Optics & Laser Technology 66 (2015) 112–121

Contents lists available at ScienceDirect

Optics & Laser Technology

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

Automatic threshold-setting method for iris detection for brown eyes in an eye–gaze interface system with a visible light camera

Kohichi Ogata*, Shingo Niino

Graduate School of Science and Technology, Kumamoto University, 2–39–1 Kurokami, Chuo-ku, Kumamoto 860–8555, Japan

ARTICLE INFO

Article history:
Received 4 December 2013
Received in revised form
25 August 2014
Accepted 1 September 2014
Available online 18 September 2014

Keywords:
Eye gaze
Iris detection
Threshold

ABSTRACT

This study describes the improvement of an eye–gaze interface system with a visible light camera. The current system detects the center of the iris from a captured eye image using image processing. During the initial stages of system use, a display window is provided to set the threshold values of the image's saturation and intensity, which is used to manually adjust the appearance of the iris region. In this study, we propose an automatic threshold setting method. The optimum threshold value for the saturation is obtained by discriminant analysis and that for the intensity is determined by finding the value that yields the same number of accumulated pixels in the detected region as threshold processing of the saturation. In our experiments with subjects with brown eyes, the automatic method obtained good threshold values in most cases. Furthermore, an adjustment function to overcome under- or over-estimated saturation threshold values is also proposed. This function provides a more robust automatic threshold setting. In experiments, we compared our automatic setting method with conventional manual techniques, which showed that the automatic method is useful for reducing the time required for threshold setting and its pointing accuracy is comparable to that of the manual approach.

1. Introduction

Eye–gaze techniques have a wide range of potential applications because of their non-contact feature and intuitive operation. Thus, any efforts have been made to study eye–gaze detection and to develop suitable application interfaces [1–11]. They can be useful support tools for people with disabilities as well as for healthy people. Some are commercially available [10,11], but they are not popular tools in daily life because of their high costs and limited availability.

We have developed an eye–gaze detection system using an image processing technique. In this system, the eye–gaze direction is estimated by detecting the center of the iris using an eye image obtained with a miniature visible light camera [12,13]. Previously, we focused on improving the image processing speed for real-time detection and the reduction of detection errors caused by merging of the iris region with the inner or outer corner of the eye [14]. The system is capable of real-time processing at 30 fps based on 320 $\times$ 240 pixels, with an accuracy of 0.6° and 1.3° in the horizontal and vertical directions, respectively [15].

Our system obtains the iris region by setting threshold values for the saturation and intensity in the HSI color space of the processed eye image. These optimum threshold values were determined manually when the system was first used. The usability of our system would be improved if the setting procedure could be performed automatically.

Discriminant analysis is a well-known method for feature extraction [16,17], which can be a useful method for determining thresholds. Indeed, it was used to determine the threshold for detecting the pupil area in a gaze-tracking method with infrared light-emitting diodes [18]. Many existing eye trackers are based on active light schemes [9], where infrared lights are used for eye detection. In contrast to these systems that employ infrared lights, our system uses a visible light camera and it detects the iris region. Therefore, it is necessary to determine the effective threshold for our system by considering the features of captured images, which would contribute to the detection method using a visible light camera.

In this study, we propose an automatic threshold-setting method based on the analysis of eye images in terms of the saturation and intensity in the HSI color space. Section 2 introduces the configuration of the system and the method for detecting the center of the iris. In Section 3, the captured eye images are analyzed in terms of saturation and intensity, and an automatic threshold-setting method is proposed and evaluated. An additional adjustment function for setting the saturation threshold is developed in Section 4, which

* Corresponding author.
E-mail address: ogata@cs.kumamoto-u.ac.jp (K. Ogata).

http://dx.doi.org/10.1016/j.optlastec.2014.09.001
0030-3992/

ensures the robustness of the method described in Section 3. In Section 5, experimental evaluations of the effectiveness of the proposed methods are described. Finally, we present the conclusions of this study in Section 6.

2. Eye–gaze system [12]

This section describes the system configuration and an overview of the iris center detection method using a color eye image.

2.1. System configuration

Fig. 1 shows the system configuration, which comprises a small, color video camera (Kyohritsu JPP-CM25F 1/3 inch CMOS 0.25 Mpixel) and a desktop computer (CPU: Pentium 4 3.2 GHz, memory: 1 GB, OS: Windows XP) with an image-capture board (Imagination PXC200). The program used for image processing was developed in the C++ language (Microsoft Visual C++). The system is capable of processing 320 × 240 pixels at a frame rate of 30 fps. The camera is attached to the user's goggles, and a computer display and 20 W fluorescent table lamp are located in front of the user. A chin support is used to facilitate a resting position.

2.2. Detection of the center of the iris

Unlike eye–gaze systems that use infrared light sources, our system detects the outer edge of the iris from an eye image obtained with a visible light camera. An overview of the image processing method is as follows.

