Pupil Detection Using Stereo-Matching Method and a Constant Interpupillary Distance Condition for a Solution of Glasses Reflection Problem in the Video-Based Gaze Detection System

Yoshinobu Ebisawa, Kiyotaka Fukumoto, and Hiroki Yamaguchi

Graduate School of Engineering, Shizuoka University, Hamamatsu, 432-8561 Japan
ebisawa@sys.eng.shizuoka.ac.jp

Abstract. In the pupil-corneal reflection detection-based eye-gaze detection method, glasses reflection of near-infrared LED light sources for producing the corneal reflection is misdetected as the pupil when a user wears eyeglasses. To improve the robustness of the pupil detection, we propose novel pupil searching and tracking methods in the gaze detection system using two stereo-calibrated cameras. The pupil searching method first chooses the true pupils from all stereo-matched pupil candidates using the suitable depth range condition, and second chooses the true pair of the right and left pupils under the constraint of the suitable 3-D interpupillary distance. Even if one pupil is not detected in the image of either camera owing to the glasses reflections, the pupil tracking method estimates the 3-D coordinates of the undetected pupil by using the constant interpupillary distance and the temporal continuity of the 3-D coordinates of the moving pupil. The experimental results show that the accuracy of pupil searching and tracking was better than that of the conventional one-camera method.

Keywords: Pupil detection, Gaze detection, Head movement, Glasses reflection.

1 Introduction

Most of the remote video-based gaze detection systems basically determine the gaze position from the relative position between the center of the pupil image and the corneal reflection image of near-infrared light source(s), which usually produce a bright pupil or a dark pupil. However, the light source causes reflection images from eyeglasses. In the gaze detection system which we have been developed, the pupils are detected from the difference image made of the bright and dark pupil images. Even if using this image difference method, the glasses reflection image remains due to the positional difference of the two light sources for generating bright and dark pupil images. Sometimes the wreck of the glasses reflection image is misdetected as the pupil because of the similarity of their images. This is a problem for general purposes of the gaze detection system. Fortunately, our gaze detection system detects the 3-D pupil position. In the present paper, we propose the pupil detection method

C. Stephanidis (Ed.): Posters, Part I, HCII 2013, CCIS 373, pp. 594–598, 2013.

using an interpupillary distance as a constraint condition in order to distinguish the pupils from the glasses reflections. The effectiveness of the proposed method is shown experimentally.

2 Our Gaze Detection System

We have been developed a pupil-corneal reflection method-based gaze detection system, which allows head movements and achieves easy gaze calibration [1]. The system includes two stereo-calibrated cameras and two light sources attached to each of the cameras, etc. as shown in Fig. 1. They were arranged under a PC display. The light source has near-infrared LEDs arranged in two concentric rings (inner: 850 nm, outer: 940 nm). The inner ring generates a bright pupil image and the outer ring generates a dark pupil image. The pupils are detected from their difference image. The image difference method is very useful for robust pupil detection because the image except the pupils is cancelled out. However, when a user wears eyeglasses, the glasses reflection images remain and sometimes are misdetected as the pupil.

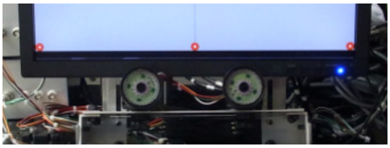

Fig. 1. Overview of two stereo-calibrated optical systems in our gaze detection system

3 Proposed Pupil Detection Method

The proposed method first detects several 2-D pupil candidates (up to 5) from the difference image for each of the two cameras. Next, the positions of 3-D pupil candidates (up to 25) are obtained by stereo-matching all 2-D candidates obtained from both cameras. If stereo-matching is wrong, the depth of the 3-D candidates is out of user's working space. So such a 3-D candidate is excluded. Furthermore, the distances between all pairs of the remaining 3-D candidates are calculated. When the distance is within the predetermined range suitable for an interpupillary distance, the corresponding pupil candidate pair is determined as the final pupil pair.

The above-mentioned processing (searching mode) is used to search the 3-D pupil pair. Once the 3-D pupil pair is found, tracking of the pupil pair (tracking mode) begins. By assuming that the midpoint of the paired pupils and the directional vector passing through them vary at a constant velocity, the 3-D positions of the pupils in the next frame are estimated. The 3-D positions are transformed into the 2-D positions in each camera. The small windows are applied to the 2-D positions. The window serves to prevent to detect the glasses reflection instead of the pupil. When the user's head moves, the effectiveness of the image difference method decreases due to the positional discrepancy between the bright and dark pupil images. During the tracking mode, the positional compensation by the corneal reflection for differentiation is performed [2].

