

駕駛昏睡偵測與注意力監控系統

Driver Drowsiness Detection and Alertness Monitor System

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摘要

近年來，交通意外事故頻繁，且九成以上肇事因素都是人為所導致，在本論文中，我們提出了一個駕駛昏睡和注意力的監控系統，分析駕駛的狀況包含：眼睛的開/閉、臉部的方向、與視線的方向。

本論文內容主要分成五個部份：主動光源取像設備、眼睛偵測與追蹤、臉部偵測與方向估計、視線方向估計、及駕駛注意力判定分析。為了能在不同光源環境可以正確的偵測和追蹤駕駛的眼睛，我們使用紅外線打光取像設備來擷取駕駛的眼睛和臉部影像；之後我們擷取可能的眼睛區域並使用支援向量機 (support vector machine, SVM) 來辨識及偵測出所有可能得眼睛區域；最後經過我們的驗證條件找出一雙眼睛。並且根據眼睛位置找出臉部範圍。在偵測階段連續三張影像成功後，進入追蹤階段。在追蹤階段我們使用了三階段方式追蹤，以儘量確保追蹤正確率。在臉部偵測與方向偵測方面，我們根據影像中所找到的雙眼距離及雙眼連線之傾斜角度判斷臉部的方向。在眼睛開/閉分析部份，我們分析了三種準則，並比較這些準則的可靠度。在視線方向偵測部份，首先我們對眼睛區域使用水平邊遮罩尋找眼睛的水平邊，再以疊代逼近自動二值化法配合區塊連結法找出眼睛的矩形框。將矩形框分成左右三等份。配合之前使用眼睛遮罩找到的眼睛中心點，依眼睛中心點在矩形框的左、中、右區塊中判定視線方向。之後再綜合左右眼的個別視線方向資訊，分析駕駛人雙眼的視線方向。最後我們根據眼睛的開閉資訊，使用 PERCLOS 昏睡判定準則來判定駕駛是否昏睡。

我們在不同的光源環境下：晴天、陰天、雨天及夜晚，測試我們的系統。目前的眼睛偵測率僅達 80%，而眼睛開閉判斷可達 95% 的正確率。眼睛偵測率不高的原因主要在於臉部亮度不均所致；例如，臉部局部照射陽光或燈光。這是我們下一階段主要改進的研究項目。

關鍵詞：先進安全車輛、駕駛昏睡偵測、眼睛偵測、眼睛開閉分析、臉部方向、支援向量機

Abstract

In this study, we propose a driver drowsiness detection and alertness monitor system for advanced safety vehicles. The proposed system consists of five parts: (1) an IR illuminated camera, (2) eye detection and tracking, (3) face detection and orientation estimation, (4) gaze estimation, and (5) drowsiness/fatigue determination.

In order to deal with various ambient light conditions, we utilize an IR camera equipped with an active IR illuminator to extract several visual cues such as eye closing/opening, eyelid movement, gaze direction and face direction. A probabilistic model is developed to model human fatigue and to determine fatigue based on the visual cues. At first, we capture face images in the same background and illumination by utilizing Iterative thresholding to find out the location of brighter pixels. Secondly, we obtain the positions of the eyes; then clip the eye region to be verified by the support vector machine (SVM). If there are a fixed numbers of image frames succeeded in detection module, we alternate the processing to tracking module. In the face detection and orientation estimation, we estimate the face direction according to the distance and slope of the two eyes. In the analysis of eye closing/opening, we consider three criteria and compare their performance. In the gaze estimation, we segment the eye region into three equally-sized subregions, then determine the pupil location in which subregion for the estimation. At last, we use the criterion of PERCLOS to judge whether the driver is in drowsy situation or not.

We have tested the proposed system in variant whether situations: sunny, cloudy, rainy, and night hours. Currently, the eye detection rate is only 80%, but the correct rate of determination for eye closing/opening is 95%. The main cause of the low rate of the eye detection is un-uniform illumination of the faces; for example, only partial face was shined by sun ray or lights. This is our next pursued task.

Keywords: advanced safety vehicle, drowsiness determination, eye detection, eye closing/opening analysis, face orientation estimation, support vector machine

1. Introduction

To achieve a driver drowsiness detection and alertness monitor system for advanced safety vehicles in complex background [8-10, 25], we need develop real-time algorithms to catch the candidates of driver's eyes and faces. Among all kinds of information applied in the field of advanced safety vehicle (ASV), image processing techniques are used most widely, because of the flexibility of visual information. Many face detection methods [1, 2, 5-7, 11, 15, 17, 18, 20-22, 26] and eye detection methods [4, 12-14, 16, 19, 24, 27] have been proposed. We here develop our algorithms to match our requirements. We also modify our developed IR illuminated camera [3] to minimize the impact of different ambient light conditions such as poor illumination, daytime and nighttime. Based on the position of eyes and face, we provide several modules including eye detector, eye tracker, gaze orientation estimation, mouth detector, facial position estimation, facial orientation estimation, and face detection.

The proposed system consists of five main components as shown in Fig. 1 and described as follows:

- i. An IR illuminated camera.
- ii. Eye detection and tracking.
- iii. Face detection and orientation estimation.
- iv. Gaze estimation.
- v. Drowsiness determination.

