Proposal of Estimation Method of Stable Fixation Points for Eye-gaze Input Interface

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Abstract. As almost all of existing eye-gaze input devices suffers from fine and frequent shaking of fixation points, an effective and stable estimation method of fixation points has been proposed so that the obtained stable fixation points enabled users to point even to a smaller target easily. An estimation algorithm was based on the image processing technique (Hough transformation). An experiment was carried out to verify the effectiveness of eye-gaze input system that made use of the proposed estimation method of fixation point. From both evaluation measures, the proposed method was found to assure more stable cursor movement than the traditional and commercial method.

Keywords: Eye-gaze input, fixation point, stabilization, task completion time, pointing error.

1 Introduction

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 has been developed [1-11]. These studies have found the advantage of eye-gaze input system. However, few studies except Murata [8] have examined the effectiveness of such systems with older adults. Murata [8] discussed the usability of an eye-gaze input system to aid interactions with computers for older adults. Systematically manipulating experimental conditions such as the movement distance, target size, and direction of movement, an eye-gaze input system was found to lead to faster pointing time as compared with mouse input especially for older adults. Eye-gaze input interfaces [1-11] are paid more and more attention as an alternative to a mouse especially for disabled persons. As the eye-gaze input interface enables users to operate PC by eye movements, even disables persons with deficiency on the upper limb can easily use it. However, at present, it is difficult to obtain a stable fixation points so that one can point to a smaller target using an eye-gaze input system.

Almost all of existing eye-gaze input devices suffers from fine and frequent shaking of fixation points. Since the edge of iris and pupil is changing smoothly during the

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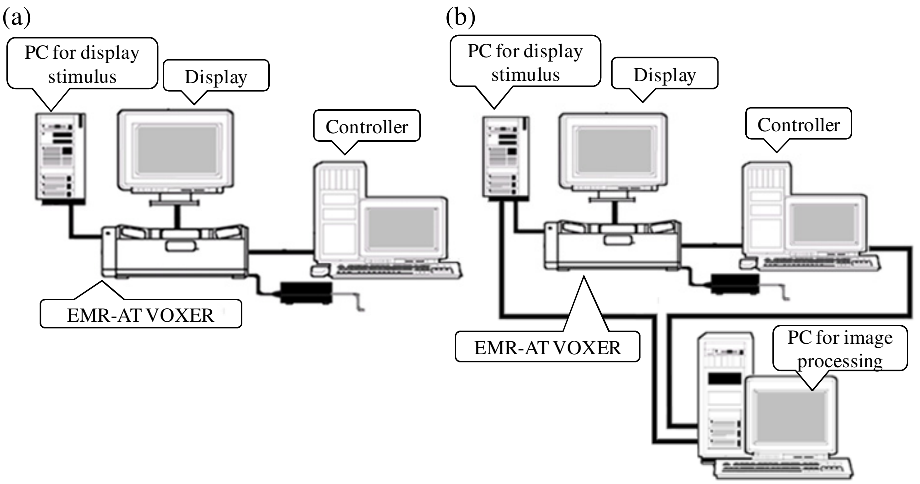

Fig. 1. (a) commercial eye-gaze measurement system used in this study and (b) addition of image processing system to the system in Fig.1(a)

extraction process of pupil image, it is difficult to extract the pupil image accurately and always obtain a stable coordinate of the pupil image. Due to this, an effective and stable estimation method of fixation points has not been established, and it is presently not easy to point to a smaller target such as ones used on GUI of Internet Explorer using the existing eye-gaze input system. An estimation algorithm based on the image processing technique (Hough transformation) had been proposed so that the obtained stable fixation points enabled users to point even to a smaller target easily.

The effectiveness of the proposed method for stably estimating fixation point and preventing the fixation points of the system from shaking was empirically verified. In the verification experiment, an easy pointing task using an eye-gaze input system was taken up. The task completion time, the operation error, and the cursor movement trajectory (the mean distance from the center of the target and the standard deviation of the coordinates) were compared between the traditional and the proposed methods.