In general, as shown in Fig. 2, there is a case when one camera cannot detect one of the two pupils (e.g., P_R) owing to overlying of the glass reflection while another camera detects the two pupils. In such a case, the 3-D position of the one pupil (P_R) is not obtained. The proposed method estimates the 3-D position of the pupil using the interpupillary distance as follows. Assume a spherical surface where the center is the pupil detected by both cameras (P_L) and the radius is the interpupillary distance. The 3-D position of the undetermined pupil (P_R) is estimated as an intersection between the spherical surface and the line determined by the direction vector (u_{L1}) and the position of the camera (O_L) that has detected the pupil (P_R). Here, when two intersections are obtained, the intersection close to the 3-D pupil position in the previous frame is chosen. Finally, the 3-D position is transformed into the 2-D position in the image of the camera (O_R) that has not been able to detect the pupil (P_R). As a result, the small window is applied around the pupil in the image of the camera. Previously, in our study, the small window was released when the pupil was not detected owing to glasses reflection overlying. The release sometimes leads to tracking the glasses reflection instead of the pupil. The proposed method (tracking mode) would make it possible to continue tracking the pupil without releasing the window even when the glasses reflection image moves across the pupil image.

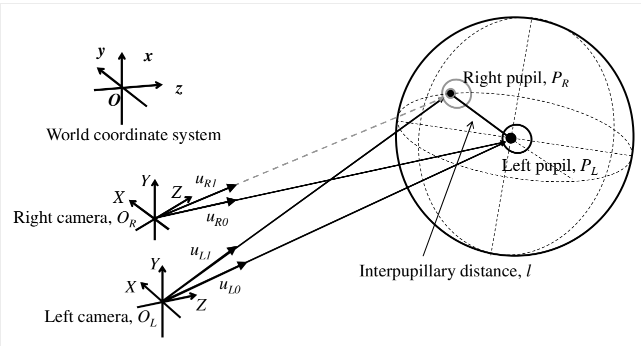

Fig. 2. Pupil tracking method using interpupillary distance as constraint condition

4 Experimental Methods and Results

Five university students wearing eyeglasses participated in two experiments: searching and tracking experiments. The position of the user's head was approximately 80 cm from the PC screen. In the searching experiment, the subject was asked to blink a few times and not to move the head during 10 sec. In the tracking experiment, the subject was asked to rotate the head from side to side during 10 sec so that the glasses reflections crosses the pupils. The same program was used for both experiments. The depth of the working space of the subject was set between 70 cm and 90 cm. The interpupillary distance was predetermined set between 63 mm and 70 mm.

Fig. 3(a) shows the sample images indicating the pupil detection results when eyes were closed in the conventional and proposed methods. Here, the conventional method is a method relying on the image processing by one camera. The conventional

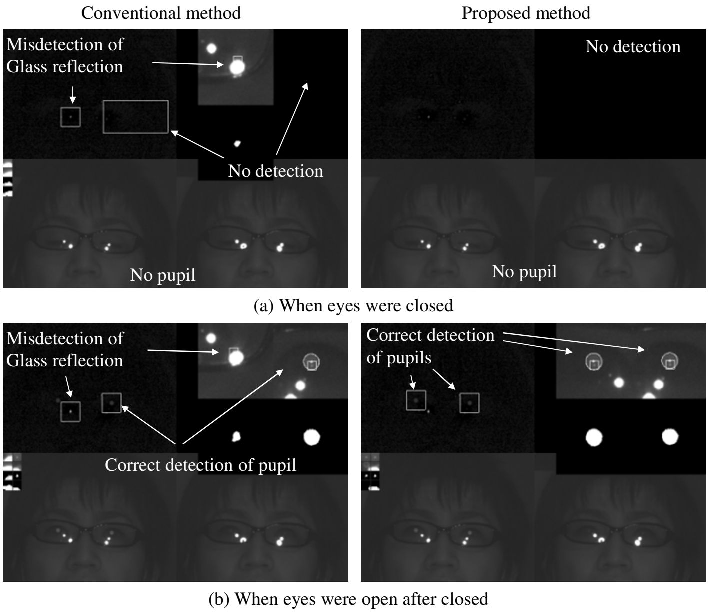

Fig. 3. Resultant samples of pupil detection when the subject blinks. In each panel, lower right and left segments indicate bright and dark pupil images. Several glasses reflection spots are seen diagonally downwards from the pupils. Squares in the difference image (upper left segment) show the small windows. Upper right segment shows the magnified images around the detected objects and shows that it detects glasses reflection or pupil, or nothing.

