The Tilt Cursor: Enhancing Stimulus-Response Compatibility by Providing 3D Orientation Cue of Pen

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ABSTRACT
In order to improve stimulus-response compatibility of touchpad in pen-based user interface, we present the tilt cursor, i.e. a cursor dynamically reshapes itself to providing the 3D orientation cue of pen. We also present two experiments that evaluate the tilt cursor's performance in circular menu selection and specific marking menu selection tasks. Results show that in a specific marking menu selection task, the tilt cursor significantly outperforms the shape-fixed arrow cursor and the live cursor [4]. In addition, results show that by using the tilt cursor, the response latencies for adjusting drawing directions are smaller than that by using the other two kinds of cursors.

Author Keywords
Cursor, Pen, Orientation, Stimulus-Response Compatibility

ACM Classification Keywords
H.5.2 [User Interfaces]: Graphical User Interfaces, Theory and methods, Interaction styles.

INTRODUCTION
With the popularity and intuitiveness of pen and paper, various aspects related to pen-based user interaction have been researched. In this paper, we focus on pen cursors in pen based user interfaces. Usually, the information that a pen input device (referred to as "pen" hereinafter) provides, includes not only its pen tip's position but also extended information such as writing pressure, 3D orientation and 3D rotation. There is some research on how to incorporate these different types of information into pen-based interaction [3] [8]. However, few of them are focused on using the information for the visual feedbacks of cursors. We notice that the cursors in pen-based user interfaces are still in GUI style. We wonder if it brings any good that the cursors dynamically provide the 3D orientation cue of pen.

In this paper, we present the tilt cursor, as shown in Fig.1. By dynamically reshaping itself, the tilt cursor uses pen's orientation as a visual cue to the user.

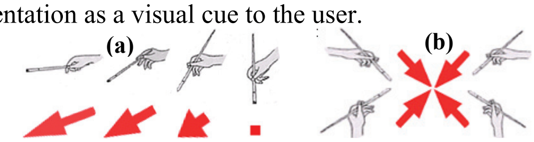

Figure 1. (a) Four tilt cursors with different altitude and same azimuth, (b) Four tilt cursors with different azimuth and same altitude

RELATED WORK
A cursor is a small, movable marker used both as an indicator of system states and as a means of providing visual feedback to user input [6]. There has been some work on selection techniques with cursors. A common approach for these studies is to use Fitts' Law. Some other studies use stimulus-response compatibility that refers to the finding that certain mappings of stimuli to responses produce faster and more accurate responding than do others [7]. With respect to visual user interfaces, S-R compatibility can be defined as the degree to which the mapping between the position and orientation of a visual stimulus matches that of the motor response [6]. The live cursor [4] is a cursor that its arrowhead follows its movement direction. Po's work suggests that choosing appropriate directions for cursors' arrowheads is especially important for pointers, but less important for mice and touch screens on S-R compatibility [6]. Phillips [5] found that arrow cursors compatible with movement direction led to slower cursor movements and less efficient cursor trajectories as response latencies were influenced by compatibilities between movement direction and cursor shape.

In this paper, we focus on touchpad, a cursor-control device that is widely applied in many fields, especially in UI design field. Comparing with other pen-based devices with touch-sensitive screen, the separation of controller and display leads to mismatches in coordinate systems. Dillen [2] conducted a kinematic analysis of cursor trajectories controlled with a touchpad. He found that the nature of inefficiencies of the touchpad compared with other devices, primarily excessive sub-movements. Moreover, he pointed out that Fitts' Law alone does not indicate all problems of touchpad. Target location, screen characteristics, and cursor-control devices all may affect the problems.

INTERVIEWING TOUCHPAD USERS

We first interview twelve UI designers who use touchpad in their designing. We are able to obtain some useful information concerning pen's orientation. We observe that the 3D orientation information (altitude, azimuth) of pen changes when they perform different tasks. For example, when the designers draw longer and thicker strokes, the altitude of pen is small. And when the designers draw details of paint, such as eyes and finger tips, the altitude of pen is large. Also, the interviewees mention that the current cursor in the designing and painting software cannot provide the 3D orientation cue of pen in drawing, which exacerbates the lack of coordination between eyes and hands inherent to touchpad interaction.

TILT CURSOR DESIGN AND IMPLEMENTATION

We use 3D Cartesian coordinates to calculate the shape of tilt cursor, as shown in Fig. 2. The head of tilt cursor is at the origin of the coordinates. The viewpoint is at the positive infinity of Z axis above the cursor. The tilt cursor is a projection of the pen vector onto the XY-plane.