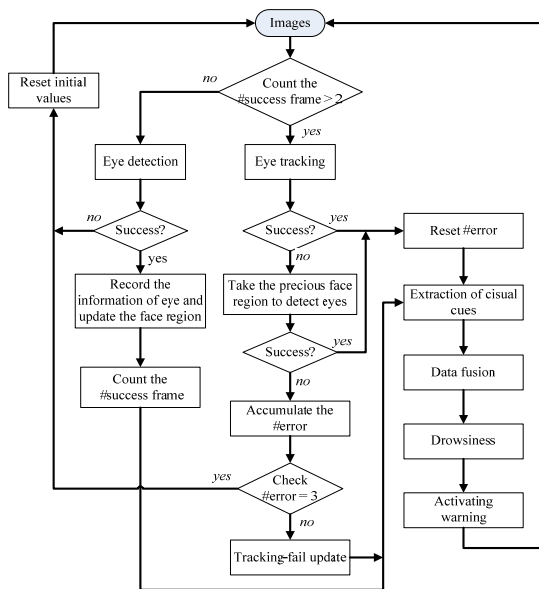


Fig. 1. The proposed drowsiness detection and alertness monitor system.

In the proposed system, the main tasks include detecting, tracking, and extracting the driver's eyes and head to infer visual cues for vigilance decision. The face position is estimated according to the relationship between eyes and face. Based on these

cues, we can monitor driver's consciousness status.

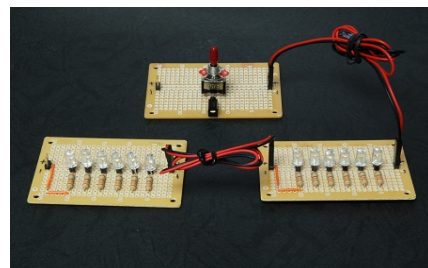
In order to work under various illumination, we utilize an IR camera equipped with a spotting IR illuminator to acquire driver's pupils and face position. To detect and track driver's eyes in our system is for preventing some accidents happened. Using an IR illuminated camera, we obtain consecutive image frames to detect and track eyes and face position. After obtaining eyes and face positions, we can own some necessary visual cues like eyelid movement and head movement to detect the possibility of driver's drowsiness.

The remaining sections of this paper are organized as follows. Section 2 introduces and compares several IR illuminators. Section 3 describes the eye detection and verification method. The face position estimation and the eye tracking method are also described in this section. Section 4 provides the methods to judge the eyelid closing/opening, gaze, and face orientation estimation. Section 5 reports experiments and the experimental results. Section 6 is the conclusions.

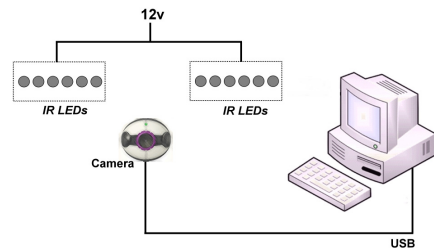
2. An IR illuminated camera

Here we provide an IR illuminated camera with two illuminators which install beside the camera. The IR illuminators are shown in Fig. 2 (a).

We keep bright to obtain the brighter face image which captured by a USB camera. The connection diagram of image acquisition equipment, interface, and PC is shown in Fig. 2 (b). We can obtain the clear face image in a less light condition, and in this paper we use this equipment to achieve our driver's drowsiness detection system by using the bright and dark face images.



(a)



(b)

Fig. 2. The active image acquisition equipment. (a) The IR illuminator. (b) Connection diagram.

3. Eye detection and tracking

In our proposed eye detection and verification system, we utilize a consecutive *RGB* color image frames as our input information and execute all functions. First, we propose the procedure of eye detection and verification as shown in Fig. 3, and then we will describe all functions in the following sections, respectively.

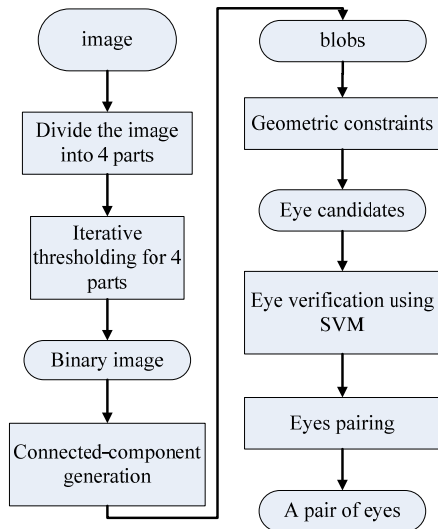


Fig. 3. The procedure of eye detection and verification.

3.1 Eye detection and verification

We obtain consecutive image frames in the first step. In order to overcome the interferences of the different poses of the head and variant illumination, we divide each *RGB* frame into four parts. We execute iterative thresholding in four parts individually for forming a bi-level image. We utilize the bi-level image to obtain the bright pixels as our interesting points for next step. After the iterative thresholding method, we can obtain a bi-level image.