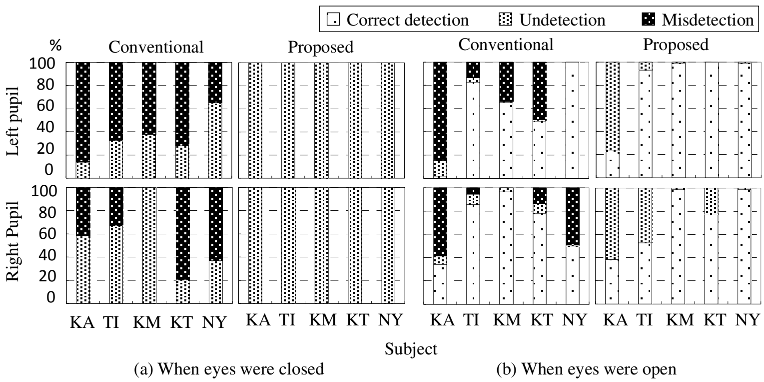

Fig. 4. Pupil detection ratios for five subjects when eyes were (a) closed and (b) open

method misdetected the glasses reflection as the pupil. However, the proposed method did not misdetect: no pupil was surely detected. Fig. 3(b) shows the results when eyes were open after closed. The conventional method continued the right pupil misdetection by the window tracking process. However, the proposed method surely

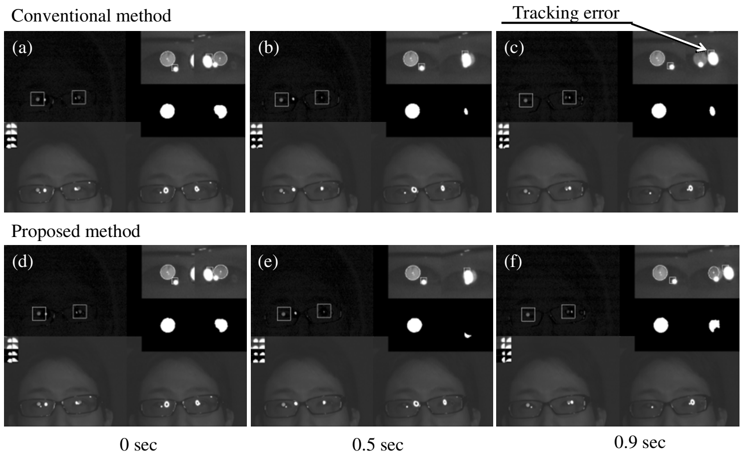

Fig. 5. Pupil detection when subject rotated his head to the right and left

detected the pupils by the proposed tracking method. Fig. 4(a) and (b) compare the detection ratios for the five subjects. When the eyes were closed, high ratio misdetection occurred in the conventional method but no misdetection occurred in the proposed method. When the eyes were open, there was no misdetection.

Fig. 4(a) and (b) show the samples of pupil detection when the subject rotates his head to the right and left in the conventional and proposed methods. The glasses reflection overlay the left pupil at 0.5 sec. After this time, glasses reflection tracking started in the conventional method but pupil tracking was kept in the proposed method.

5 Conclusion

The present paper proposed the novel pupil detection method to avoid misdetecting the glasses reflection in our remote, head-free, pupil-corneal reflection detection-based gaze detection system. The experimental results showed that the proposed method is effective for both pupil searching and tracking. The method would be also useful in other gaze detection systems that use stereo-calibrated cameras.

References

1. Ebisawa, Y., Fukumoto, K.: Head-Free, Remote Gaze Detection System Based on Pupil-Corneal Reflection Method with Using Two Video Cameras – One-Point and Nonlinear Calibrations –. In: Proceeding of 15th International Conference, HCI International (to appear, 2013)
2. Ebisawa, Y., Nakashima, A.: Increasing Precision of Pupil Position Detection Using the Corneal Reflection. The Institute of Image Information and Television Engineers 62(7), 1122–1126 (2008)