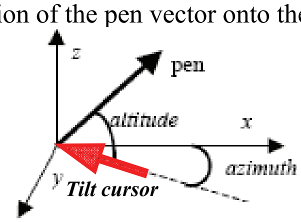

Figure 2. 3D coordinates of calculating the shape of tilt cursor

The shape is calculated according to the following formulas:

$$\begin{cases} \Delta x = \left(altAdjust - \dfrac{|altitude|}{altF} \right) \times \sin\left(\dfrac{azimuth}{aziF} \right) \\ \Delta y = \left(altAdjust - \dfrac{|altitude|}{altF} \right) \times \cos\left(\dfrac{azimuth}{aziF} \right) \\ Width = normalWidth \times \left(altAdjust - \dfrac{|altitude|}{altF} \right) \Big/ altAdjust \\ Transparency = 155 + 100 \times \left(\dfrac{|altitude|}{altF} \right) \Big/ altAdjust \end{cases}$$

where Δx is the difference between the end and the head of the cursor in X axis; Δy is the difference between the end and the head of the cursor in Y axis; $altAdjust$ is the altitude zero adjust; $altF$ is the altitude factor; $aziF$ is the azimuth factor; $Width$ is the width of the arrowhead; $Transparency$ is the transparency of the cursor.

Three values, $altAdjust$, $altF$ and $aziF$, are used to map different coordinate systems between the pen/touchpad and screen/cursor. To adding a virtual light above the cursor, $Transparency$ is used to give user more clear visual cues about pen's orientation. It should be noted that, besides arrow, the tilt cursor could have other appearances. We adopt arrow as the tilt cursor's appearance in our research to make it consistent with the other two cursors, which are used in the evaluations. The size of the arrow cursor is the same as that in Windows XP for UI consistency.

EXPERIMENTS

We conduct two experiments with touchpad. One is a circular menu selection task [1]. The other is a specific marking menu selection task which is different from original marking menu selection task [9]. In our experiments, the specific marking menu selection task is a task about drawing a straight stroke from the center of start item to the center of destination item. In two experiments, we compare the movement time and movement precision of three cursors: the shape-fixed arrow cursor (In this paper, the shape-fixed arrow cursor is defined as the normal cursor in GUI which has a fixed arrowhead), the live cursor, and the tilt cursor. Two experiments are used for validating our two hypotheses:

- Whether the 3D orientation cue of pen could not improve user performance in a circular menu selection.
- Whether the 3D orientation cue of pen could significantly improve user performance in a specific marking menu selection task by enhancing S-R compatibility in drawing a straight stroke.

Experiment 1: Circular Menu Selection Task

In experiment 1, the circular menu task shares similarities to several previous experiments that examined various aspects of S-R compatibility [1] [6]. Within each block, trials are fully randomized in a manner consistent with other experiments of this kind, meaning that every block of trials had a unique order of presentation and that every ordering was visibly different from all other orderings given to all participants. The movement time is defined as the period of time from trial initiation to the point at which a highlighted item was selected, measured in milliseconds (ms). The movement precision is described by error rate. If participant does not select the destination when experiment asked, the error count is increased by one. Figure 3 presents a visual description of typical trials of experiment 1.

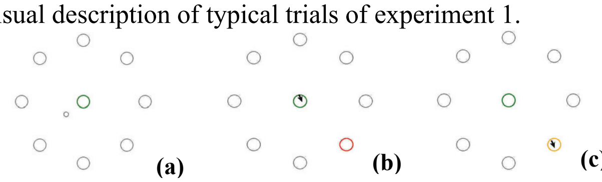

Figure 3. (a) Participants started a trial by tapping the circle at the center. (b) Then, one of the eight circular menu items is highlighted to indicate it should be selected. (c) Participants are instructed to select the center of the highlighted item and to emphasize speed and accuracy equally.

Experiment 2: Specific Marking Menu Selection Task

In experiment 2, the experimental design is similar to that of experiment 1, except that the user's action is changed to drawing a straight stroke from the central item to the destination item. Participants are instructed to follow the center line which is a line from the center of the central item to the center of destination item. The movement time is defined as the period of time from pen tip put down at central item to the point at which the pen tip lifted up at a highlighted item. The movement precision is described by error rate. If the stroke cross the two tangent lines between the start item and destination item, the error count is increased by one. Figure 4 presents a visual description of typical trials of experiment 2.