Fig. 2(a) shows an example of eye images obtained with the camera. The color eye image is converted into the HSI color space and the iris region is obtained by setting threshold values for the saturation and the intensity. In Fig. 2(b), the pixels that belong to the detected regions are shown in red. Some eyelashes are also detected in the figure, but these regions can be eliminated by thresholding the histogram, as demonstrated in Fig. 2(c). The center of the iris is obtained by circular pattern matching with the outer edge of the detected iris region, as shown in Fig. 2(d). In the pattern matching process, the centroid of the region obtained in Fig. 2(c) is used as the initial value to find the center of the iris.

Fig. 3 shows an example of the saturation and intensity graph mentioned above, which indicates the distributions of the pixels belonging to the iris region and other regions, such as the sclera and the skin. The pixels indicated by black crosses (X) correspond to the iris region, which can be detected by setting thresholds for the saturation and intensity values.

In our previous system, the saturation and intensity thresholds were adjusted manually via a window shown on the display screen. Before using the system, the user or a support operator would adjust the thresholds by confirming the detected region shown in the window while the user gazed at the center of the front display. These threshold values were used for the subsequent real-time detection of the iris. The adjustment process required considerable skill to set adequate threshold values. Therefore, to simplify the operation of our system, it is necessary to develop an automatic function for setting appropriate iris detection threshold values. In the present study, captured eye images were analyzed in terms of their saturation and intensity characteristics. Based on the results, we developed an automatic threshold-setting method and we evaluated its effectiveness, as described in the next section.

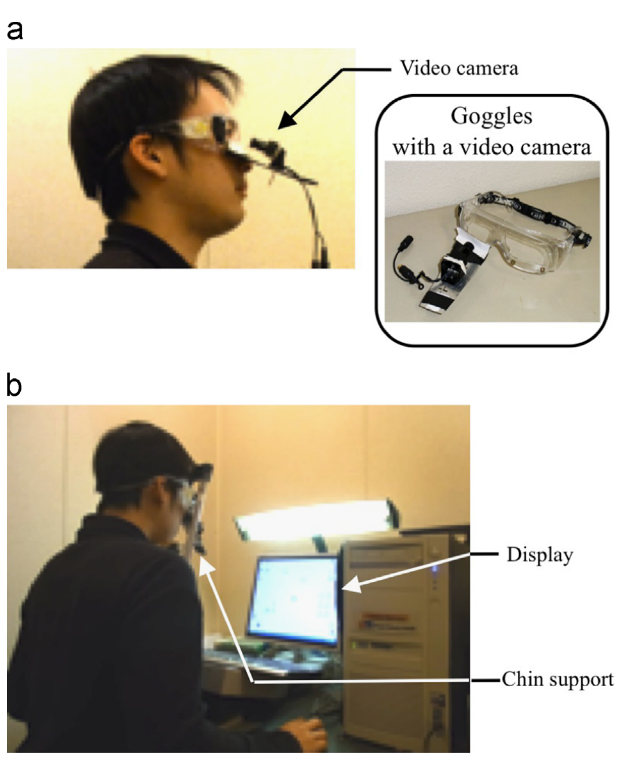

Fig. 1. System configuration. (a) User with a video camera. (b) Overall view of the system.

3. Analysis of eye images and automatic threshold setting

In this section, we present the method used to analyze the captured eye images in terms of their saturation and intensity characteristics. Fig. 4 shows an example of the captured eye images. Similar to filtering in the HSI color space (see Fig. 2(b)), the outer and inner corners of the eye, the eyelashes, and the iris region are detected. In Fig. 4(a), which includes a shadow from the upper eyelid, part of the sclera is also detected because of its similar saturation and intensity characteristics. Therefore, it is important to analyze the region detected by filtering to obtain a practical solution. Fig. 4(b) shows a mask image in green that is used to set the “detected region”, which is assumed to be obtained by filtering. The pixels that comprise the candidate “detected region” are obtained by filtering in the HSI color space based on the manually adjusted saturation and intensity thresholds using the window described above. In the following section, the characteristics of the “detected region” and the other regions are investigated in terms of their saturation and intensity.

3.1. Image format conversion

As mentioned earlier, we use the HSI color space. The image conversion from the RGB to HSI format is given by Eqs. (1)–(5) [19], where Eq. (2) finds the minimum value among r, g, and b.

In our system, we employ the modified equation for saturation given by Eq. (9), which is based on the experimental finding that shifting the blue value of pixels using Eq. (6) obtains good results [13]. Fig. 5 shows a comparison of the saturation histograms obtained using Eqs. (5) and (9). In each figure, the distribution in black corresponds to the “detected region” shown in Fig. 4(b). The distribution in gray corresponds to the other pixels, including the skin and sclera regions. Using the mask image in Fig. 4(b), we can plot each distribution in black or gray. As shown in Fig. 5(a), the distribution of the detected region overlaps with that of the other regions. By contrast, Fig. 5(b) shows the separation of these regions, where the detected region has a higher saturation value than the other regions. Thus, using Eq. (9) instead of Eq. (5) is an effective