Point-and-Click Interface Based on Parameter-Free Eye Tracking Technique Using a Single Camera

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Abstract. We propose a method for the estimation of point of gaze with neither user- nor environment-dependent parameters. The gaze direction is calculated from the centers of both the pupil and the eye rotation. The center of the eye rotation is determined using the centers of both the pupil and the iris and the edge of the iris when at least four calibration targets, for which only the distances between them are known, are fixated on the screen. The mean horizontal and vertical errors for seven subjects were 0.91 deg and 0.77 deg, respectively. Next, a point-and-click interface, in which a user can move a cursor by a gaze shift and click a computer mouse by a voluntary eye blink or short fixation, was developed. On average, it took 1.2, 0.9, and 0.8 sec to point and click for each target with eye blink, short fixation, and normal hand manipulation, respectively.

Keywords: Eye-gaze estimation, Pupil, Iris, Center of eye rotation.

1 Introduction

An eye tracking technique using a single camera could be a key for an eye-gaze input interface of a wearable head-mounted computer. However, previous methods with a single camera require user parameters that depend on the shape of the eyeball and/or environmental parameters such as distances between the eye and the camera or the screen to calculate gaze direction from the pupil and corneal reflections of near-infrared lights in the eye image [1, 2]. The cumbersome calibration procedures that determine these parameters would reduce the convenience of using a wearable computer with an eye-gaze input interface.

In this paper, we propose a method for the estimation of point of gaze with neither user- nor environment-dependent parameters and introduce a point-and-click interface as an example of an implementation of the proposed technique. Just looking at a few calibration targets makes it possible to calculate gaze direction and point of gaze on the screen. Pupil and iris detection are described in Section 2. The parameter-free eye tracking technique and estimation of point of gaze are described in Section 3. The accuracy of the estimated point of gaze is shown in Section 4. The point-and-click interface is described in Section 5. Finally, the conclusion is given in Section 6.

C. Stephanidis (Ed.): Posters, Part I, HCII 2013, CCIS 373, pp. 608–612, 2013.

2 Pupil and Iris Detection

Fig. 1 shows eye images under near-infrared light after the detection of the pupil and iris. First, the pupil area is extracted from the segmented images. Next, the center of the pupil is computed from an ellipse fitted to the edge of the pupil after removal of outliers. An algorithm based on the Taubin method [3, 4] is employed to fit the ellipse. The ellipse parameter $\boldsymbol{u}$ is obtained by solving a generalized eigenvalue problem, shown in equation 3.

$$Ax^2 + Bxy + Cy^2 + Dx + Ey + F = 0 \tag{1}$$

$$\boldsymbol{u} = (A \;\; B \;\; C \;\; D \;\; E \;\; F)^T \tag{2}$$

$$\boldsymbol{Vu} = \lambda \boldsymbol{Wu} \tag{3}$$

where $\boldsymbol{V}$ is a 6×6 matrix obtained from the data of the pupil $(x_i \;\; y_i)$ and $\boldsymbol{W}$ is a 6×6 weighting matrix. The edge of the iris is detected using a differential filter. An ellipse is fitted to the edge to obtain the center of the iris and feature points that are two intersection points of the fitting ellipse and the horizontal axis of the ellipse.