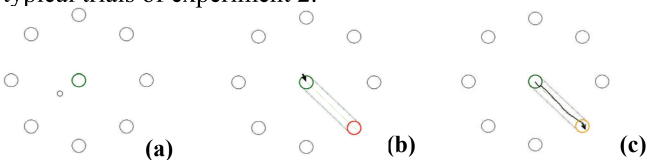

Figure 4. (a) Participants initiate a trial by starting drawing stroke at the center of the central item. (b) Then, one of the eight marking menu items, one center line and two tangent lines are highlighted to indicate it should be drawn following the center line to the item. (c) Participants are instructed to draw a straight line to the center of the highlighted item and to emphasize speed and accuracy equally.

Subjects, Apparatus and Procedure

Twelve subjects, eight male and four female, participated in two experiments. Participants ranged in ages from 19 to 27. To minimize experimental bias due to handedness, we ensure that all participants were right-handed via self-report. We also ensure that all participants had normal or corrected-to-normal vision via self-report. A Wacom 12'*12' touchpad and a 17' LCD screen with the resolution in 1024x768 pixels are used for the experiments.

We use a completely within-subject experimental design. Participants are instructed to complete all trials in two experiments. A Latin square is used to balance the order in which participants tried the three cursors. Participants first start with in experiment 1 followed by experiment 2. As for the session of the shape-fixed arrow cursor (four fixed shapes of arrow were used: up-left, up-right, down-left, down-right), each combination of trial parameters is repeated three times, thus a total of 4 cursor fixed shapes * 8 menu positions * 3 repetitions test trials are collected from each participant. As for the session of the live cursor and the tilt cursor, the 4 cursor shapes would be changed to additionally multiply 4 times, to maintain the consistency of the number of total trials. Participants are given 2 minutes break between sessions. Participants are given forty practice warm-up trial sets to familiarize themselves with each cursor. Practice trials consist of trials presented in the same fashion as experimental trials. Experiments totally last about 30 minutes for each participant.

RESULTS

Experiment 1

Repeated measures analysis of variance show a significant main effect for cursor type ($F_{2,22} = 4.046$, $p = .032$). The descriptive statistics of movement time of three cursor types are shown in Figure 5. The mean movement time of the shape-fixed arrow cursor, the live cursor and the tilt cursor are 1267.0959 ms, 1351.2921 ms and 1291.6011 ms. We observe that the movement time of the tilt cursor is significantly shorter than that of the live cursor ($F_{1,11} = 5.439$, $p = .040$). The movement time of the shape-fixed arrow cursor is significantly shorter than that of the live cursor ($F_{1,11} = 8.464$, $p = .014$). However, there is no significant difference between the movement time of the shape-fixed arrow cursor and the tilt cursor ($F_{1,11} = 0.466$, $p = .509$). All mean error rates of cursor are lower than 10%, and statistically, there are not significantly different from each other.

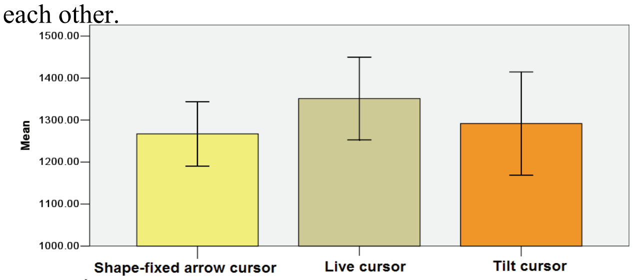

Figure 5. Mean movement times for three cursor types in experiment 1. Error bars show mean ±one std error.

Experiment 2

Repeated measures analysis of variance show a significant main effect for cursor type ($F_{2,22} = 12.064$, $p < .0001$). The descriptive statistics of movement time of three cursor types are shown in Figure 6. The mean movement time of the shape-fixed arrow cursor, the live cursor and the live cursor are 1789.3537 ms, 1793.8524 ms and 1593.3967 ms. We observe that the movement time of the tilt cursor is significantly shorter than that of the shape-fixed arrow cursor ($F_{1,11} = 15.720$, $p = .002$), and significantly shorter than that of the live cursor ($F_{1,11} = 20.764$, $p = .001$). However, there is no significant difference between the movement time of the shape-fixed arrow cursor and the live cursor ($F_{1,\ 11} = 0.009$, $p = .924$). All mean error rates of cursor are lower than 10%, and statistically, they are not significantly different from each other.

