

A Fatigue Detection System with Eyeglasses Removal

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Abstract—A fatigue detection system is designed to alert the driver and thus prevent the possible accidents. The detection is mainly based on the result of the face/eye detection or the pupil of the eyeball to determine whether the driver in the fatigue condition or not. Most of the previous studies assume that the driver does not wear the eyeglasses. However, the eye detection is easily influenced by the eyeglasses and thus decreases the correct detection ratio. In order to overcome the influence of the eyeglasses, a fatigue detection method with eyeglass removal is proposed in this paper. Firstly, the face area is detected by using the functions in the OpenCV library. Then, the eyeglasses are removed by using the morphological operations. After eyeglasses removal, the eye areas are detected by using the functions in the OpenCV library and tracking by using a template matching method. The binarization result of the eye area is performed the horizontal projection and Kalman filter. Then, the open/close state of eyes is determined, and then fatigue is determined based on the series state of eyes. Four testing videos are used to evaluate the performance of the proposed method. The average correct detection ratio of the eye state is 88.5% and the fatigue detection can reach 100%. The preliminary results show that the proposed method is feasible.

Keywords—Face detection, Eye detection, Eye tracking, Kalman filter, Template matching

I. INTRODUCTION

When a user drives a car for a long time, the user is easily tired and a traffic accident may occur under such condition. Therefore, the fatigue detection system is useful to prevent the car accident by sounding the alarm to the driver. The fatigue must be detected in real-time. Currently, the eyes are the main target of the fatigue detection. If the eyes close for a period of time, it means that the fatigue of the driver occurs.

Therefore, the first step of the fatigue detection is face detection. A popular method proposed by Viola and Jones is used here [1]. The eyes area is then detected based on the face area. However, the eyes detection is easily influenced by the eyeglasses. Several methods for removing eyeglasses were proposed in the previous studies [2-4]. Some of them are difficult to implement on the embedded system due to the processing burden. The method proposed by Liu, Sun *et al.* was based on the HSL (Hue, Saturation, Lightness) color space [5]. It is quite efficient and is utilized in the proposed method.

In this paper, a method is proposed to detect the fatigue of the driver. The method can remove the eyeglasses in the real-time image to improve the accuracy of the fatigue alarm and reduce the number of false alarms.

The rest of the paper is organized as follows. Section II presents the related work. Section III presents the fatigue detection method. Section IV presents the experimental study and Section V is the conclusion of this paper.

II. RELATED WORK

In-vehicle camera is popularly installed to realize the possible reasons of car accidents. Such a camera can also be used to detect the fatigue of the driver. Several studies related to the fatigue detection are described as follows.

Authors Horng *et al.* [6] and Sharma *et al.* [7] utilized the number of pixels in the eye image to determine the eye state, open or close. Horng *et al.* [6] established an edge map to locate the eyes locations and the eye state is determined based on the HSL color space of the eye image. Its accuracy is depended on the location of the eyes. Sharma and Banga [7] converted the face image to YCbCr color space. The average and standard deviation of the pixel number in the binarization image is computed. Then, fuzzy rules [8] are used to determine the eye state. Liu *et al.* [9] and Tabrizi *et al.* [10] proposed methods to detect the upper and lower eyelids based on the edge map. The distance between the upper and lower eyelids is then used to analyse the eye state. Besides, Dong *et al.* [11] and Li *et al.* [12] proposed methods by utilizing AAM (Active Appearance Model) to locate the eyes. Then, a PERCLO (PERcentage of eye CLOsure) was computed to detect the fatigue. For the above methods, the locating of eye areas was easily influenced by the change of brightness. Circular Hough transform is popular method to overcome the influence of brightness. Several studies [13-15] proposed methods to locate the pupil of eyes by using circular Hough transform. Then, the eye state was analysed according to the locations of pupils.

The above related studies didn't address the issue of eyeglasses. Eyeglasses may reduce the correct ratio of the fatigue detection. A driver wearing eyeglasses is often seen. Therefore, a fatigue detection method should considerate such a condition.

III. METHOD

The process of the proposed method is depicted in Figure 1. When the face area is detected successfully in the real-time image frame, the eyeglasses removal step is applied to the face area based on the method proposed in [16]. If the template of the eye area is not established yet, an eye detection step is performed to get the initial area of eyes. Otherwise, the eye tracking step is performed to keep tracking the eyes. When the eyes area is detected, the RGB color space of the area is converted to HSL color space. The S-channel is then projected horizontally. The projected results are then filtered by Kalman filter to analyse the eye state. Then, the fatigue is detected according to the successive eye states.

