A MOVEMENT TIME MODEL OF ONE-HANDED TOUCH INPUT ON A MOBILE PHONE

Yong S. Park, Sung H. Han
Department of Industrial and Management Engineering
Pohang University of Science and Technology (POSTECH)
San 31, Hyoja. Pohang, 790-784
Kyung-buk, South Korea
Corresponding author’s e-mail: shan@postech.edu

Abstract: This study examined three design factors such as touch key size, movement direction, and movement distance when pressing touch keys on a mobile device. A total of twenty eight subjects participated in an experiment in which they were asked to press two touch keys using the thumb, while holding a mobile device with one hand. Movement time and movement convenience were measured. The results provided a movement time prediction model having $R^2$ of 0.96. In addition, the results showed that the northeast thumb movement is the fastest in terms of the movement time, while all movement directions except for the southwest and northeast were acceptable in terms of the movement convenience. The results of this study could be used to design and evaluate a touch key interface on a mobile device in order to improve its usability.

1. INTRODUCTION

Touch screens are widely used for a variety of mobile devices such as personal digital assistants (PDAs), portable multimedia players (PMPs), and mobile phones because they are highly intuitive and require little space (Colle and Hiszem, 2004; Scott and Conzola, 1997). Moreover, touch interfaces are easy to adjust the design parameters, such as key size, spacing between keys and location on the screen.

Karlson et al. (2006) surveyed usage patterns of mobile devices and found that most people use only one hand. In other words, they hold a mobile phone with one hand and interact with it using a thumb. In addition, they would use both hands only when the user interface makes one hand interaction impossible. Although one handed interaction on a mobile devices is popular, it is difficult to find research studies that examined critical design factors such as optimal key size and key spacing on a touch screen of a mobile device. These design factors are critical to the usability since people are using mobile devices frequently these days.

The Fitts’ law has been applied to a variety of research areas, including kinematics, human factors, and human computer interaction (HCI), because it can model human psychomotor behaviors. In the HCI areas, many studies have been conducted on a variety of input interfaces/devices in order to develop movement time models using the Fitts’ law. The Input interfaces/devices include pointing devices (MacKenzie et al., 1991), on-screen keyboards (MacKenzie and Zhang, 1999; Zhai et al., 2002), physical keyboards (Drury and Hoffmann, 1992), etc. A few relevant studies was carried out on one-handed thumb input on a mobile phone with a physical keypad (Pavlovych and Stuerzlinger, 2004; Silfverberg et al., 2000). However, there are few studies on a one-handed thumb input on touch screen.

This study aims to understand one-handed thumb input on a touch screen. In particular, a movement time model is developed by using the Fitts’ law. In addition, two research hypotheses are tested. The one is that there are no significant effects of the touch key size, the movement direction, and the movement distance on the movement time. The other is that the movement direction doesn’t significantly affect movement convenience felt by the users.

2. METHODS

2.1 Subjects

A total of twenty eight right-handed subjects participated in a human factors experiment. Their age ranged from 19 to 27 (Mean=23.2, SD=2.4). All the subjects had normal vision and no problem to move their right thumbs. Twenty of them had no experience in using a mobile device with a touch screen (e.g. PDA and PMP), while the others had experience of an average of 1.1 years.
2.2 Experimental Factors

Three within-subject factors were manipulated in the experiment. They included a touch key size, a movement direction, and a movement distance. The touch keys were assumed to have a square shape and had three different sizes (18 pixels, 32 pixels, 46 pixels). The size of 18 pixels was similar to that of the smallest input interface that typical commercial PDAs provided on a touch screen.

A total of eight movement directions (that is, N, S, E, W, NW, SE, NE, and SW) were used in the study. The N direction means that the thumb moves upward to complete a task and the W means that the thumb moves left. The other directions were similarly defined in the experiment.

The movement distance factor had seven levels such as 60 pixels, 100 pixels, 150 pixels, 190 pixels, 235 pixels, 275 pixels, and 300 pixels. In this study, one pixel was 0.23 mm long.

The three factors, however, were not completely crossed to make experimental conditions because the mobile device used in this study had a limited size (the width of 240 pixels and the height of 320 pixels). For example, movement of 300 mm to right or left directions was not tested because it was infeasible to be implemented on the device. A total of forty-six conditions per each touch key size were used in the experiment, which meant a total of 138 experimental conditions (46 conditions × 3 touch key sizes). Table 1 showed the forty-six experimental conditions, which are combinations of the movement directions and the movement distances.