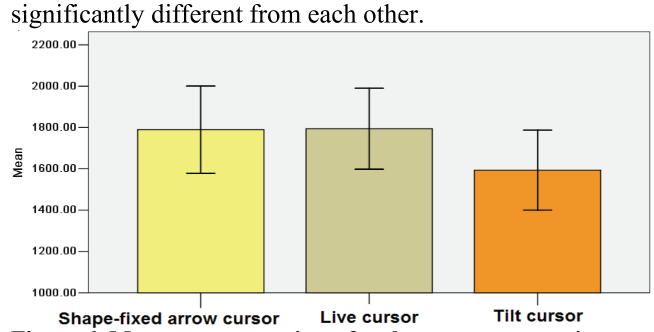

Figure 6. Mean movement times for three cursor types in experiment 2. Error bars show mean ±one std error.

DISCUSSION

In experiment 1, the users' attention is on the position of destination rather on the path to the destination. In a circular menu selection task, the primary function of cursors was a marker to indicate the current position of pen. Kinematic analysis show that such a task in touchpad involves more wrist movement [2]. As the 3D orientation of pen tends to be unchanged, the shape of the tilt cursor is nearly the same as that of the shape-fixed arrow cursor.

Therefore the influence on user performance by the 3D orientation cue of pen could be ignored. However, the shape of the live cursor is always changing according to the eight movement directions. From the viewpoint of Phillips [5], the response latencies are influenced by compatibilities between movement direction and cursor shape. Therefore, the live cursor brings more response latencies between movement direction and cursor shape.

Results of experiment 2 demonstrate that the improvement of user performance in specific marking menu selection task with the tilt cursor is significant, comparing to the other two cursors. This is because in a specific marking menu selection task, the users' attention is not only on the position of destination item, but also on the drawing path. Therefore, the cursor not only acted as a marker to indicate the positions of pen, but also functions more as a visual cue of the pen to help user in drawing. Kinematic analysis shows that performing such a task in touchpad involves more finger movements [2]. Thus the 3D orientation of pen tends to widely vary. With the 3D orientation cue of pen provided by the tilt cursor, participants could adjust their drawing directions dynamically and easily to follow the center lines.

We conduct an analysis of how participants dynamically adjust drawing direction to follow the center line with the three cursors. For each cursor, we calculate three values ($\overline{Q}$, $\overline{L}$, $\overline{I}$) based on all strokes in successful trails. $\overline{Q}$ is the average deviation of strokes from center lines, which is calculated by least square fittings. $\overline{L}$ is the average length of strokes. $\overline{I}$ is the average count of strokes' intersection counts with the center lines. The results show that:

$$\begin{cases} \overline{Q}_{TiltCursor} < \overline{Q}_{ArrowheadCursor} < \overline{Q}_{LiveCursor} \\ \overline{L}_{TiltCussor} < \overline{L}_{ArrowheadCurosor} < \overline{L}_{LiveCursor} \\ \overline{I}_{ArrowheadCursor} < \overline{I}_{LiveCursor} < \overline{I}_{TiltCursor} \end{cases}$$

Note that, for the tilt cursor, its $\overline{T}$ (the mean movement time), $\overline{Q}$ and $\overline{L}$ are all smaller than those of the others, while its $\overline{I}$ is larger than that of the others. This suggests that, with the tilt cursor, participants experience a shorter period (shorter time and shorter length of stroke) to adjust the direction to follow the center line. Figure 7 demonstrates the strokes drawn with three cursor types. We can observe in Fig.7 that the stroke of the tilt cursor follows the center line closer than the others two strokes.

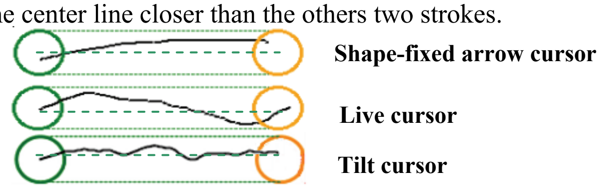

Figure 7. Three typical strokes drawn by different cursors

The time and the length of stroke consumed in adjusting drawing direction can be considered as the response latencies on mapping between visual stimuli (drawing direction, and the center line) to motor response (adjusting the drawing direction to follow the center line). With the tilt cursor, user needs smaller response latencies to create compatible mapping. It clearly suggests that the tilt cursor can enhance S-R compatibility of touchpad especially in adjusting drawing directions.

CONCLUSION AND FUTURE WORK

We present the tilt cursor, a cursor using the pen's orientation as a visual cue to the user. We conducted two experiments to compare the tilt cursor with the other two cursors. Experimental results show that the tilt cursor provides a better S-R compatibility of touchpad in specific marking menu selection tasks than the other two cursors.

Further research would include addressing two questions: First, is the result of this research still valid for pen devices with touch-sensitive screen? Second, do different cursors influence the ways in which users hold pens? Answering these questions will let us know more about pen cursors and pen input devices.

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