The main target of eye detection is bi-level thresholding and connected-component generation. Based on the algorithms, we label each brighter pixel and find the information of the center, size, and boundary box to form the blobs. After executing connected component generation, we have obtained many binary candidate blobs. We can find the eyes somewhere in these candidates. However, it is too difficult to isolate eye blob unless we pick the accurate threshold value. We observe that the eyes are usually small and not bright enough compared with other noise blobs. In our proposed system, in order to distinguish eye blobs with other noise blobs, we define several constraints based on the geometric shapes as follows:

i. $5 < \text{blob size} < 300$,

ii. $3 < \text{Width of blob bounding box} \leq 40$,

iii. $3 < \text{Height of blob bounding box} \leq 30$, and

iv. $(\text{Bounding box size} - \text{blob size}) < 100$.

After the execution, a support vector machine classification [23] is employed to detect whether each candidate blob is an eye blob or not with the train images shown in Fig. 4.



(a)



(b)

Fig. 4. Some training images for SVM. (a) Eye images. (b) Non-eye images.

We then proposed several constraints based on the geometric shapes to verify the eyes pairing:

i. The distance between two centers of eyes is larger than 30.

ii. The distance in *y*-coordinate between two centers of eyes is smaller than 30.

iii. The distance in *x*-coordinate between two centers of eyes is smaller than 100.

3.2 Eye tracking

We provide the methods of face position estimation and eye tracking. First, we estimate the face position by the positions of left/right eyes which based on the eye detection. When eye detection is successful in consecutive three frames, we turn our procedure to tracking phase. We provide three strategies to verify the left/right eyes in eye tracking as follows:

s1. We use the Kalman filter to track and detect eyes in the predicted region.

- s2. If strategy 1 is fail, we search the darkest part as the centers of left/right eyes in the predicted region.
- s3. If both strategy 1 and 2 are fail, we use the face position in the predicted region to search the eyes by *SVM* classification.

The flow chart of eye tracking is shown in **Fig. 5** and we will describe the detail steps in the following sections.

After the prediction of strategy 1, we detect the eyes in the predicted regions. This strategy can reduce the detection time and avoid much unnecessary detecting results.

Because of the face orientation or external illumination, the strategy 1 may fail. We use strategy 2 to search the centers of left/right eyes. In the strategy 2, we clip the predicted region from the correct frame, set a threshold value to make a binary image from the clipped region. The threshold value is made by iterative thresholding algorithm. And then we use connected component algorithm to find the center and boundary box of each blobs. We choose the largest blob and take its center as the eye center. And then we take these eyes to be a pair of eyes by defined two constraints as:

- i. $20 < \text{blob size} < 400$.
- ii. The distance between this position and position of last frame < 10 .

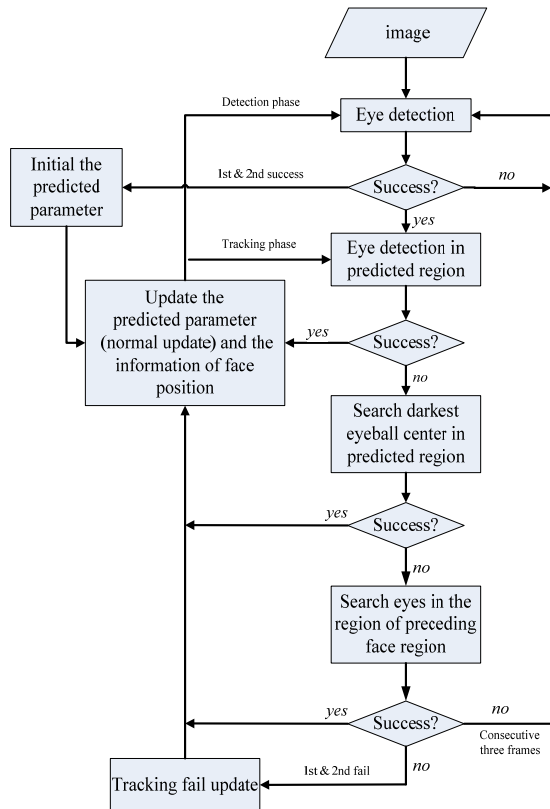


Fig. 5. The flow chart of eye tracking.

In order to make our system for eye tracking accurately and avoid the interference of external illumination, we propose a method to estimate the face position based on the ellipse filter. The estimation process is described as follows:

- Step 1.* Based on the positions of left/right eyes in detection stage, we can use a connected-component algorithm to find the maximum blob and its center. And then we take two centers of left/right eyes to calculate the distance and angle.
- Step 2.* According to the angle we obtain, we propose a method to classify what kind of face position we estimate. If the angle is equal to zero, we classify it into the front face; otherwise, we classify it into the side face.
- Step 3.* We design an ellipse filter based on the shape of human face. After obtaining the information of face position classification in *Step 2*, we use two methods to deal with front face and side face individually as following cases:

Case 1. Front face: we take two centers of left/right eyes named (X_{p1}, Y_{p1}) and (X_{pr}, Y_{pr}) and the distance between two eyes named Dis . We first find the center of (X_{p1}, Y_{p1}) and (X_{pr}, Y_{pr}) , and add $0.2 Dis$ to y -coordinates to find the center (X_e, Y_e) of the ellipse. We define the initial length of major axis is $2.4 Dis$ and the initial length of minor axis is $1.6 Dis$. Here we obtain an initial ellipse and then we design a method to expand the ellipse to find the face edges. We divide equally the length of major/minor axis into forty parts, and based on these divisions we obtain several ellipses. To reduce the computing time, we execute the vertical edge detection focused on the edge of our ellipses and accumulate the difference values. When the maximum difference value occurs, we can choose this ellipse position as our suitable face position as illustrated in **Fig. 6**.