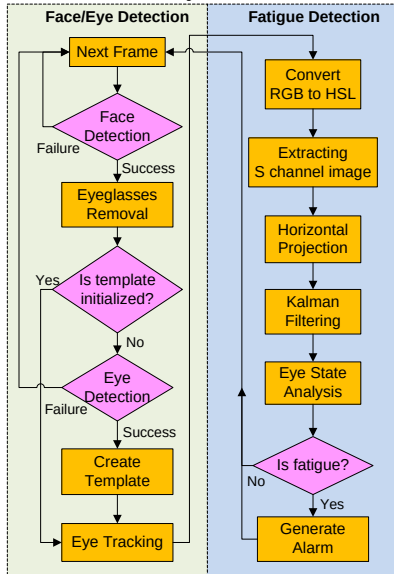


Figure 1. The fatigue detection process

A. Face and Eye Detection

In this subsection, the methods of face detection, eyeglasses removal, and eye detection are presented in turns.

1) Face Detection

Face detection is the first step of fatigue detection. A conventional function of OpenCV library is utilized in this step [1]. The resolution of a real-time camera frame is reduced to 320×240 pixels. The face area of the current frame is the detection result with a shortest distance to the area in the previous frame.

2) Eyeglasses Removal

The ratio of eyes to the face area is based on the analysis result of face database presented in the previous study [17]. Therefore, assume the face area is denoted as FR and the left, top, width, height of FR are denoted as FR_{left} , FR_{right} , FR_{top} and FR_{bottom} . The region of interest (ROI) of eyes, denoted RI , is determined by using Eq. (1).

$$\begin{aligned} RI_{left} &= FR_{left} + FR_{width} / 8 \\ RI_{top} &= FR_{top} + FR_{height} / 4 \\ RI_{right} &= FR_{left} + FR_{width} - FR_{width} / 8 \\ RI_{bottom} &= FR_{top} + FR_{height} / 2 \end{aligned} \quad \dots\dots\dots(1)$$

The area of RI is then split into two equal areas for left and right eyes, denoted as RI_L and RI_R . Although the RI cannot match the ratios of every people, it is suitable to include the eye image in the area. Two examples are shown in Figure 2.

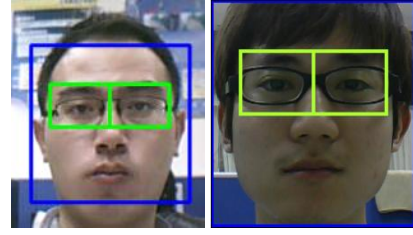


Figure 2. Two examples of the ratio of eyes to face area

When the eye area, RI , is determined, the next step is the creation of the eyeglasses mask. The method proposed in [16] is modified here. The sub-steps are listed as follows:

- S1: The RI image is converted to greyscale and binarized using a threshold 40.
- S2: A dilatation operation is applied to the above result. Two blobs (binary large object) which are closest to the center of RI_L and RI_R separately are selected.
- S3: The binarization image is inverted.
- S4: Two blobs selected in S2 is applied the boundary fill function to remove the eye balls. The left white area is the mask of the eyeglasses.

An example of the above sub-steps is shown in Figure 3. The mask is then filled by a skin color. Although the mask is still visible, it will not influence the following steps.

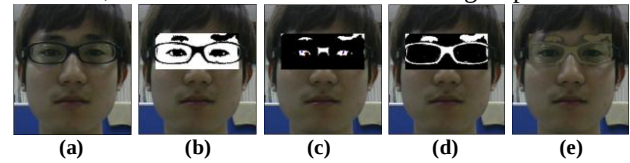


Figure 3. The process of extracting eyeglasses mask (a) original image (b) binarization result of eye area RI (c) dilation (d) boundary fill to remove the eyeballs (e) mask filled by a skin color

3) Eye Detection and Tracking

Eyes are very important to the fatigue detection. The area should be as accurate as possible. The sub-steps of eye detection are listed below.

- S1: The cascade classifier of OpenCV library is used to generate the eye areas in the eye area RI .
- S2: The areas of two eyes are recorded as the initial templates for eye tracking.
- S3: Two eyes are tracking separately using the above templates. If the face area cannot be detected in the previous face detection step, the template is discarded and back to S1.

An example of the eye detection result is shown in Figure 4. In this step, the template size of eyes is fixed to 32×18 pixels. The template tracking function is also utilized the OpenCV library. The matching area is 1.4 times of the eye template.

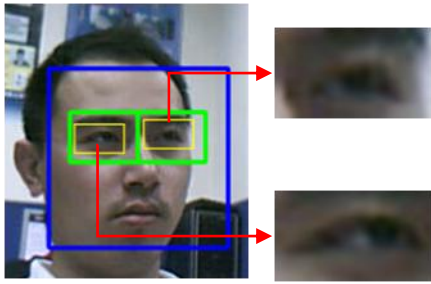


Figure 4. Eye area and the corresponding image

B. Fatigue Detection

The fatigue detection consists of two sub-steps. The first one is the extraction of the S-channel image from HSL color space of eye image. The second sub-step is the analysis of eye state, i.e. open or close, for fatigue detection.

