Efficient Measurement of Eye Blinking under Various Illumination Conditions for Drowsiness Detection Systems

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Abstract

In this paper, we propose an efficient way of measuring the level of eye blinking under various illumination conditions (such as day and night) for drowsiness detection systems which use a single camera. Determining the level of drowsiness by using eye blinking, it is an important way of detection eye positions and measuring eyelid movements. For robust eye detection under various illumination conditions, we propose a simple illumination compensation algorithm and a novel way of measuring of eyelid movements. In order to estimate the performance of the proposed methods, we collected video data during real driving situations under various illumination conditions, such as during the day and during the night. Experimental results demonstrate an average eye detection rate of over 98% and an accurate measurement of eye blinking when using the proposed drowsiness detection system.

1. Introduction

Within the past decade, many efforts have been made to detect drowsiness among drivers [1],[2],[3],[4]. In many of these drowsiness detection systems, the monitoring of a given driver's visual state by the use of a camera has been applied to many real systems due to accuracy and non-intrusiveness [1],[2]. Eye blinking is a very confidential visual cue when it comes to monitoring a driver's level of alertness. PERCLOS (the percentage of time that an eye is closed time in a given period) is the most popular method of measuring eye blinking because high PERCLOS scores are strongly related to drowsiness [5]. Therefore, this paper describes an efficient way to measure eye blinking in order to acquire the PERCLOS scores accurately for drowsiness detection systems.

On the other hand, these vision-based systems are very sensitive to changes in illumination [4]. In the case of a moving vehicle during the day, a camera is totally exposed to various illuminations. Furthermore, it is difficult to distinguish sensitive and spontaneous eye blinking from driver's face under real driving. Some systems are used the pupil reaction against an infrared light as the frame difference between a pupil which appears bright and that which appears dark [2],[3]. However, this kind of research has mainly been performed in indoor studios or laboratories without the interruption of infrared illumination from sunlight because pupils which appear bright were not explicitly generated under strong daylight.

This paper proposes a way to measure eye blinking which allows for various changes in illumination conditions - not only during the day but also at night. Through experiments that use real driving data, we demonstrate that the proposed method is robust under a wide range of illumination conditions.

The remainder of this paper is organized as follows. Section 2 describes extraction of eye candidates by an infrared illuminator and an eye corner filter. In Section 3, we propose a novel illumination compensation algorithm for eye detection. Section 4 describes the verification of eye images. Experimental results are provided in Section 5, and finally we make conclusions and suggestions for future research in Section 6.

2. Extraction of Eye Candidates

We use an infrared image that remained stable regardless of whether it was used during the day or at night. The camera lens with an infrared band-pass filter as shown in Fig.1 removes all visible light and only allowed infrared light in. The use of an infrared image has some advantages [2]. The light source of infrared light is sunlight during the day and Infrared Light-Emitting Diodes (IR LEDs) during the night or on cloudy days when infrared light is not abundant.

On the other hand, depending on the position of infrared light source in relation to the position of the camera, the pupil reaction can be represented differently [2],[3]. Fig.1 represents a general principle used to generate pupils which appear dark under both day and night illumination conditions. Only a small amount of sunlight (reflected by the pupils) flows into the camera. This is because most sunlight is scattered

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in all directions. Therefore, pupils that appear bright may not really be clear during the day (if there is strong sunlight) while pupils that appear dark may actually be clear. Therefore, with this system, only pupils that appear dark can be used during both the day and the night.

A camera is installed on the dash board and two infrared illuminators are installed on the ceiling of car as shown in Fig.2.

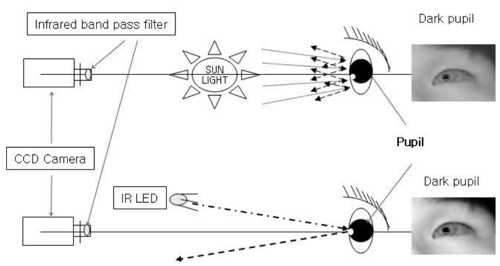

Figure 1. Generation of dark pupils that appear dark during both the day and the night

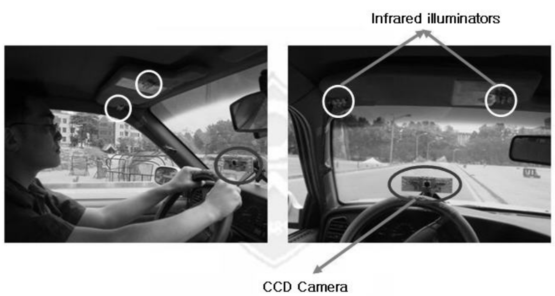

Figure 2. Configuration of the camera and the infrared illuminators

Meanwhile, the input video includes not only the driver's face but also the background (which showed parts of the vehicle as well as scenery outside the car). In order to measure eye blinking under the rapidly changing circumstances, eye detection must first take place. For this, eye corner filter is a fast and reliable preprocessing method [7]. Therefore, the eye corner filter method as proposed by Jie Zhu and Jie Yang [6] is applied in order to detect suitable candidates of eye region in this paper.