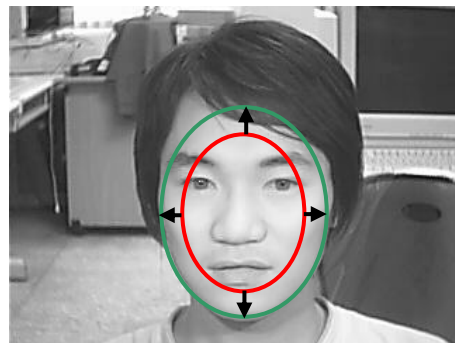


Fig. 6. The images of front face position estimation.

Case 2. Side face: we take two centers of left/right eyes named (X_{p1}, Y_{p1}) and (X_{pr}, Y_{pr}) and the

distance between two eyes named Dis . We first find the center of (X_{p_1}, Y_{p_1}) and (X_{p_2}, Y_{p_2}) , and add $0.2 Dis$ to y -coordinates to find the center (X_e, Y_e) of the ellipse. We define the initial length of major axis is $2.4 Dis$ and the initial length of minor axis is Dis . Here we obtain an initial ellipse and then we design a method to expand the ellipse to find the face edges. We divide equally the length of major/minor axis into forty parts, and based on these divisions we obtain several ellipses. By our observation, we add a condition based on the angle in *Step 1* to rotate these ellipses to form more ellipse candidates. To reduce the computing time, we execute the vertical edge detection focused on the edge of our ellipses and accumulate the difference values. When the maximum difference value occurs, we can choose this ellipse position as our suitable face position as illustrated in **Fig. 7**.

In the strategy 3, we first take the face image of preceding image frame based on the face orientation estimation. We use iterative thresholding algorithm to set a threshold value to make a binary image from the face image. Then we use connected component algorithm to find each blobs. For each blob, we use some geometric constraints as the same in eye detection to choose the possible eye candidates. And then we use *SVM* classification to remove some false results and obtain the suitable eyes. Finally, we take the eyes to be a pair of eyes based on some constraints as

- i. The distance between two centers of eyes is larger than 30.
- ii. The distance in y -coordinate between two centers of eyes is smaller than 30.
- iii. The distance in x -coordinate between two centers of eyes is smaller than 100.

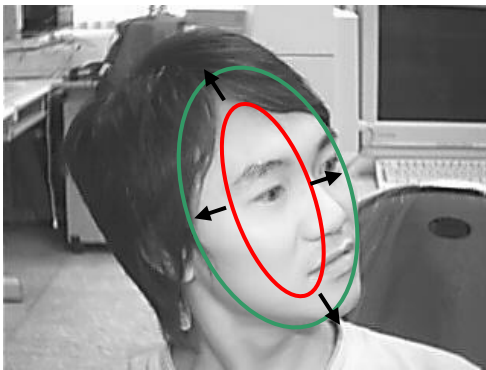


Fig. 7. The images of face position estimation.

4. The judgments on driver's attention

We first use a mask to find the center of eyes. The mask is shown in **Fig. 8**. Then we provide

several methods to judge the driver's attention for drowsiness detection which include eye close/open, face orientation estimation, and gaze orientation estimation in the following sections.

0	0	1	1	1	1	1	0	0
0	1	1	1	1	1	1	1	0
1	1	1	1	1	1	1	1	1
1	1	1	2	2	2	1	1	1
1	1	1	2	2	2	1	1	1
1	1	1	2	2	2	1	1	1
1	1	1	1	1	1	1	1	1
0	1	1	1	1	1	1	1	0
0	0	1	1	1	1	1	0	0

Fig. 8. The mask for finding the center of eye.

4.1 Eye opening and closing

To determine the eyes being open or closed, we first find the eye's height. Based on the position of the dark pupil, we take the position (X_p, Y_p) as our calculating point and along y -axis direction to find the biggest and smallest difference values. By our observation in the situation of dark pupil image, the difference value between pupil and iris is usually larger than between iris and eyelid in the y -axis direction. To avoid the interference of dark pupil, we shift the X_p position to set two new calculating points as

$$L_Xp = Xp - 2, \text{ and } R_Xp = Xp + 2.$$

After obtaining two new calculating points, we calculate the biggest and smallest difference values upward and downward along y -axis direction for two calculating points individually. Based on the y -axis positions of two biggest and two smallest difference values, we select the higher y -axis positions as our top-detected point and select the lower y -axis position as our bottom-detected point. The illustration is shown in **Fig. 9**. Finally, we calculate the distance L between the top-detected and bottom-detected points and define N as our threshold value. If the distance L is larger than N , we determine the eyes are open; otherwise, the eyes are closed.