1) Extraction of S-channel image

The areas of two eyes are converted from RGB to HSL color space. Then, the S-channel is applied the histogram equalization operation to increase the contrast of eyeball. Then, the S-channel image is binarized by using a pre-defined threshold 30.

2) Eye State Analysis

Eye state (open or close) is the main information of fatigue detection. By observing the binarization result of S-channel image, the blob of the eyeball is close to a round shape. When the eye is close, the blob is close a flat shape. Therefore, a horizontal projection is applied to the binarization image. The maximum number of consecutive white pixels for every horizontal line is computed. Two examples of the horizontal projection are shown in Figure 5.

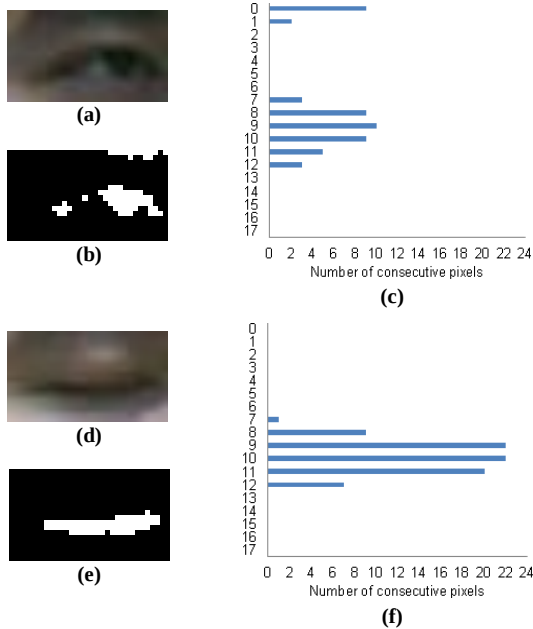


Figure 5. The process of horizontal projection (a) eye open image (b) binarization of S-channel image (c) horizontal projection (d) eye close image (e) binarization of S-channel image (f) horizontal projection

We found the value of horizontal projection in successive frames is unstable. It causes the result of fatigue detection is unstable, too. A Kalman filter is used to stabilize the value [18]. After the estimation of Kalman filter, the eye state is judged as “close” when the value, i.e. maximum number of consecutive white pixels, is larger than 0.45 times of the eye area, RI_L or RI_R . Otherwise, the eye state is judged as “open”. Sometimes, the rotation of the head cause only one eye can be judged successfully. Therefore, if one eye is judged as “close”, the output state is “close”. In advance, a fatigue is detected when the eye is judged as “close” for two seconds, i.e. 30 frames at 15 fps (frames-per-seconds). A fatigue alarm be enabled according to the above result.

IV. EXPERIMENTAL STUDY

A fatigue detection system based on the above method was implemented by using Visual C++. An experiment was also designed to evaluate the performance of the implemented system. Four test videos about 5~10 minutes are recorded. Two of them are the subjects wear eyeglasses and two of them are the subjects don't wear eyeglasses. The maximum consecutive pixels of eyes are depicted in Figure 6. Figures 6(a) and (b) are the result without eyeglasses.

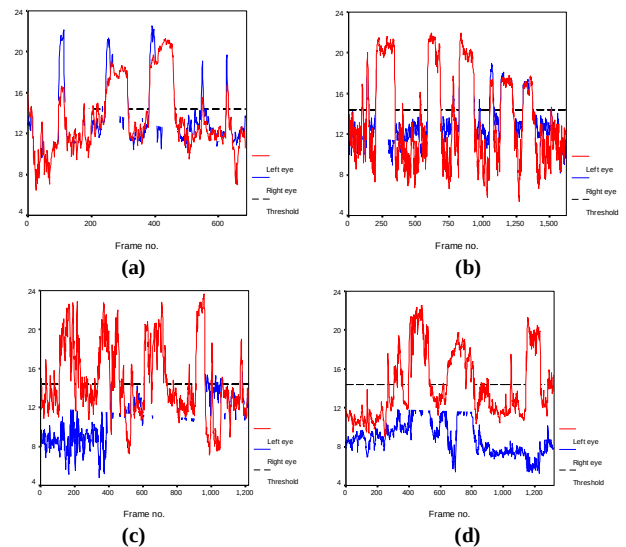


Figure 6. The fatigue detection results of four test videos (a)/(b) without eyeglasses; (c)/(d) with eyeglasses

The proposed method is compared with the method presented by Flores *et al.* [19]. The results are listed in TABLE 1. For every test videos, the total frames are marked in the parentheses. The number of frames with eye open and close area also marked below. For example, the total frames of V1 are 686 where 493 frames are eye open and 193 frames are eye close. The correct ratio is computed for every test videos. The overall ratio is also listed at the bottom of the table.