2 Method for Estimating Stable Fixation Points

An estimation algorithm based on the image processing technique (Hough transformation) and detection of Purukinje image had been proposed so that the obtained stable fixation points enabled users to point even to a smaller target easily. The commercial eye-gaze measurement system used in this study is shown in Fig.1(a). The image processing system was added to the system (See Fig.1(b)).

When gazing at the lower part of the display, both eyelash and Purkinje image overlaps a pupil and consequently the pupil cannot be extracted. Due to this, stable eye fixation points cannot be obtained. In order to measure fixation points stably, we must manage to compensate for the lack of pupil image. In this study, we used Labview (NATIONAL INSTRUMENTS), added image processing component to the

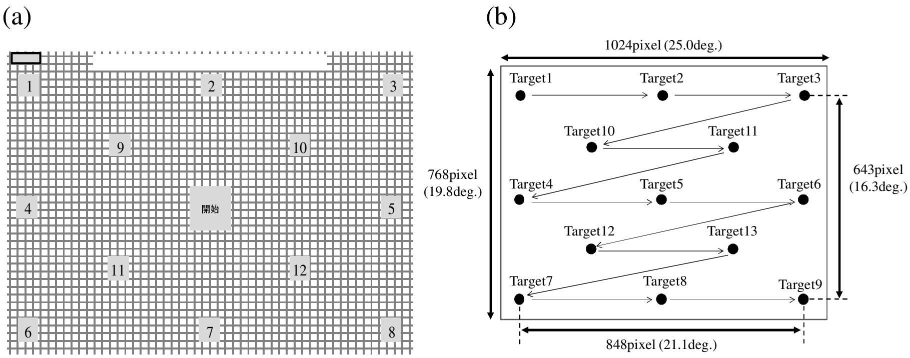

Fig. 2. (a) Experimental display and (b) Procedure of pointing task (From Target1 to Target9)

commercial system as in Fig.1(a), and made an attempt to extract pupil images using Hough transformation and obtain stable fixation points.

The pupil image was extracted by applying Hough transformation of a circle to an extracted edge as a candidate of pupil boundary. By setting the radius of the circle, Purkinje image can also be detected. It is well known that the movement of eye-gaze point is nearly proportional to the rotation of an eyeball. An attempt was made to estimate eye-fixation points on the basis of the change of distance between pupil and Purkinje image using the method by Mackworth et al. [12].

3 Experimental Method

3.1 Participants

Using five undergraduate or graduate students aged from 21 to 23, the usability of the proposed eye-gaze input system was experimentally compared with that of the conventional system. All participants were

3.2 Experimental Task

The participants were required to point to a target on a display as accurately and quickly as possible. The task completion time and the pointing accuracy were measured. The illumination and brightness on the experimental display were 500 lx and 98cd/m^2, respectively. The viewing distance was about 450mm.

Three kinds of squares (60 X 60 pixel^2 (2.09 degree of visual angle), 40 X 40 pixel^2(1.39 degree of visual angle), and 30 X 30 pixel^2 (1.05 degrees of visual angle)) were used in the experiment. The participant was required to point to the targets in ascending order from Target1 to Target10 (See Fig.2(a) and (b)). The outline of experimental situation is shown in Fig.3.

Fig. 3. Outline of experimental situation

3.3 Design and Procedure

The cursor movement to the target was conducted using an eye-gaze system, and the click was done using a mouse when the cursor entered the target square. When the target was successfully pointed to, a beep sound rang and the movement to the next target started. The participant must judge whether the target was successfully clicked using only the click sound. When all of 10 targets were clicked, one task was completed.

