Improving Selection Performance on Pen-Based Systems: A Study of Pen-Based Interaction for Selection Tasks

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Two experiments were conducted to compare pen-based selection strategies and their characteristics. Two state transition models were also formulated which provide new vocabulary that will help in investigating interactions related to target selection issues. Six strategies, which can be described by the state transition models, were used in the experiments. We determined the best strategy of the six to be the "*Slide Touch*" strategy, where the target is selected at the moment the pen-tip touches the target for the first time after landing on the screen surface. The six strategies were also classified into strategy groups according to their characteristics. We determined the best strategy group to be the "*In-Out*" strategy group, where the target is selected by contact either inside or outside the target. Analyses show that differences between strategies are influenced by variations in target size; however, the differences between strategies are not affected by the distance to the target (i.e., pen-movement-distance) or the direction of pen movement (i.e., pen-movement-direction). We also found "the smallest maximum size" of five pixels, i.e., the boundary value for the target size below which there are significant differences, and above which there are no significant differences between the strategies in error rate. Relationships between interaction states, routes, and strategy efficiency were also investigated.

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Theory and methods; I.3.6 [**Computer Graphics**]: Methodology and Techniques—*Interaction techniques*

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1. INTRODUCTION

Pen-based systems (incorporating a small touch-sensitive screen) have emerged as an important access technology having carved out a large niche in the computer market. Pen-based input is well suited to jotting down text and accessing information in mobile computing situations. "Notepads" made pen-based systems more popular a few years ago; however, not enough empirical tests have been performed to determine how we can improve their usage and efficiency. Goldberg and Richardson [1993], MacKenzie et al. [1994], Venolia and Neiberg [1994], and MacKenzie and Zhang [1999] are a few exceptions.

In small pen-based systems, accessing information by the selection of a target is more often attempted than by inputting handwritten data. Common targets are menus, data (one character of the text or graphic segment, etc.), ranges etc., and the selection of keys on a software keyboard displayed on a screen. As the amount of information displayed on the screen is increasing, users have to select smaller targets. The trade-off between the size and accessibility of targets and the amount of information presented on the screen is a fundamental problem in human-computer design. This is especially obvious in mobile products, such as personal digital assistants (PDAs), personal information managers (PIMs), and other mobile pen-based applications.

In order to solve the problem, some leading studies have developed a variety of relatively efficient selection strategies for the touch-screen [Potter et al. 1988; Sears and Shneiderman 1991; Sears et al. 1992], the mouse [Kabbash and Buxton 1995; MacKenzie et al. 1991],[1] and 3D input systems [Zhai et al. 1996]. Potter et al. [1988] conducted an empirical experiment to compare three selection strategies for touch-screens; however, only one target size was used, and finger-movement-distance and finger-movement-direction were not considered. Sears and Shneiderman [1991] tested three selection devices; touch-screen, touch-screen with stabilization, and mouse. The task was the selection of rectangular targets of 1, 4, 16, and 32 pixels per side. Their results showed that a stabilized touch-screen was effective for reducing the error rates when selecting a target. Kabbash and Buxton [1995] developed an area cursor which is larger than normal in order to improve target selection. Moreover, Worden

[1]MacKenzie et al. [1991] also used a stylus but with an *indirect* tablet.

et al. [1997] have provided a study of the effectiveness of two strategies for target selection: "area cursors" and "sticky icons." Zhai et al. [1994] designed and demonstrated the effectiveness of the "silk cursor" which provided the volume/occlusion cues for target selection.

However, current target selection strategies for pen-based systems are mostly only imitations of selection techniques for mouse and touch-screen devices. Investigations aimed at improving selection strategies for pen-based input devices have been neglected. This article looks at selection strategies suitable for selecting small targets, and identifies and quantifies the influential factors that make strategies more or less efficient with a view to improving selection performance on pen-based systems.

This article is organized as follows. Section 2 introduces two interaction models for describing and designing 2D and 3D target selection strategies. It also describes and evaluates six strategies and six strategy groups which were tested in the experiments. Section 3 presents the experiment which determined the best individual strategy and the best strategy group. We explore the effect of target size, pen-movement-distance, and pen-movement-direction on the differences between selection strategies. We also investigate the relationships between interaction states, routes, and strategy efficiency. Section 4 presents another experiment for determining "the smallest maximum size," i.e., the boundary value of the target size below which the degree of difficulty was significantly affected when selecting targets on pen-based systems. Section 5 gives a conclusion and directions for future research.

2. CHARACTERISTICS OF SELECTION STRATEGIES

2.1 State Transition Models for Selecting a Target with a Pen

State transition models are very useful for describing and designing pointing/selecting interactions. Buxton [1990] suggested a state transition model to help characterize graphical input. However models for target selection have not been considered in detail. Chen [1993] proposed a state transition diagram for describing interactions with a target, but 3D targets have not been reported. Our models shown in Figure 1 and Figure 2 may expand and refine their research on target selection using a pen.

2.2.1 *A State Transition Model Describing Two-Dimensional Selection Strategies*. Figure 1 shows a simple state transition model which elucidates a number of properties for selecting two-dimensional (2D) targets. This model can describe target selection not only on electromagnetic type tablets but also on touch-sensitive type tablets (touch-screens) which are used in general-purpose pen-based systems. The tip of the stylus pen interacts with the electromagnetic tablet so that it switches on when in contact with the screen surface. The pen switches off when the pen-tip is not in contact with the screen surface.