TABLE 1. THE COMPARISON OF EYE STATE DETECTION

Videos (total) open + close	Our method			Flores <i>et al.</i> [19]		
	Open	Close	Ratio(%)	Open	Close	Ratio(%)
V1 (686) 493+193	471	180	94.9	488	171	96.1
V2 (1621) 1041+580	974	552	94.1	1027	544	96.9
V3 (1217) 545+672	450	599	86.2	433	574	82.7
V4 (1319) 361+958	350	710	80.4	316	696	76.7
Overall	4286/4843=88.5			4249/4843=87.7		

The following conclusions can be drawn from TABLE 1.

- For the method presented in [19], the correct ratio of eye open is higher than that of eye close.
- For the test videos with eyeglasses (V3 and V4), our method has higher correct ratio than the method presented in [19].
- When a subject in the test video rotates his head about 45 degrees. The eyeglasses will be failed to remove by our method. It causes the misjudgement of eye state.

Next, the fatigue detection is also evaluated. The results are listed in TABLE 2. The abbreviations used in the table are described below:

- EB: the number of eye blinking
- RD: the number of real dozing
- AG: the number of alarm generated by the system
- NF (Negative False): the number of false alarm.
- PF (Positive False): the number of real dozing without alarm
- CA (Correct Alarm): the number of real dozing with alarm generated
- CR (Correct Ratio): the correct percentage of fatigue alarm
- PR (Precision Rate): the precision percentage of the generated alarm

The computation of CR and PR is based on the Eq. (2).

$$CR = CA / RD$$

$$PR = RD / AG \quad \text{.....(2)}$$

The above data is collected manually. Only the human can make sure the subject in the test video is real dozing or not.

TABLE 2. THE COMPARISON OF FATIGUE DETECTION

Methods	Test Videos							
	V1		V2		V3		V4	
	Our	[19]	Our	[19]	Our	[19]	Our	[19]
EB	8		11		9		5	
RD	2		6		4		3	
AG	2	2	6	6	4	6	3	4
NF	0	0	0	0	0	2	0	1
PF	0	0	0	0	0	0	0	0
CA	2	2	6	6	4	4	3	3
CR(%)	100	100	100	100	100	100	100	100
PR(%)	100	100	100	100	100	66.7	100	75

According to the results listed in TABLE 2, our method and the method presented in [19] can generate alarm with 100 percent. However, the method presented in [19] generates

false alarms when the subjects wear eyeglasses. It causes the precision ratio is decreased to 66.7 and 75 percent.

In advance, the execution time is also measured. The system is executed on a PC with Intel Core2 Quad CPU Q8400 @ 2.66GHz and 3GB RAM. The average execution time of every steps of the proposed method is measured. The result is listed in TABLE 3.

TABLE 3. THE AVERAGE EXECUTION TIME

Steps	Elapsed time (ms)
Face detection	15.885
Eyeglasses removal	1.393
Eye detection and tracking	1.722
Fatigue detection	0.439
Overall of the method	19.439
A frame processed by the system	61.995

According to the results listed in TABLE 3, face detection is the most time-consuming step since the whole frame must be processed. The rest of the steps are limited in the ROI, the execution time is shorten substantially. So, the overall execution time of the proposed method is about 19 milliseconds. Besides, the system consumes about 62 milliseconds for processing a frame, including the display of the GUI (Graphical User Interface). It means that the system can handle 15~16 frames per second.

V. CONCLUSION

In this paper, a fatigue detection method with eyeglasses removal is proposed. The removal of eyeglasses increases the precision of eye detection and thus reduces the false alarms. According to the results of experimental study, the correct ratio of the eye state detection can reach 94 and 86 percent when the subjects don't and do wear eyeglasses, respectively. The overall correct ratio can reach 90 percent.

Although the proposed method seems promising, some issues are discussed below:

1. Several threshold values are used in the method. The current settings are based on the result of empirical study. However, these fixed values are hard to keep the same system performance in the practical environment. Some automatic or adaptive mechanism should be designed to improve the feasibility of the method.
2. Eyeglasses removal may be fail when the rotation of the driver's head is over 30 degrees. Therefore, the install of the camera is suggested in front of the driver to prevent such a problem.
3. When the driver is back to the light, it causes the face and eyes area is dark. The detection of eyes area may be failed and causes the generation of false alarms.

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