4 Results

4.1 Task Completion Time

The task completion time is shown as a function of target size (30, 40, and 60 pixel square) and estimation method of fixation point (the commercial and the proposed ones) in Fig.4(a). When the target was 30 X 30 pixel^2, the mean task completion time of the proposed method was reduced by about 34% as compared with that of the traditional and commercial method. In Fig.4(b), the mean task completion time is plotted as a function of target location and estimation method of fixation point (the conventional and the proposed ones) in case of target size of 30 pixel.

4.2 Number of Errors

The number of errors is shown as a function of target size (30, 40, and 60 pixel square) and estimation method of fixation point (the commercial and the proposed ones) in Fig.5(a). In Fig.5(b), the mean task completion time is plotted as a function of target location and estimation method of fixation point (the conventional and the proposed ones) in case of target size of 30 pixel. The number of input errors for the proposed method was reduced by about 54% as compared with that of the traditional and commercial method. No differences of performance were detected between both methods when the target sizes were 40 X 40 pixel^2 and 60 X 60 pixel^2.

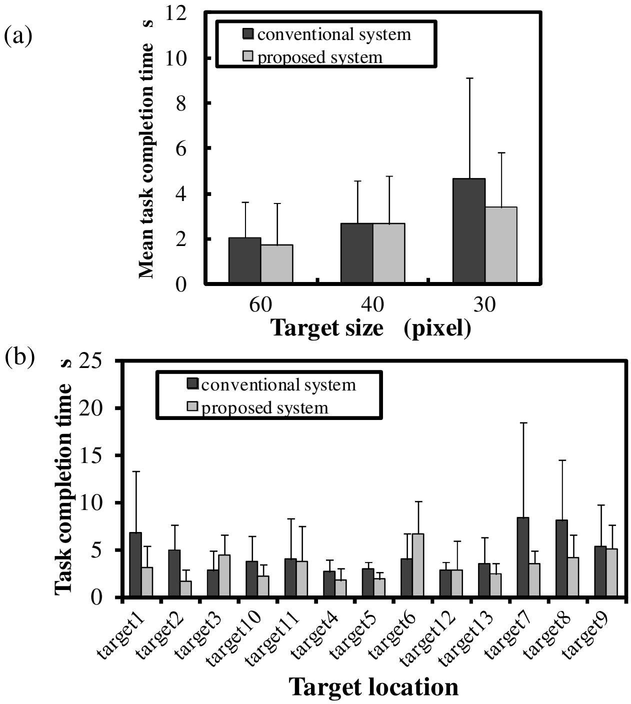

Fig. 4. (a) Mean task completion time as a function of target size (30, 40, and 60 pixel square) and estimation method of fixation point (the conventional and the proposed ones), (b) Mean task completion time as a function of target location and estimation method of fixation point (the conventional and the proposed ones) (target size: 30 pixel)

4.3 Cursor Movement Trajectory

The significant difference of performance (task completion time and number of errors) between two methods (traditional and proposed methods) was detected for the square target of 30 X 30 pixel^2. Therefore, the stability of cursor movement trajectory was analyzed only for the square target of 30 X 30 pixel^2. The cursor movement trajectory until 10 sample points (1/30 s X 10=1/3 s) before the mouse click was used for the analysis of cursor movement stability. Using these data, the mean distance from the center of the target and the standard deviation of the coordinates were calculated. The results for the target size of 30 pixel are depicted in Fig.6(a) and (b). From both evaluation measures, the proposed method was found to assure more stable cursor movement than the traditional and commercial method.