Table 1. Forty-six experimental conditions for each touch key size

<table>
<thead>
<tr>
<th>Movement direction</th>
<th>Movement distance (pixels)</th>
<th>Movement direction</th>
<th>Movement distance (pixels)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E, W</td>
<td>60, 100, 150, 190</td>
<td>NW, SE</td>
<td>60, 100, 150, 190, 235, 275, 300</td>
</tr>
<tr>
<td>N, S</td>
<td>60, 100, 150, 190, 235</td>
<td>NE, SW</td>
<td>60, 100, 150, 190, 235, 275, 300</td>
</tr>
</tbody>
</table>

2.3 Experimental Tasks

Each subject was asked to press two touch keys presented on the touch screen in sequence using the right thumb. The first target was shown in blue while the second target was shown in red on the screen. The subject was asked to press the keys in sequence as fast and exactly as possible. When the subject succeeded to press the targets, a beep sound was presented.

Each subject performed a total of 690 experimental trials (128 experimental conditions × 5 times of repetition). In order to minimize learning effects, the presentation orders of the conditions was determined by using a Latin Square Balancing technique. In addition, two targets in each trial were randomly presented on the touch screen.

The subject was asked to hold a PDA with his/her right hand. If thumb movement on the touch screen was interfered by the PDA, however, it was allowed to put a left hand underneath the PDA in order to support easy and free thumb movements.

2.4 Dependent Measures

Two types of dependent measures such as movement time and movement convenience were collected in the experiment. The movement time was defined as the elapsed time between releasing the first target (a blue one) and pressing the second target (a red one), and it was automatically calculated and recorded during the experiment.

After finishing all the experimental conditions, each subject was asked to rate movement convenience for the eight movement directions. The rating scale ranged from 1 (extremely inconvenient) to 9 (extremely convenient).
Figure 1. An example of experimental tasks
(touch key size: 7mm, movement direction: E, movement distance: 150 pixels)

Figure 2. A regression line of movement time

2.5 Apparatus

A commercial PDA (HP iPAQ rz1717 with touch screen size of 240×320 pixels) was used in this study because of the following two reasons. It had a smaller size than other mobile devices with touch screens (e.g. PMPs and other PDAs). Also, it was easy to develop experimental prototypes using a programming tool, Microsoft Visual Studio 2005. Figure 1 illustrates an example of experimental tasks on the PDA.

3. RESULTS

3.1 Movement time model

To develop a movement time model, the target sizes and movement distances manipulated in the experiment were transformed into an index of difficulty (ID). This transformation identified twenty one IDs that ranged from 1.2 to 4.1. Then, the movement time data with the same ID were pooled and averaged.

A linear regression method was applied to developing a movement time model. Figure 2 shows the data points and the resulting regression line. The movement time model has a quite good prediction power ($R^2 = 0.96$), which is shown in Equation 1.

\[
\text{Movement Time (mS)} = 137.1 + 152.2 \text{ ID} \tag{1}
\]
3.2 Effects of experimental factors on dependent measures

3.2.1 Movement time

A part of experimental data was used in order to compare movement times by the experimental factors. Experimental data only with four movement distance (60 pixels, 100 pixels, 150 pixels, and 190 pixels) were analyzed using an analysis of variance (ANOVA) with a significant level of 0.05. As a post-hoc analysis, the Student Newman-Keuls (SNK) test was conducted on significant main effects.

The results showed that all the main effects and two-way interaction effects, except for one between the movement direction and the movement distance, had significant effects on the movement time at the significance level of 0.05 (p<0.01 for all significant effects).

An SNK test on the touch key size showed the movement time decreased as the touch key size increased. As expected, the longer the movement distance, the longer the movement time. In addition, it was found that the movement time in the NE direction was the fastest, while the movement time in one of the three directions (i.e. W, NW, and N) was the longest (see Figure 3).

3.2.2 Movement convenience

Movement convenience scores were transformed into ranks because the original data didn’t meet the assumptions of an ANOVA (Hesel and Hirsh, 2002). Then, a one-way ANOVA computed on ranks. The movement direction was revealed to significantly affect the movement convenience (p<0.01).
An SNK test showed that the subjects rated lower convenience scores when moving their thumb in the NW and the SE directions than in the other directions. The convenience scores of the six directions, except for the NW and the SE, were not significantly different. The average convenience scores for eight directions are presented in Figure 4.

