Applied Ergonomics 68 (2018) 54–60

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

Extended Fitts' model of pointing time in eye-gaze input system - Incorporating effects of target shape and movement direction into modeling

Atsuo Murata*, Daichi Fukunaga

Dept. of Intelligent Mechanical Systems, Graduate School of Natural Science and Technology, Okayama University, Okayama, Japan

A R T I C L E I N F O

Keywords:
HCI
Fitts' modeling
Pointing time
Eye-gaze input system
Target shape
Movement direction

A B S T R A C T

This study attempted to investigate the effects of the target shape and the movement direction on the pointing time using an eye-gaze input system and extend Fitts' model so that these factors are incorporated into the model and the predictive power of Fitts' model is enhanced. The target shape, the target size, the movement distance, and the direction of target presentation were set as within-subject experimental variables. The target shape included: a circle, and rectangles with an aspect ratio of 1:1, 1:2, 1:3, and 1:4. The movement direction included eight directions: upper, lower, left, right, upper left, upper right, lower left, and lower right. On the basis of the data for identifying the effects of the target shape and the movement direction on the pointing time, an attempt was made to develop a generalized and extended Fitts' model that took into account the movement direction and the target shape. As a result, the generalized and extended model was found to fit better to the experimental data, and be more effective for predicting the pointing time for a variety of human-computer interaction (HCI) task using an eye-gaze input system.

1. Introduction

Although the possibility of using electroencephalography (EOG) (Gips et al., 1993) and electroencephalography (EEG) (Farwell and Donchin, 1988; Wolpaw et al., 1991) as a tool for moving a cursor or selecting an object was discussed, the usage of such systems are limited to a discrete input such as the selection of an object. On the other hand, a method using an eye tracking system allows for continuous inputs such as cursor movement and the selection of an object which is ubiquitous in human-computer interaction (HCI). Therefore, the development of an eye-gaze input system using an eye tracking system has been paid attention to since around early 1990s (Ware and Mikaelian, 1987; Huchinson et al., 1989; Fray et al., 1990). The progress (increased accuracy and resolution) of an eye tracker has made it possible to carry out an actual HCI task using an eye-gaze input system.

Pointing using an eye-gaze input system is more intuitive and faster than that using a mouse (Zhai et al., 1999; Sibert and Jacob, 2000; Murata, 2006), because we can naturally direct our eyes toward the location of a target to be pointed and eye movements are faster than hand movements. Sibert and Jacob (2000) and Murata (2006) found that target acquisition performance was faster using gaze with short dwell times less than 150 ms than that using a mouse. San Agustin et al. (2009) evaluated the potential of gaze input for game interaction. They suggested that there is a potential for gaze input in game interaction, given a sufficiently accurate and responsive eye tracker and a well-designed interface.

Partala et al. (2001) studied the benefit of combining gaze pointing and facial-muscle EMG clicking compared to mouse input in target acquisition tasks. They found task completion times to be shorter for the eye-gaze input for long distances (above 100 pixels) after removing the error trials. However, a very high error rate (34%) was observed for the gaze-EMG combination. Surakka et al. (2004) extended the previous study with a more detailed Fitts' law analysis. They also showed that gaze-EMG input combination was more effective for long-distance movement than the mouse, but for short distances the mouse was more effective.

The technology for measuring a user's visual line of gaze in real time has been advancing. Appropriate human-computer interaction techniques that incorporate eye movements into a human-computer dialogue have been developed (Jacob, 1990, 1991, 1993a, 1993b, 1994; Jacob et al., 1994; Sibert and Jacob, 2000; Murata, 2006; Murata and Moriwaka, 2009a). These studies have found the advantages of eye-gaze input system to assure faster pointing time. As eye-gaze input interfaces enable us to interact with PC by making use of eye movements, it is expected that even disables persons with deficiency on the upper limb can easily use it. Many studies (Murata and Miyake, 2008; Murata

* Corresponding author. Dept. of Intelligent Mechanical Systems, Graduate School of Natural Science and Technology, Okayama University, Okayama 3-1-1, Tsushimanaka, Kita-ku, Okayama, 700-8530, Japan.

E-mail address: murata@iims.sys.okayama-u.ac.jp (A. Murata).

http://dx.doi.org/10.1016/j.apergo.2017.10.019
Received 7 June 2016; Received in revised form 3 August 2017; Accepted 28 October 2017
0003-6870/

and Moriwaka, 2009b, 2009c; Murata et al., 2012; Murata and Uetsugi, 2012; Murata et al., 2013) are reported on eye-gaze input interfaces as an alternative to a mouse. In these studies, an optimal click method (Murata and Miyake, 2008; Murata and Moriwaka, 2009b), a menu selection method (Murata and Moriwaka, 2009c), and a character input method (Murata et al., 2013) have been discussed.

However, there are still a lot of problems we must overcome so that such an input system can be put into practical use in actual HCI tasks. For example, the shape of mouse cursor suitable for general HCI except for eye-gaze interfaces is discussed, for example, by Pastel (2011), Lecuier (2008), and Phillips (2003). Like general HCI, we should use a proper cursor shape which enhances the usability of eye-gaze input system. As the eye-gaze input system differs from the mouse input in input mechanism, and has a lower resolution as compared with the mouse input, it is natural and reasonable to predict that the optimal cursor shape proper for the mouse input does not necessarily lead to the high usability of eye-gaze interfaces. Although a conventional arrow-type cursor is used even in eye-gaze input interfaces, there seems to be no definite reason to use such a conventional cursor shape in eye-gaze input interfaces. It has been explored what type of cursor shape is suitable for eye-gaze input interfaces (Murata and Uetsugi, 2012). This study, however, did not investigate the effect of target shape on the pointing time to develop an extended Fitts' model that incorporated the effect of cursor shape or target shape as a model parameter.