4.4 Performance for Target Size of 20 Pixel

In order to further verify the effectiveness of the proposed method, the data for the target size of 20 pixel was also collected. Fig.7(a) shows the mean task completion time as a function of estimation method of fixation point (the conventional and the

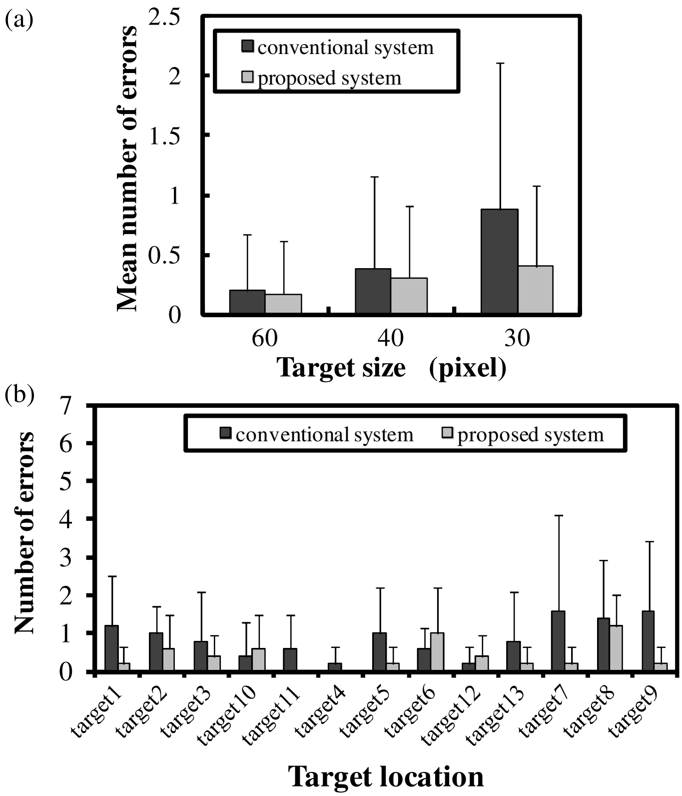

Fig. 5. (a) Mean number of errors as a function of target size (30, 40, and 60 pixel square) and estimation method of fixation point (the conventional and the proposed ones) and (b) Mean number of errors as a function of target location and estimation method of fixation point (the conventional and the proposed ones) (target size: 30 pixel)

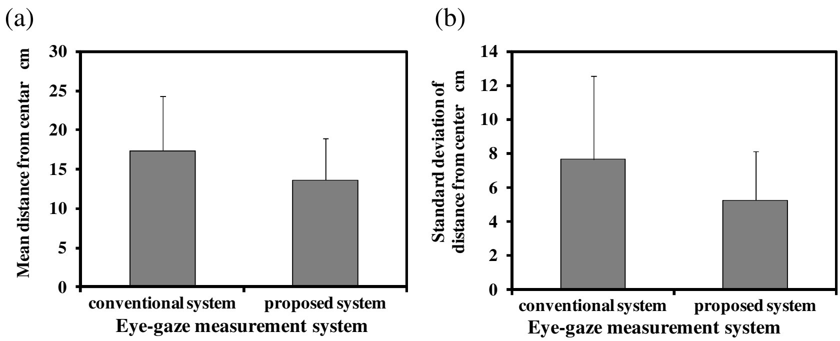

Fig. 6. (a) Mean distance from center as a function of estimation method of fixation point (the conventional and the proposed ones) (target size: 30 pixel) and (b) Standard deviation of distance from center as a function of estimation method of fixation point (the conventional and the proposed ones) (target size: 30 pixel)