4. DISCUSSION

The movement time model developed in this study can be used to evaluate the user interfaces of mobile devices that have touch screens. Mackenzie et al. (1991) compared three desktop input devices (a mouse, a tablet, and a trackball) by using a performance index (IP). The IP was considered an important performance metric and was obtained by a reciprocal of the slope of a Fitts’ law regression. Table 2 summarizes movement time models and performance indexes of three studies (i.e., this study and other two studies (Silfvergerg et al., 2000; Zhai et al., 2002)).

Table 2. Comparison of movement time models and performance indexes

<table>
<thead>
<tr>
<th>Source</th>
<th>This study</th>
<th>Zhai et al. (2002)</th>
<th>Silfvergerg et al. (2000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target device</td>
<td>Small touch screen (PDA)</td>
<td>Large touch screen (Table)</td>
<td>Mobile Phone with physical buttons</td>
</tr>
<tr>
<td>Input method</td>
<td>Thumb</td>
<td>Stylus pen</td>
<td>Index finger</td>
</tr>
<tr>
<td>Hand use</td>
<td>One hand</td>
<td>Two hands</td>
<td>Two hands</td>
</tr>
<tr>
<td>Intercept</td>
<td>137.1</td>
<td>83</td>
<td>165</td>
</tr>
<tr>
<td>Slope</td>
<td>152.2</td>
<td>127</td>
<td>52</td>
</tr>
<tr>
<td>Performance index</td>
<td>6.6</td>
<td>7.9</td>
<td>19.2</td>
</tr>
</tbody>
</table>

Table 1 shows the one-handed thumb input on the touch screen has the smallest performance index. In addition, its predicted movement time is always longer than the others. This results could be explained by differences in the input recognition algorithm and the amount of feedback information during the task. Touch keys are activated only if the centroid of a pressed area falls in the region of a target key, while traditional physical buttons work when the user presses any part of it. This difference means more delicate control is required when pressing touch keys than when pressing physical buttons.

According to Meyer et al. (1990), feedback information is necessary during a rapid human movement to check if a movement reaches a target. The users can get only visual information from the touch screen because it is difficult to implement tactile feedback on the touch screen. On the other hand, both visual and tactile information are available for the physical key buttons. Worse yet, when using a mobile device by one hand, it is difficult to get even visual information if a target is visually interfered by the hand and fingers.

In addition to evaluating overall performance of input interfaces, a movement time model based on the Fitts’ law can be used to other HCI applications like developing a task completion time model for a specific task and evaluating design alternatives. For example, previous studies developed task completion time models for text entry on a mobile phone with physical buttons and compare text entry methods such as multi-press, T9, and two-key (Pavlovych and Stuerzlinger, 2004; Silfvergerg et al., 2000). Because there are few task completion time models for mobile devices with the touch screen, it is necessary to develop models for frequently used tasks using the results of this study.

The results of this study showed that when the subjects pressed touch keys on a small screen, the touch key size significantly affected the movement time. These results are consistent with previous studies (Colle and Hiszem, 2004; Martin, 1988; Parhi and Benderson, 2006; Scott and Conzola, 1997). However, large touch keys with the best usability often cannot be applied to a mobile phone in which a large number of touch items should be presented at the same time. Therefore, future studies are necessary to examine the relationship between usability and applicability to a mobile device according to the touch key sizes.
Right handed users felt thumb movement in the directions of the NW and the SE is more difficult than the others, which might be explained by the anatomy of the hand. Movements in these directions require considerable flexion (Karlson et al., 2006). Therefore, it is recommended to avoid these movements in designing an interface.

5. CONCLUSION

This study was conducted to systematically develop a movement time model of one-handed thumb input on a touch screen. Also, the effects of three factors (the touch key size, the movement distance, and the movement direction) on usability were investigated.

As a result a regression model was developed, which could predict the movement time of the thumb input on a touch screen. The model had good prediction power ($R^2 = 0.96$) enough to be applicable to other HCI areas. Based on the model, it was found that the one-handed thumb input on the touch screen required a longer movement time than the other input interfaces for mobile devices. In addition, thumb movement in the NE direction took the shortest time among the eight directions. Finally, it was revealed that thumb movement in the SE and the NW directions is not preferred. The results of this study may be applied to designing touch interfaces for a mobile phone and to comparing task performances of various design alternatives.

6. REFERENCES