The state transition model (Figure 1) shows an interaction with a 2D target. The model shows the target and the status and position of the

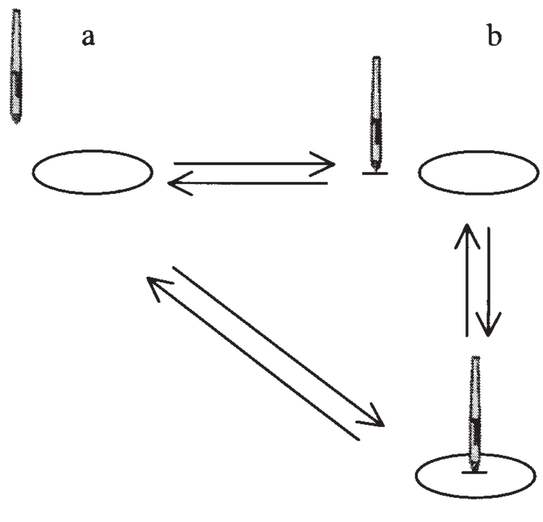

Fig. 1. A state transition model describing 2D target selection with a stylus pen. The ellipses illustrate 2D targets. The line arrows show the transition between two states which may be in either direction. The short lines under the pen-tip (in *b* and *c*) show the pen-tip in contact with the screen (the pen is switched on by contact with the screen). State *a*: pen outside/above the 2D plane, pen-tip switched off (pen not in contact with the screen); state *b*: outside the target, switched on (pen in contact with the screen); state *c*: inside the target, switched on (pen in contact with the screen). If we assume for example that state *a* is an initial state and *c* is a final state, the state transition route may be either $a \rightarrow b \rightarrow c$ or $a \rightarrow c$.

pen-tip. The ellipses represent 2D targets on the screen. The line arrows show the transition between two states. The short lines under the pen-tip show that the pen-tip is in contact with the screen (the pen is switched on). State *a* shows the pen outside/above the 2D plane, pen not in contact with the screen (the pen-tip switched off). State *b* shows the pen in contact with the screen (and therefore switched on) but outside the target area. State *c* represents the pen in contact with the screen (therefore switched on) inside the target. In state *a* the pen is approaching the 2D screen surface from above, in 3D space. In states *b* and *c* the pen is in contact with the screen (the pen is dragged over the 2D plane). Thus there are three states: state *a*: outside/above the 2D plane, not in contact with the screen (switched off); state *b*: outside the target, in contact with the screen (switched on); state *c*: inside the target, in contact with the screen (switched on).

2.2.2 *A State Transition Model Describing Three-Dimensional Selection Strategies*. Figure 2 shows a state transition model which elucidates a number of properties for selecting three-dimensional (3D) targets. We used an electromagnetic tablet in the experiments. This type of tablet also allowed us to trial 3D selection strategies, because when the pen-tip is above the tablet screen surface (within a height of 1 cm), the computer can recognize the coordinates (x, y) of the pen-tip. Thus, even though the bottom of a target (e.g., a menu or a button) on the screen is 2D, it can be highlighted or selected when the pen is above the tablet surface (within 1 cm). This means that the target can also be expressed as a 3D target.

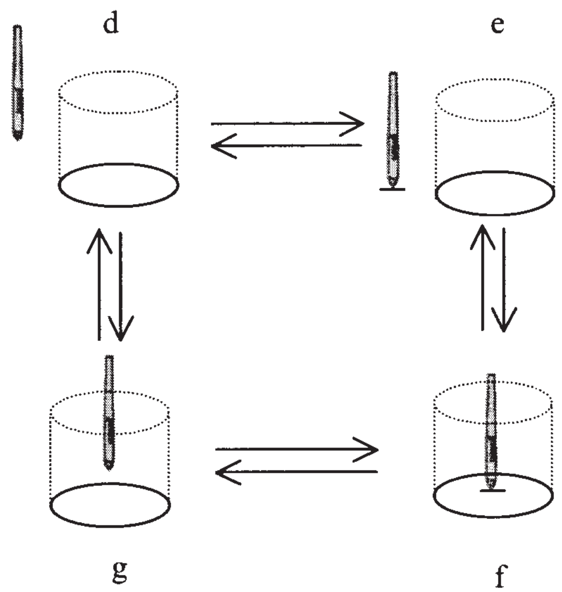

Fig. 2. A state transition model describing 3D target selection with a stylus pen. The cylinders with dashed lines show the body of a 3D target. The ellipses with a solid line illustrate the bottom of 3D targets on the tablet screen surface. The short lines under the pen-tip (in *e* and *f*) show the pen-tip in contact with the tablet surface. State *d*: the pen-tip is outside the 3D target, pen-tip switched off (pen not contact with the screen); state *e*: the pen-tip is outside the 3D target, switched on (the pen is in contact with the screen); state *f*: the pen-tip is inside the 3D target, switched on (pen in contact with the screen); state *g*: inside the 3D target but not in contact with the screen and therefore switched off.

The state transition model in Figure 2 showing an interaction with a 3D target consists of the target and the status and position of the pen-tip. The ellipses with a solid line illustrate the bottom of the 3D targets on the screen surface. The cylinders show the body of the 3D target. Some responses (e.g., highlighting) will take place when the pen is in the cylinder even though the pen-tip is not in contact with the screen surface. The short lines under the pen-tip show that the pen-tip is in contact with the screen surface. States *d* and *e* represent the pen outside the target. State *f* and state *g* represent the pen inside the target. States *e* and *f* represent the pen in contact with the screen surface (the pen is dragged over the 2D plane). States *d* and *g* represent the pen as not in contact with the screen surface. In this model we considered the two pen positions above and beside the 3D target as the same in effect. There may, however, be some design value in considering the implied approach paths as offering different selection options. Thus there are four states: state *d*: pen not in contact with the screen, outside the target (before or after entering the 3D target sensitive zone); state *e*: in contact with the screen surface, outside the target; state *f*: in contact with the screen, inside the target; and state *g*: approach or removal from the 2D plane inside the 3D target sensitive area (3D cylinder).

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