc. UIST'07, ACM Press, pp. 159–168.

APPENDIX

To determine the appropriate user's reach r and speed ratio α, we conducted two pilot studies with six participants (four male, two female). In the first study, participants were asked to stand at one corner of the large display and reach targets as far away and in as relaxed a manner as possible. We recorded the longest reach distances of all the participants; accordingly r without learning effects was 14.2 in.

We sought to estimate the range of α in the second study, and then calculated its exact value according to the size of our display. α was set as an integer from 1:1 to 10:1, and all the participants tested ShifTable with different α. We found that (i) with too small α (1:1 to 3:1), the screen shifted too slowly, and too many moves were required to reach the desired target; (ii) when α ranged from 4:1 to 8:1, the subjects' performance was relatively stable; (iii) with too big α (9:1 or 10:1), the screen shifted too quickly for participants to react in time. Thus, the suitable range of α was from 4:1 to 8:1.

To further calculate the exact value of α, we defined S to be the biggest area where targets can be acquired. Thus, S could be determined by $S = \pi(\alpha \times r)^2$, as shown in Fig. 9. The exact value of α should make S cover all the targets on the display, so that any desired target can be brought near to the user. Therefore, the determination of α was also influenced by the display's size. d was the diagonal length of the display. In our experiment setting, d was 59.6 in. Thus the ratio of d and r was around 4.2:1. Considering this and the participants' comments, α was chosen as 5:1 in our experiment.