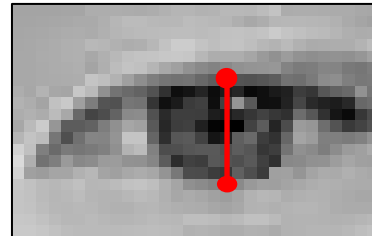


Fig. 9. Height of an eye.

After obtaining the eye open/close, we measure the driver's fatigue level based on the definition of *PERCLOS* (Percent of time eyelid are closed in a

specific period) set up by *NHTSA* (National Highway Traffic Safety Administration). The definition is the percentage of closed eye frames in all frames for a specified time interval. We take 5 seconds as our time interval to monitor the driver's fatigue level at each time instance.

4.2 Face orientation

Face orientation estimation always plays an important role for driver's drowsiness in many researches. In order to give a warning to driver immediately when the danger driving occurs, we propose the method to calculate the distance and roll angle between two eyes to estimate the face orientation. The executing steps are described as:

Step 1. First image in detection stage, we obtain the eye regions and find their center points. Based on two center points, we calculate the distance and roll angle named (D_{i-1}, θ_{i-1}) as

Step 2. Next frame in tracking stage, we use the same method in *Step 1* to calculate the distance and roll angle named (D_i, θ_i) . Then we propose the criteria to estimate the face orientation as

$$\left\{ \begin{array}{l} \text{if } |D_{i-1} - D_i| \leq 9, \text{ and } \theta_{i+1} \leq \pm 7^\circ, \\ \quad \text{it is a front side,} \\ \text{if } |D_{i-1} - D_i| > 9, \text{ and } \theta_{i+1} < 0^\circ, \\ \quad \text{it is a right side,} \\ \text{if } |D_{i-1} - D_i| > 9, \text{ and } \theta_{i+1} > 0^\circ, \\ \quad \text{it is a left side;} \end{array} \right.$$

Step 3. In order to make our judgment correctly, we propose the method to calculate the average distance value per five front side images and set it to be new D_i as our standard judgment value. If eye tracking succeeds, return to *Step 2* and we take new D_i to compare with the tracking result; otherwise, return to *Step 1* and we take new D_i to compare with the detection result.

4.3 Gaze estimation

To perfect our drowsiness warning system, we propose a method to estimate the gaze orientation. According to the result of gaze orientation, we can know immediately the driver's attention and give a warning to the driver to avoid the accident happens. The executing steps are as follows:

Step 1. After obtaining two eye regions and their center points, we use the vertical gradient mask to detect horizontal edges as the upper and lower eyelids. Then we translate it to be a bi-level image.

Step 2. We extract the connected components from bi-level images, and find the maximum white block. According to the block, we can find the

left/right points.

Step 3. Based on left/right points, we calculate the distance L along x-axis. Then we divide the distance into three equal parts.

Step 4. In *Step 1*, we already know the positions of center point for two eyes. Based on the positions named (X_{pl}, Y_{pl}) and (X_{pr}, Y_{pr}) , we can determine the gaze orientation as the following cases:

- i. When (X_{pl}, Y_{pl}) and (X_{pr}, Y_{pr}) are fell in region A, or (X_{pr}, Y_{pr}) is fell in region A and (X_{pl}, Y_{pl}) is fell in region B. We consider the gaze orientation is at right side.
- ii. When (X_{pl}, Y_{pl}) and (X_{pr}, Y_{pr}) are fell in region C, or (X_{pr}, Y_{pr}) is fell in region B and (X_{pl}, Y_{pl}) is fell in region C. We consider the gaze orientation is at left side.
- iii. When (X_{pl}, Y_{pl}) and (X_{pr}, Y_{pr}) are fell in region B. We consider the gaze orientation is at front side.
- iv. Here we propose a method to deal with the case when (X_{pl}, Y_{pl}) is fell in region C and (X_{pr}, Y_{pr}) is fell in region A. The method is to calculate the distances of (X_{pl}, Y_{pl}) to left point and (X_{pr}, Y_{pr}) to right point along x-axis. When the distance of (X_{pl}, Y_{pl}) to left point is larger than (X_{pr}, Y_{pr}) to right point, we consider the gaze orientation is at right side; otherwise, we consider the gaze orientation is at left side.

One example of left eye for gaze estimation is shown in **Fig.10**.

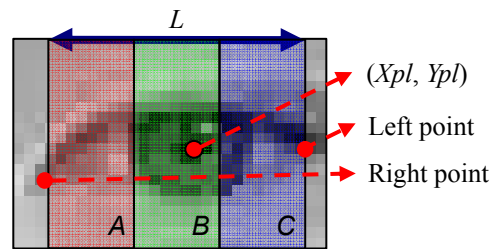


Fig. 10. Gaze orientation estimation

5. Experiments

The proposed system was evaluated to judge its correctness and accuracy. We have tested the proposed system on our experimental vehicle which runs on the highway and urban road, and we display the experimental results of real-time driver's drowsiness detection. Our experimental vehicle mounted the two-side *IR* illuminator is shown in **Fig. 11**.