3. Illumination Compensation Algorithm

Infrared images always include pupil that appear dark (by pupil's reaction to infrared light). Based on this property, eye shapes that appear dark must remain dark while brighter areas must be compensated for reliable eye shapes. For illumination compensation, We calculate the Average Intensity (AI) of input image (P_{NM}) which is the size of N multiplied by M as Equation 1. In Equation 2, EAI represents the Expected Average Intensity, which is empirically set by the user. For the AI to be equal to the EAI , the AI used in Equation 2 is multiplied by a constant T . Each pixel of P_{NM} is multiplied by the T acquired by Equation 2 in order to increased intensity. If this increased intensity value is more than the value of the EAI , this intensity is replaced by the EAI .

$$AI = \frac{1}{N \times M} \sum_{i=0}^{N-1} \sum_{j=0}^{M-1} P_{ij} \tag{1}$$

$$EAI = AI \times T \tag{2}$$

This calculation is applied to each eye candidate locally. Fig.3 shows the pseudo code for the main part of the illumination compensation algorithm. *IMG* represents an input frame. EAI represents the expected average intensity and is empirically fixed as 190 in this paper. *N* and *M* represent the size of the input frame. *NEW_IMG* represents the image after illumination compensation.

```
CONST EAI = 190;
AI = MEAN OF IMAGE (IMG);
T = EAI / AI;

WHILE I< N AND J<M
   NEW_IMG(I, J) = IMG(I * J) * T;
   IF NEW_IMG(I, J) > EAI
      NEW_IMG(I, J) = EAI;
END
```

Figure 3. Pseudo code for illumination compensation

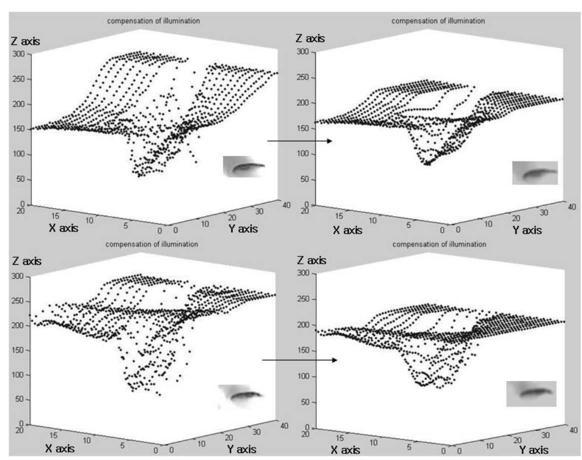

Figure 4. The results of illumination compensation. Left and right image, as shown before and after illumination compensation.

Fig.4 presents the results obtained by the illumination compensation algorithm. The left and right images show the results before and after illumination compensation. In the three dimensional graph, the X-axis represents the horizontal length, the Y-axis represents the vertical length and the Z-axis represents the intensity in the input image. In the left images, the distribution of the intensity of the surrounding areas of the eye varies. This is because the level of illumination changes, except the intensity of the eyelid and pupil areas. In contrast, in the right images, the proposed illumination compensation algorithm keeps a constant distribution of the intensity of the eyelid and pupil areas while it compensates for the intensity in the surrounding areas of the eye (approximately EAI).

If the eye region retains minimum intensity for separating eye shape, the proposed illumination compensation algorithm only approximates the background of the eye region to EAI because the eye pupil is kept dark and minimum intensity when using the infrared illuminators.

4. Eye Verification

In this paper, the eye verification is performed by cascaded SVM, which represents the cascade form of a Support Vector Machines (SVM). The cascaded SVM as proposed by S. Romdhani *et al* [8] retains the accuracy of the SVM and speeds up the test phase for real-time systems.

Filtered candidates of eye region (obtained by the eye corner filter) are classified into eye groups and non-eye groups by hand for the configuration of classifiers. Eye groups are again separated into open eye groups and closed eye groups. Therefore, the cascaded SVM is used for two classifiers in this paper; open eye classifiers and closed eye classifiers. If open eyes are detected by the open eye classifiers, eyelid movements could be measured. However, if open eyes are not detected by the open eye classifiers, closed eyes are sequentially detected by the closed eye classifiers, in order to measure eyelid movements. If closed eyes are also not detected, the current frame is ignored for the eye detection because there are no proper eye regions.

It is sometimes possible to obtain open eye and closed eye regions within the same feature space. This leads to many false representations because closed eyes and horizontal edges are very similar. Therefore, cascaded SVMs are configured respectively for open eyes and for closed eyes.

On the other hand, to measure eye blinking, the measure of eyelid movements has to be measured. Based on the detected eye position, we propose a novel way of measuring eyelid movements. This can be represented by the sum of the angles between the two eye corner points and the top point of the upper eyelid as Fig. 5. The open degree of the eye is shown in Equation 3. The eye state to measure eye blinking is determined by the threshold for the Degree (Eye). This approach offers the scalability and consistency for eye blobs.