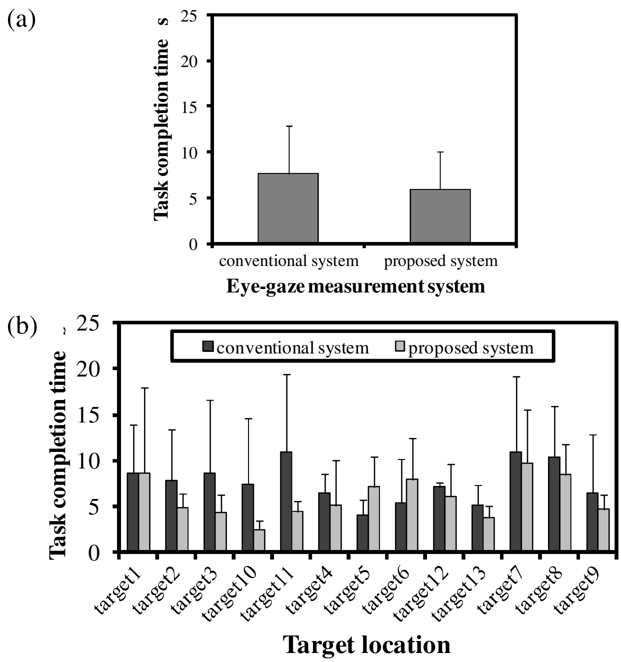

Fig. 7. (a) Mean task completion time as a function of estimation method of fixation point (the conventional and the proposed ones) (target size: 20 pixel) and (b) Mean task completion time as a function of target location and estimation method of fixation point (the conventional and the proposed ones) (target size: 20 pixel)

proposed ones) for the target size of 20 pixel. Fig.7(b) shows the mean task completion time as a function of target location and estimation method of fixation point (the conventional and the proposed ones)for the target size of 20 pixel. In Fig.8(a), the mean number of errors is shown as a function of estimation method of fixation point (the conventional and the proposed ones) for the target size of 20 pixel. In Fig.8(b), the mean number of errors is plotted as a function of target location and estimation method of fixation point (the conventional and the proposed ones) for the target size of 20 pixel. Fig.9(a) shows the mean distance from center as a function of estimation method of fixation point (the conventional and the proposed ones) for the target size of 20 pixel. Fig.9(b) compares the standard deviation of distance from center between the two estimation methods of fixation point (the conventional and the proposed ones) for the target size of 20 pixel.

5 Discussion

5.1 Task Completion Time

As shown in Fig.5(a) and Fig.7(a), it was confirmed that the task completion time of the proposed system tended to be shorter as compared with that of the traditional

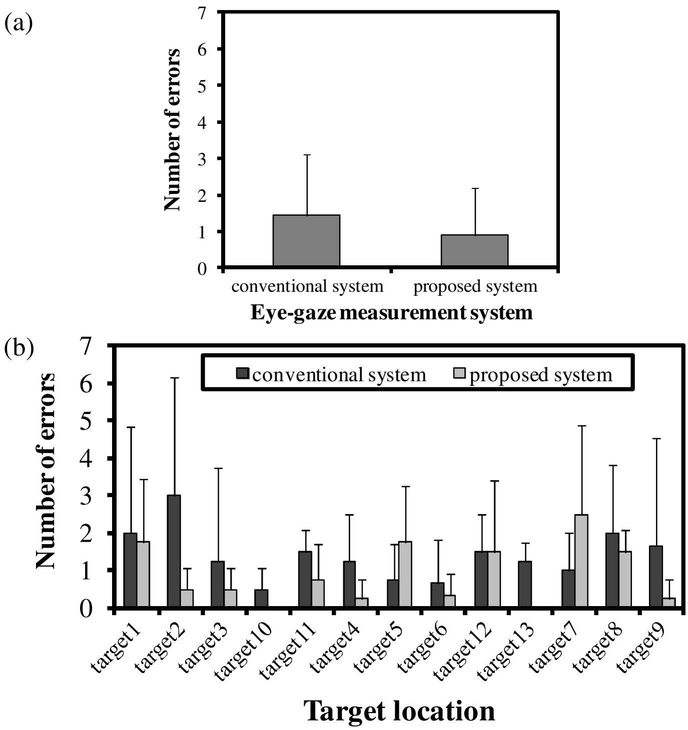

Fig. 8. (a) Mean number of errors as a function of estimation method of fixation point (the conventional and the proposed ones) (target size: 20 pixel) and (b) Mean number of errors as a function of target location and estimation method of fixation point (the conventional and the proposed ones) (target size: 20 pixel)