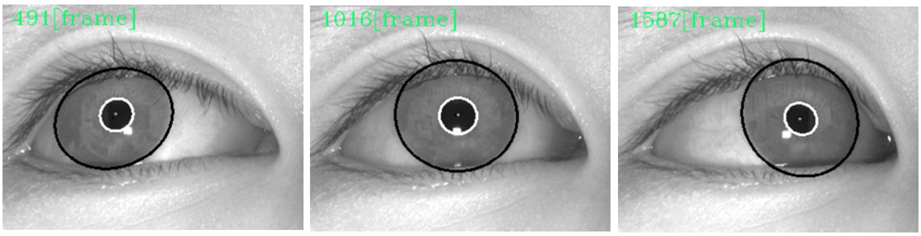

Fig. 1. Ellipses fitted to the pupil and iris

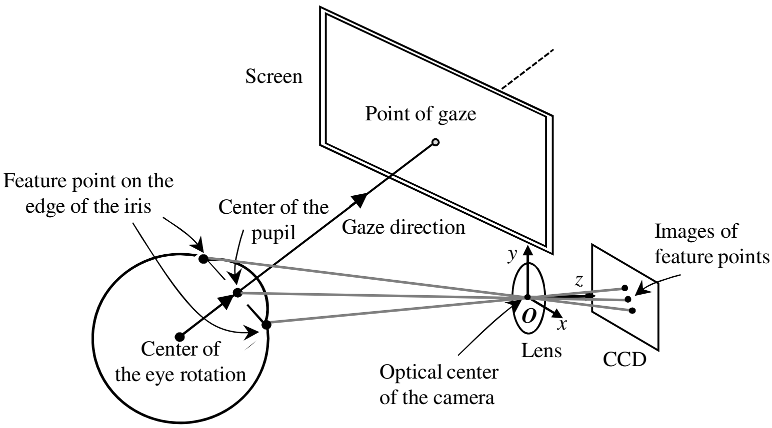

Fig. 2. Schematic view of the eye, a camera, and point of gaze on the screen

3 Parameter-Free Eye Tracking Technique

Fig. 2 shows the camera coordinate system when a user fixates on a point on a screen. The center of the eye rotation and position of the screen are determined based on *N*-point calibration when at least four targets are sequentially fixated. The eyeball is assumed to be a sphere and to rotate around a fixed point relative to the camera.

3.1 Estimation of Visual Angles Using Feature Points of the Iris

When a user fixates on the calibration target, the normalized position of a feature point on the edge of the iris $\boldsymbol{Q_{ij}}$ ($i = 1, \ldots, N,\quad j = 1,2$) divided by the distance between the centers of both the iris and the iris-based eye rotation can be expressed as the following equation with unknown parameters α_{ij} and an image of the feature point $\boldsymbol{q_{ij}}$:

$$\boldsymbol{Q_{ij}} = \alpha_{ij} \cdot \boldsymbol{q_{ij}} \tag{4}$$

Next, the feature point $\boldsymbol{Q_{ij}}$ is located on the surface of a sphere with a radius of one from the center of the eye rotation $\boldsymbol{E_I}$.

$$|\, \boldsymbol{Q_{ij}} - \boldsymbol{E_I} \,|^2 = 1 \tag{5}$$

The distance between the feature points on the iris is expressed as:

$$|\, \boldsymbol{Q_{i1}} - \boldsymbol{Q_{i2}} \,|^2 = D^2 \tag{6}$$

In equations 4, 5, and 6, there are *2N+4* unknown parameters and *3N* equations. If the number of calibration targets $N \geq 4$, then we can estimate the position of feature point $\boldsymbol{Q_{ij}}$ and the center of the eye rotation $\boldsymbol{E_I}$. The iris-based direction vector $\boldsymbol{g_I}$ between the centers of both the iris $\boldsymbol{Q_C}$ and the eye rotation $\boldsymbol{E_I}$ is given by:

$$\boldsymbol{g_I} = \boldsymbol{Q_C} - \boldsymbol{E_I} \tag{7}$$

The visual angles between calibration targets can be obtained from the above vectors.

3.2 Eye-gaze Estimation Using the Center of the Pupil

The position of the center of the pupil normalized by the distance between the centers of the pupil and the pupil-based eye rotation can be expressed by:

$$\boldsymbol{P_i} = \beta_i \cdot \boldsymbol{p_i} \tag{8}$$

The moving distance of the center of the pupil when the point of gaze moves from one to another is given by the following equation using the visual angle θ.

$$\left|\boldsymbol{P_i} - \boldsymbol{P_j}\right|^{\boldsymbol{2}} = \{2\sin\left(\tfrac{\theta_l}{2}\right)\}^2 \tag{9}$$

where $i = 1, \ldots, N-1, j = 2, \ldots, N$ $(i < j)$, $l = 1, \ldots, {}_N\mathrm{C}_2$