Murata (1996) empirically evaluated performance models of pointing accuracy and speed with a PC mouse by extending a target size to a two-dimensional movement. Murata (1999) also attempted to extend Fitts' model to a two-dimensional pointing task by proposing a two-dimensional effective target width. These study also did not incorporate the effect of a target shape on the pointing time into Fitts' modeling, although these studies proposed how to define a target in a two-dimensional HCI task.

Murata and Iwase (2001) made an attempt to extend Fitts' law to a three-dimensional movement (pointing) task to enhance its predictive performance. An experiment was conducted in which ten participants performed three-dimensional pointing (gaze) movements under the manipulation of target size, distance to target and direction to target. They extended the conventional Fitts' model by incorporating movement directions into the model. The extended model was shown to better fit the data than the conventional Fitts' model, both in terms of contribution (R^2) and the standard error of the residual between the measured movement time and the value predicted by model fit. The extended Fitts' model that took into account movement directions has not been applied to model a pointing time in HCI. Although Murata (1996) empirically evaluated performance models of pointing time with a PC mouse by extending a target size to a two-dimensional movement, this study did not incorporate the movement direction into the model. Murata (1999) also attempted to extend Fitts' model to a two-dimensional pointing task by proposing a two-dimensional effective target width, which also did not take into account the movement direction. As the effects of target shape or movement direction on the pointing time have not been incorporated into the model, it cannot be said that Fitts's modeling of an eye-gaze input system has not been fully explored.

This study aimed at investigating the effects of the target shape or the movement direction on the pointing performance using an eye-gaze input system and proposing an extended Fitts' model that took into account the target shape and the movement direction. An experiment was designed so that the target shape, the target size, the movement distance, and the movement direction were within-subject experimental variables. The target shape included: a circle and rectangles with an aspect ratio of 1:1, 1:2, 1:3, and 1:4. The direction of movement included eight directions: upper, lower, left, right, upper left, upper right, lower left, and lower right. In this manner, an attempt was made to model the pointing time using an extended Fitts' model that took into account the target shape or the movement direction, and enhance the predictive power of Fitts' modeling of pointing time.

2. Method

2.1. Participants

Fifteen young adults aged from 21 to 24 years old took part in the experiment. All had usage experience of PC from 8 to 10 years. The visual acuity of the participants was more than 20/20. They had no orthopedic or neurological diseases. All participants provided informed consent after receiving a brief explanation of the aim and the contents of the experiment.

2.2. Apparatus

Using EMR-AT VOXER (Nac Image Technology) and Visual C# (Microsift), an eye-gaze input interface was developed. This apparatus enables us to determine eye movements and fixations by measuring the reflection of low-level infrared light (800 nm), and also admits the head movements within a predetermined range. The eye tracker was connected with PC (HP, DX5150MT) with a 15-inch (303 mm × 231 mm) CRT. The resolution was 1024 × 768 pixel. Another PC was also connected to the eye-tracker via a RS232C port to develop the eye-gaze input system. The line of gaze, via a RS232C port, is output to this computer with a sampling frequency of 60 Hz. The system has inherently no delay according to the specification of this apparatus. The illumination on the keyboard of a PC was about 200 lx, and the mean brightness of 5 points (four edges and a center) on CRT was about 100 cd/m^2. The viewing distance was fixed to 70 cm. The experimental setting using the eye tracker EMR-AT VOXER is shown in Fig. 1.

2.3. Task

The task was to point to a target presented either of eight directions in Fig. 2. The participants moved fixation from the initial fixation point (start button in Fig. 2) to the target, and fixated it for 100 ms. The movement distances were 210 pixel and 290 pixel, respectively. The movement distance corresponds to the distance from the center of a start button to the center of a target. The target shapes were a circle and rectangles with an aspect ratio of 1:1, 1:2, 1:3, and 1:4 (see Fig. 3). The areas of target were 100 × 100 pixel^2, 75 × 75 pixel^2, and 50 × 50 pixel^2. In Fig. 3, the visual angle when the viewing distance is 70 cm and the center of vision coincided with the center of a target is also depicted.

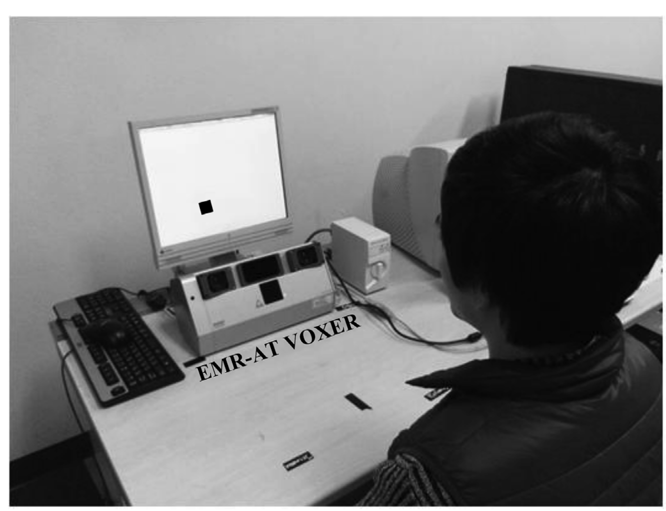

Fig. 1. Outline of experimental setting using an eye tracker (EMR-AT VOXER).