Just Blink Your Eyes: A Head-Free Gaze Tracking System

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ABSTRACT
We propose a head-free, easy-setup gaze tracking system designed for a gaze-based Human-Computer Interaction. Our system enables the user to interact with the computer soon after catching the user's eye blinks. The user can move his/her head freely since the system keeps tracking the user's eye. In addition, our system only needs a 10 second calibration procedure at the very first time of use. An eye tracking method based on our unique eye blink detection and a sophisticated gaze estimation method using the geometrical eyeball model realize these advantages.

Keywords
gaze tracking, eye movement, eyeball model, eye tracking, eye blink detection.

INTRODUCTION
Eye gaze is one of the powerful and helpful modals in Human-Computer Interaction (HCI). It has been used to select objects on the screen, estimate users' intentions [2], and also supports communication between users [5]. For that purpose the gaze tracking system possibly plays a key role for interaction with computers and for communicating with other people.

To use a gaze tracking system for an everyday HCI like a mouse and a keyboard, the system must meet the following crucial requirements: (1) simplicity for starting up (minimal personal calibration), (2) no attachments to the user's head, and (3) unrestricted head movements. However, currently available gaze tracking systems do not satisfy above requirements, making a gaze-based interaction a stressful task. For example, conventional systems need complicated personal calibration procedures, some systems require users to wear head-mounted gears, and some other systems restrict users' head positions within a quite narrow area.

TOWARD STRESSLESS GAZE TRACKING
To realize a stressless gaze-based HCI, we propose a head-free, easy-setup gaze tracking system. To satisfy requirement (1), the user only needs a simple personal calibration only at the first time of use. To satisfy requirements (2) and (3), we place a stereo camera unit in front of the user to locate and track the use's eye position in case that the user moves his/her head.

Head-Free Gaze Tracking Method
Our gaze tracking system consists of two components; an eye positioning unit and a gaze tracking unit (Fig. 1). The eye positioning unit detects the user's eye position in 3-D coordinates for controlling the gaze tracking unit, and the gaze tracking unit detects and tracks the user's pupil and the corneal reflection image (the Purkinje image) to calculate the gaze direction.

Eye Tracking from Eye Blink
The eye positioning unit detects the user's eye position by an eye tracking algorithm [1]. It detects the user's eye blink from the differences between two successive frames. Once an eye blink has been detected, a template image of two-eye area is created. Then, the present eyes position is searched based on the measured middle position of two eyes and the previously detected eye position. Based on the eye position derived from the stereo image, the 3-D coordinates of the eye is calculated and sent to the gaze tracking unit. Even when the system loses the eye position, an eye blink of a user is used to re-track the current location

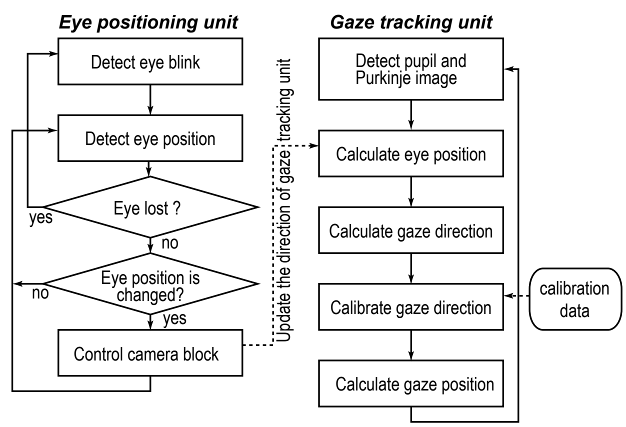

Fig. 1: Eye and gaze detection flow.

of the eye. This blink-based algorithm works robustly against the variation of face colors, because it does not use the skin-color information.

Simple Personal Calibration by the Eyeball Model

The gaze tracking unit uses the pupil and the Purkinje image for calculating the gaze direction. To simplify the personal calibration procedure, an eyeball-model-based gaze detection method is developed [2]. Since this model reduces the non-linear factors of the gaze estimation error, a personal calibration needs only two markers. Residual errors are adjusted by a linear transformation using the two calibration points. This method shows good performance even if the user wears eyeglasses or soft contact lenses.

An ideal solution to condition (1) is to omit all the personal calibration procedure. However, when a gaze direction is calculated from the position of the pupil and the Purkinje image, an estimated gaze direction is different from the real direction because of individual differences of eye shapes, namely the eyeball size, the corneal curvature, and also the refraction of eyeglasses. A calibration-free gaze estimation method, which uses two light sources and two cameras, was proposed [4]. However, human's visual axis is differ from the estimated gaze direction, which is equal to the optical axis of the eyeball, leading to some measurement errors.

Use Case Scenario

To use this gaze tracking system, the user calibrates the system by looking at two markers on the display. This procedure finishes within 10 seconds. Once the calibration has been finished, the calibration parameters are stored. At the next time of use, these parameters enable the system to start up without any calibration. When the user blinks his/her eyes, the system detects the eye position and tracks the head movement to calculate the gaze direction. Therefore, the user can concentrate on the gaze-based HCI itself

Prototype System

To confirm the validity of this system concept, we developed a prototype gaze tracking system that consists of an eye positioning unit (two cameras on top of the display) and a gaze tracking unit (one pan-tilt infrared camera with an infrared LED array) to detect the user's gaze direction (Fig.2). Eye tracking and gaze tracking are performed by two different computers connected by network that have Linux OS and a BT878 frame grabber respectively. The system outputs the gaze direction at the rate of 30 Hz. The recommended distance from the display to the user's eye is between 60cm and 90cm. When the distance is 60cm, the acceptable eye area is set about 10 cm x 10cm. When the distance is 90cm, the eye area is set about 15cm x 15cm. The measurable area can be expanded by changing the stereo camera's focal length and the convergence angle. Camera base of the gaze tracking unit is pan-tilted, and the camera focus is also adjusted by the user's eye position.

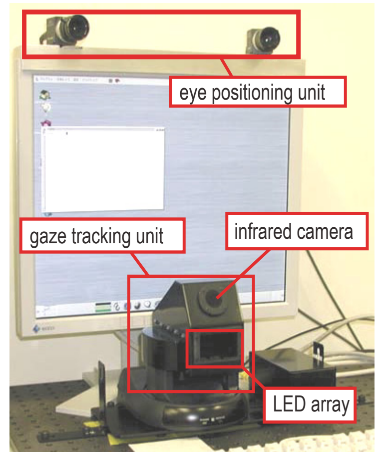

Fig. 2: The overview of the prototype system.

EVALUATION

We conducted an experiment to evaluate the accuracy of the gaze tracking system. One subject with eyeglasses and two subjects with naked eyes participated in the experiment. In the experiment, the system was calibrated by looking at two markers on the screen. Then, for evaluation, 20 markers on the screen were displayed (condition 1). The participants were asked to press the space bar as they look at each of the markers to record the gaze data. Then, they left the desk for a while, and returned to do the same evaluation test again (condition 2).

The result showed that the average accuracy in condition 1 was 0.68 degrees in view angle, and in condition 2, 0.89 degrees in view angle. This data suggests that this system works well without re-calibrations as he/she comes back to the HCI environment.

CONCLUSION

We proposed a head-free gaze tracking system designed for a gaze-based HCI. It enables the user to concentrate on interacting with computers by gaze.

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