The position of $\boldsymbol{P_i}$ is determined by solving the above equations for β_i. The center of the pupil-based eye rotation $\boldsymbol{E_P}$ can be obtained from the following equations.

$$|\boldsymbol{P_i} - \boldsymbol{E_P}|^2 = 1 \tag{10}$$

The center of the pupil in any gaze direction can be obtained from the above equation using $\boldsymbol{E_P}$. The eye-gaze vector is determined by the following equation:

$$\boldsymbol{g_P} = \boldsymbol{P} - \boldsymbol{E_P} \tag{11}$$

The parameters of a screen plane can be estimated using the eye-gaze vector and the distances between the calibration targets by the least squares method. Finally, the point of gaze on the screen is determined as an intersection point of the line through the eye-gaze vector and the screen plane.

4 Accuracy of Estimated Point of Gaze

An experiment was performed to evaluate the accuracy of the proposed method. The subject, with the head fixed by a chin rest and a bit bar, was instructed to fixate on a target on the screen 580 mm away from the right eye. The target sequentially appeared for three seconds on one of 21 grid points shown in Fig. 3. Five calibration targets, located at (0mm, 0mm), (0mm, ±150mm), and (±200mm, 0mm), were used to estimate parameters. Images of the eye were captured in 320×240 size at 30 frames per second by a CCD camera. Fig. 3 shows the accuracy of the estimated point of gaze. The mean horizontal and vertical errors for seven subjects were 0.91 deg and 0.77 deg, respectively.

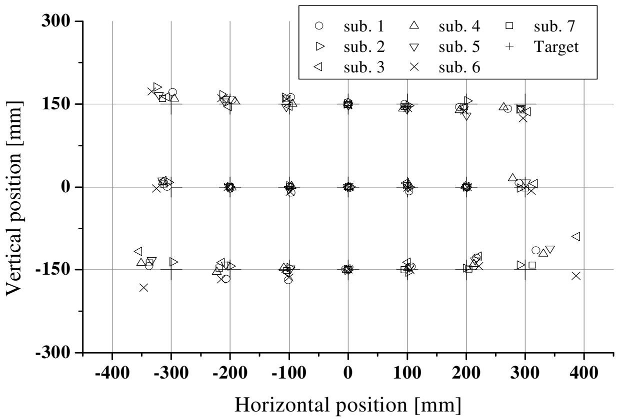

Fig. 3. Accuracy of the estimated point of gaze on the screen 580mm away from the eye

5 Application

A point-and-click interface was developed as an example of an implementation of the proposed method. A user can move a cursor presented on a point of gaze on the screen and click a computer mouse by a voluntary eye blink or short fixation. Duration of eye blink was computed using the derivative of the horizontal to the vertical ratio of the pupil. An eye blink longer than 0.33 sec (10 frames) was detected as a voluntary eye blink for a mouse click. Short fixation was detected using the variance in the position of the center of the pupil in a time window of 0.5 sec (15 frames). A usability test was conducted for a subject familiar with the system in the same environmental condition as in Section 4. The subject was instructed to point and click a 50×50mm-sized target, which was selected from among 15 grid points in the horizontal range of ±200mm, appeared in a pseudo-random order immediately after five-point calibration for approximately 5 sec. Another target appeared after the click within the current target area. Each trial consisted of 45 targets. On average, for five trials, it took 1.2, 0.9, and 0.8 sec to point and click per target with eye blink, short fixation, and normal hand manipulation, respectively.

6 Conclusion

In this paper, we proposed a method for the estimation of point of gaze with neither user- nor environment-dependent parameters using a single camera. A point-and-click interface that implemented the proposed technique made it possible to utilize an eye-gaze input with less calibration effort. This method would be more useful for a mobile computer with a wearable display and an eye camera.

Acknowledgements. This work was supported by JSPS KAKENHI Grant Number 23700670.

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