Three kinds of experiments were performed:

- i. Eye detection in six different kinds of images.
- ii. Eye tracking and face position estimation in three

different kinds of images.

- iii. Eye open/close, face orientation estimation, and gaze orientation estimation in three different kinds of images.



Fig. 11. The illustrations of our experimental vehicle mounted the two-side IR illuminator.

5.1 Eye detection

The conditions for testing eye detection include: strong light image, normal light image 1, normal light image 2, normal light with glasses image 1, normal light with glasses image 2, dark image are shown in Fig. 12.

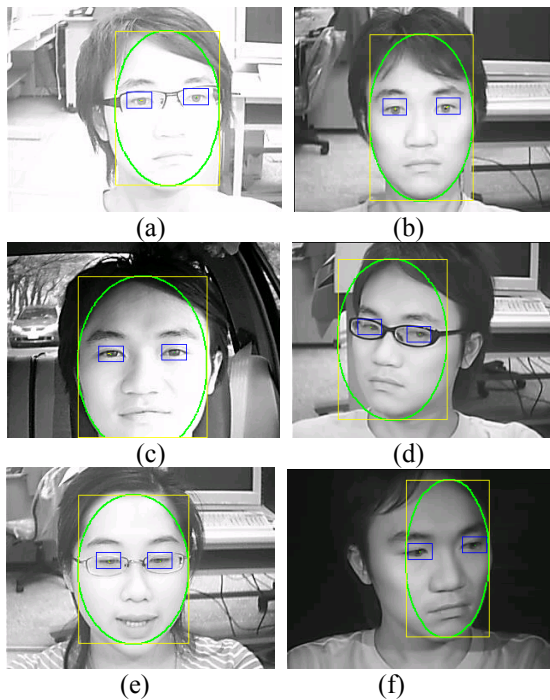


Fig. 12. Results of eye detection in different situations. (a) Strong light image. (b) Normal light image 1. (c) Normal light image 2. (d) Normal light with glasses image 1. (e) Normal light with glasses image 2. (f) Dark image.

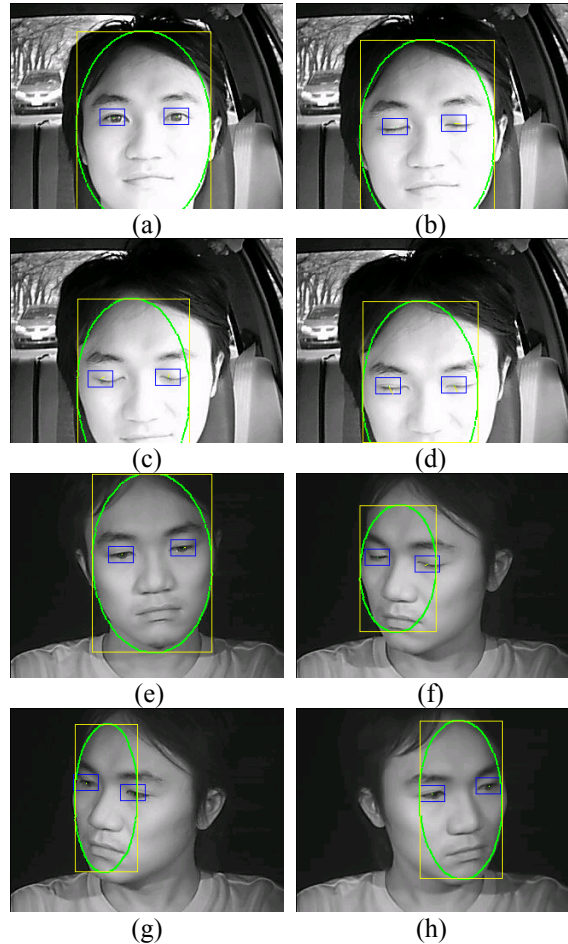
The eye detected rates in three videos are shown in Table 1. The #Frame is the number of frames in a video. The #Correct is the number of extracted eyes. The #Error number indicates the number of eye which is appeared but isn't extracted. The detected rate is the ratio of appeared eye number to #Frame. From the results, we find that the detected rate is high in different situations.

Table 1. The Results of Three Different Testing Videos

Video	# frame	# Correct	# Error	Detection rate
Night	800	748	42	93.5%
Indoor	800	790	10	98.7%
In a car	308	249	57	80.8%

5.2 Eye tracking and face position estimation

Three videos were used to evaluate the eye tracking and face position estimation as shown in Fig. 13. Even if the driver's head is turning much, our system can still track the eye positions and find the suitable face position.