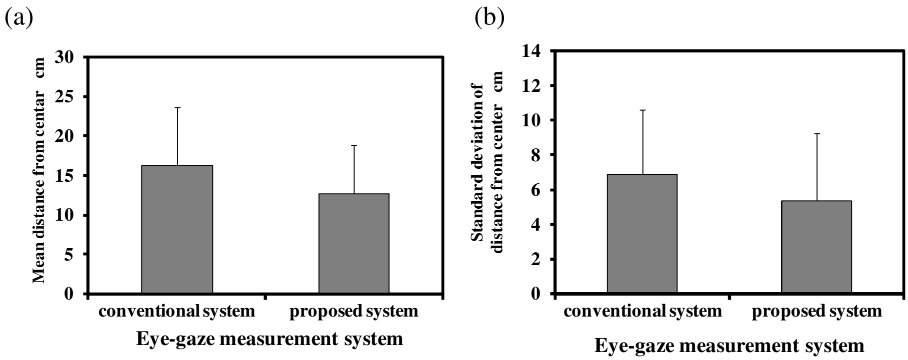

Fig. 9. (a) Mean distance from center as a function of estimation method of fixation point (the conventional and the proposed ones) (target size: 20 pixel) and Standard deviation of distance from center as a function of estimation method of fixation point (the conventional and the proposed ones) (target size: 20 pixel)

system especially when the target size was smaller (20 pixel and 30 pixel) . When the cursor shakes to a larger extent, it is difficult to keep the cursor inside the smaller target (20 or 30 pixel), and consequently the task completion time is prolonged. When the target size is large enough relative to the shaking of the cursor, the shaking of the cursor does not affect the task completion time. Therefore, no significant difference of task completion time must be detected between the traditional and the proposed methods when the target size was 60 pixel or 40 pixel as shown in Fig.5(a). The task completion time of the proposed system for the target size of 20 pixel was reduced by 36% as compared with that of the traditional system (see Fig.7(a)). The proposed system is more effective when the target size is smaller and less than 30 pixel.

5.2 Mean Number of Errors

As shown in Fig.6(a) and Fig.8(a), the error trial tended to be less for the proposed method than for the traditional method in particular when the target size was less than 30 pixel. In case of the target size of 30 pixel, the number of error for the proposed method was reduced by 54% as compared with that of the traditional system. When the target size was 20 pixel, the number of error for the proposed method was reduced by 44% as compared with that of the traditional system. It tended that the error pointing frequently occurs at the target location 7, 8, and 9 in Fig.2(b) when the traditional method was used. The following problems in the traditional method must be due to such a frequent error at the lower part of the display. When viewing the lower part of the display, the pupil image is to a larger extent covered by the eyelash or Purkinje image. Such a problem could be overcome by the proposed method, which led to the stable estimation of fixation points. The error data also supported the effectiveness of the proposed method.

5.3 Cursor Movement Trajectory

The participants must click the target using an eye-gaze input system at the instance when the participants felt that the click could be properly carried out. Therefore, the cursor movement trajectory before and after the click operation was examined to check whether the cursor movement was stable or not.

From Fig.6(a) and (b) and Fig.9(a) and (b), it is clear that the cursor position of the proposed method was nearer to the center of the target and less dispersive than that of the traditional method. This means that the reduced shaking of the cursor by the proposed method led to the nearer click to the center of the target, and less dispersive click location.

5.4 Implication for HCI Design

When the target size was large (more than 40 pixel), no significant differences of the task completion time and the number of errors were detected between the conventional and the proposed methods. Therefore, both methods are applicable to larger target more than 40 pixel. When the target is less than 30 pixel, the proposed method should be used, because the proposed method is superior to the conventional method from the perspectives of task completion time, the entry error, and the stability of clicked coordinates.

The validity of the present study should be verified by increasing the number of participants. Future work should explore whether more stable fixation point can be obtained by adding the smoothing technology of coordinates to the proposed method.

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