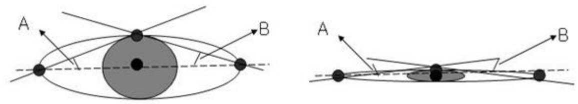

Figure 5. The measurement of eyelid movements: (a) the measurement of an open eye and (b) the measurement of a closed eye

$$Degree\ (Eye) = |Degree\ (A) + Degree\ (B)| \quad (3)$$

5. Experiments

The experiments are divided into two processes. Firstly, eye detection is performed for the collected own data and secondly, a decision about drowsiness is made by measuring the PERCLOS using eye blinking. Data for testing are acquired under a wide range of illumination conditions during periods of real driving.

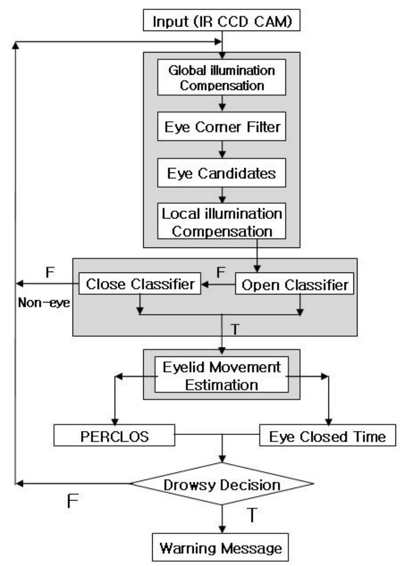

Figure 6. Algorithm for the proposed method

Fig.6 shows the proposed algorithm. Fig.7 represents the results of the eye detection process. The mesh model refers to an average face model, which consists of 70 feature points. This mesh model is rectified by two eye positions and the mouse position, which are automatically detected in each frame. Fig.8 shows the graphs of the PERCLOS measured over 250 seconds. The time that the eye is closed is continuously accumulated for latest 30 seconds in order to acquire the PERCLOS. In Fig.8, the upper line represents a drowsy state while the bottom line represents a non-drowsy state. The two lines in each graph are acquired from the same person. The first 30 seconds is used to accumulate the data. For the non-drowsy state, the graph is very stable while for the drowsy state, the graph changes severely. Furthermore, the PERCLOS are mostly higher than those of the non-drowsy state. The decision boundary for the drowsiness is empirically 40% obtained by graphs from 10 drivers. When the scores exceeded 40%, drivers are given a warning message for the drowsy state by our system.

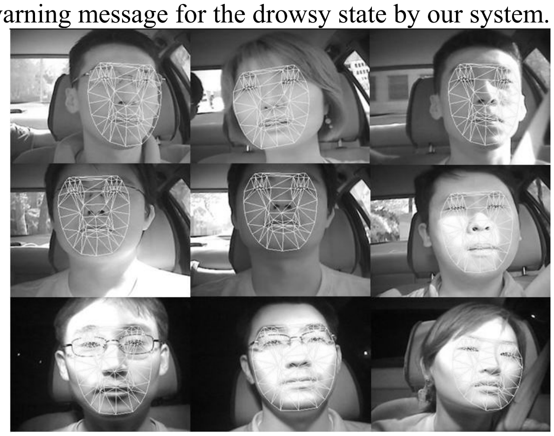

Figure 7. Results of the eye detection process under various illumination conditions

Table 1. Comparison of eye detection ratio with/without illumination compensation.

Person	Total Frame	Eye Detection Rate (%)	
		Without I.C	With I.C
1	1723	91.41	97.79
2	1783	94.95	97.86
3	1780	97.97	98.93
4	1790	94.30	98.04
5	1787	92.05	98.54
6	1784	93.32	97.98
7	1790	91.11	97.76
8	1790	98.44	99.83
9	1781	95.49	98.14
10	1773	96.76	99.04
Average		94.58	98.39

Table 1 shows the eye detection performance of the proposed system and a comparison of the eye detection rate for 10 drivers during the daytime with/without the proposed illumination compensation. In Table 1, if the driver's eyes are not completely seen, these frames are not included. The average eye detection rate with I.C (Illumination Compensation) is 98.39%, while that without I.C is 94.58%.

6. Conclusion

In this paper, we have proposed a reliable measurement of eye blinking using a novel illumination compensation algorithm and the measurements of eyelid movements. The PERCLOS are accurately measured by the proposed method for real driving data under various illumination conditions. Therefore, the proposed method represents an improvement over earlier approaches.

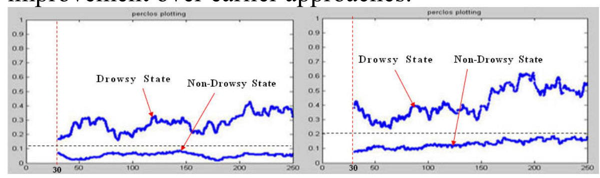

Figure 8. Measure of PERCLOS scores with for real driving data from two drivers.

Acknowledgments

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