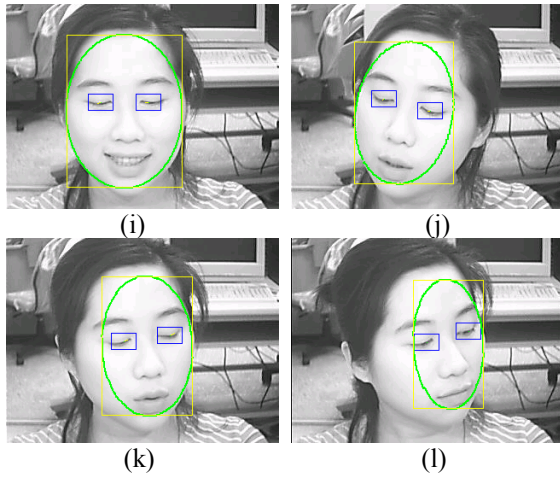


Fig. 13. The eye tracking results in three videos.

5.3 Eye open/close, face orientation, and gaze estimation

To judge the driver's attention, we propose three videos to evaluate eye open/close, face orientation, and gaze estimation in different situations as shown in Fig. 14.

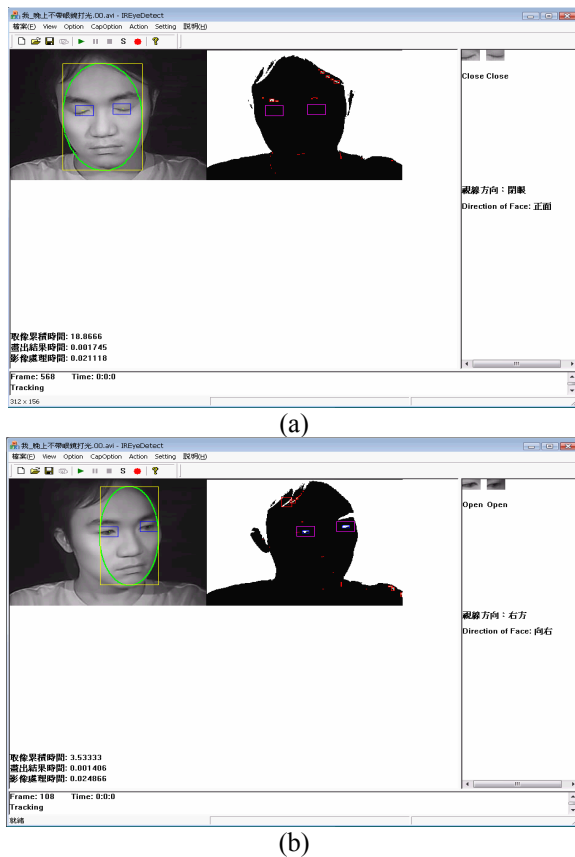


Fig. 14. Two examples for eye open/close, face orientation, and gaze estimation. (a) Open-eyed case. (b) Close-eyed case.

The average processing time of judging the driver's attention is shown in Table 2.

Table 2. The Detection Rate of Judging the Driver's Attention

	Eye open/close	Face orientation estimation	Gaze estimation
Night	94.1%	80.3%	82.5%
Indoor	85.2%	81.1%	80.2%
In a car	94.7%	78.3%	80.3%

We record PERCLOS measurement to represent the driver's fatigue level as shown in Fig. 15. We take 5 seconds as our time interval and extract #closed eye frame and #total frames. According to the percentage of #closed eye frame and #total frames, we take 10% as our judgment to detect if the driver is drowsing or not.

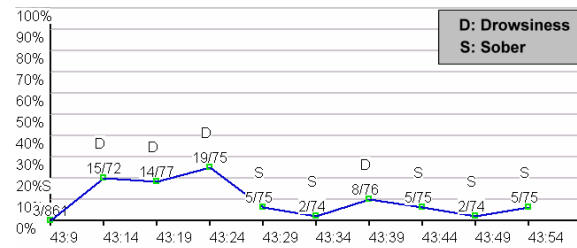


Fig. 15. PERCLOS for representing the driver's fatigue level.

6. Conclusions

In this study, the prototype computer vision-based eye detection with an IR illuminated camera for monitoring driver's fatigue behaviors is developed. We proposed several algorithms for eye detection / tracking, eye open/close, face orientation estimation, and gaze estimation. Based on these features we can judge the driver's attention.

Driver's fatigue behaviors are various from person to person and too many unexpected behaviors that lead to traffic accident happened. In order to make our system correctly, we can try to combine with some sensors such as heart-beat and brain wave detectors. Based on the fatigue data, we can enhance the probability of correct fatigue and give a suitable warning to the driver. And we can use the information of detecting lane, based on the lane departure warning, we will know the driving behaviors immediately. The above problems will be the next challenges as our future works.

References

[1] Bae, H. and S. Kim, "Real-time face detection and recognition using hybrid-information extracted from face space and facial features," *Image and Vision Computing*, vol.23, pp.1181-1191, 2005.

- [2] Berbar, M. A., H. M. Kelash, and A. A. Kandeel, "Faces and facial features detection in color images," in *Proc. of the Geometric Modeling and Imaging*, 2006, pp.209-214.
- [3] Chang, K.-S., *A Driver Drowsiness Detection Based on An Active IR illumination*, Master thesis, Computer Science and Information Engineering Dept., National Central Univ., Chung-Li, Taiwan, 2005.
- [4] Chen, Y.-R., *Computer Vision-based Eye Detection and Warning System for Driver Fatigue*, Master thesis, Civil Engineering Dept., National Taiwan Univ., Taipei, Taiwan, 2005.
- [5] Cristinacce, D. and T. Cootes, "Facial feature detection using adaboost with shape constraint," in *Proc. 14th Conf. Machine Vision*, British, 2003, pp. 231-240.
- [6] Garcia, C. and G. Tziritas, "Face detection using quantized skin color regions merging and wavelet packet analysis," *IEEE Trans. on Multimedia*, vol.1, no.3, pp.264-177, 1999.
- [7] Hong, K.-D., *A Real-time Face and Feature Location System*, Master thesis, Computer Science Dept., National Chung Hsing University, Taichung, Taiwan, 2006.
- [8] Hong, S.-X., *Hazardous Driver Behavior Analysis Using Pupil Detection and Fatigue Variation*, Master thesis, Computer Science and Information Engineering Dept., National Central Univ., Chung-Li, Taiwan, 2005.
- [9] Horng, W.-B., C.-Y. Chen, Y. Chang, and C.-H. Fan, "Driver fatigue detection based on eye tracking and dynamic template matching," in *Proc. Int. Conf. on Networking, Sensing & Control*, Taipei, Taiwan, Mar. 21-23, 2004, pp.7-12.
- [10] Hsiung, C.-Y., *An Attention Detection System for Vehicles*, Master thesis, Computer Science and Information Engineering Dept., National Central Univ., Chung-Li, Taiwan, 2005.
- [11] Ji, Qiang, "3D face pose estimation and tracking from a monocular camera," *Image and Vision Computing*, vol.20, pp.499-511, 2002.
- [12] Kawato, S. and J. Ohya, "Two-step approach for real-time eye tracking with a new filtering technique," in *proc. IEEE Int. Conf. on System, Man & Cybernetics*, Tennessee, Oct.8-11, 2000, pp.1366-1371.
- [13] Kawato, S. and N. Tetsutani, "Circle frequency filter and its application," in *Proc. Int. Conf. Workshop on Advanced Image Technology*, Taejon, Korea, Feb.8-9, 2001, pp.217-222.
- [14] Kawato, S. and N. Tetsutani, "Real-time detection of between-the-eyes with a circle frequency filter," in *Proc. 5th Asian Conf. on Computer Vision*, Melbourne, Australia, Jan.23-25, 2002.
- [15] Lee, T., S.-K. Park, and M. Park, "An effective method for detecting facial features and face in human robot interaction," *Information Sciences*, pp3166-3189, 2005.
- [16] Li, Y., X.-L. Qi, and Y.-J. Wang, "Eye detection by using fuzzy template matching and feature-parameter-based judgement," *Pattern Recognition Letters*, vol.22, iss.10, pp.1111-1124, 2001.
- [17] Lin, C.-H., *Face Detection, Pose Classification, and Face Recognition Based on Triangle Geometry and Color Features*, Ph.D. dissertation, Computer Science and Information Engineering Dept., National Central Univ., Chung-Li, Taiwan, 2001.
- [18] Lo, C.-H., *An Intelligent Face Detection System for Video Retrieval*, Master thesis, Computer Science and Engineering Dept., Yuan Ze Univ., Chungli, Taiwan, 2006.
- [19] Orazio, D., T. Leo, M. Cicirelli, G. Distanto, and A. Distanto, "An algorithm for real time eye detection in face images," in *Proc. 17th Int. Conf. on Pattern Recognition*, Cambridge, UK, Aug.23-26, 2004, pp.278-281.
- [20] Siana, L., *A Study of Human Tracking and Face Detection on A Pan-Tilt-Zoom Camera*, Master thesis, Elect. and Control Eng. Dept., National Chiao Tung Univ., Hsinchu, Taiwan, 2005.
- [21] Tan, Y.-H., *A Human Face Tracker System Design Study Using the Technology of Digital Image Processing*, Master thesis, Elect. Eng. Dept., National Cheng-Kung Univ., Tainan, Taiwan, 2000.
- [22] Tsao, Y.-C., *Measurement of Face Recognizability for Visual Surveillance*, Master thesis, Computer Science and Information Engineering Dept., National Chiao Tung Univ., Hsinchu, Taiwan, 2004.
- [23] Vapnik, V., *The Nature of Statistical Learning Theory*, Springer-Verlag, 1995.
- [24] Wang, S.-W., *Automatic Eye Detection and Glasses Removal*, Master thesis, Elect. and Control Eng. Dept., National Chiao Tung Univ., Hsinchu, Taiwan, 2004.
- [25] Wang, T. and P. Shi, "Yawing detection for determining driver drowsiness," in *Proc. IEEE Int. Workshop VLSI Design & Video Tech.*, Suzhou, China, May 28-30, 2005, pp.373-376.
- [26] Yan, S., C. Liu, S. Z. Li, H. Zhang, and H. Yeung, "Face alignment using texture-constrained active shape models," *Image and Vision Computing*, vol.12, pp.69-75, 2002.
- [27] Zheng, Z., J. Yang, and L. Yang, "A robust method for eye features extraction on color image," *Pattern Recognition Letters*, vol.26, pp.2252-2261, 2005.