Effective Driver Fatigue Monitoring through Pupil Detection and Yawing Analysis in Low Light Level Environments

Article *in* International Journal of Digital Content Technology and its Applications · September 2012

DOI: 10.4156/jdcta.vol6.issue17.41

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Effective Driver Fatigue Monitoring through Pupil Detection and Yawing Analysis in Low Light Level Environments

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Abstract

Monitoring driver fatigue is an important method to improving transportation safety. The statistics shows that a number of transportation accidents are caused by driver fatigue. Therefore, a system which can monitor driver fatigue and issue warning timely could help in preventing many accidents, and consequently reduce personal suffering and save money greatly. Effective driver fatigue monitoring in low light level environments has been challenging for it is difficult to get the exactly state of the driver. This paper have made an attempt to design a system that uses video camera that points directly towards the driver's pupil and yawning in order to detect fatigue. With IR illuminator, the system works robustly in low light level environments. If the fatigue is detected, a warning signal is issued to alert the driver. The authors have worked on the video files recorded by the camera. Video file is converted into frames. Firstly, a method based on Ada-Boost is adopted to locate the face and eyes through the driver's picture. Secondly, we introduce a new method to identify eyes' state and yawning detection. Finally the driver's state is monitored by PERCLOS algorithm. If the driver fatigue state are detected for 6 consecutive frames, the system draws the conclusion that the driver is falling asleep and issues a warning signal. Experiment results demonstrated that the proposed system and algorithm can achieve satisfactory performance.

Key words: *driver fatigue, Ada-Boost classifier, pupil detection and yawning analysis*

1. INTRODUCTION

Driver fatigue severely affects the alertness and vigilance of a driver to respond to a dangerous situation and is also frequently underestimated by drivers. Statistics show that between 10% and 20% of the traffic accidents are due to driver's fatigue or diminished vigilance level [1], which has become a serious problem for the society. In China, driver fatigue resulted in 3056 deaths in vehicular accidents in 2004, and caused 925 deaths in highway accidents which amounted to about 14.8 % of all deaths. According to the National Highway Traffic Safety Administration (NHTSA) [2] estimates, 100 000 police-reported crashes are directly caused by driver fatigue each year, which result in an estimated 1550 deaths, 71 000 injuries, and $12.5 billion losses. Therefore, driver fatigue is an important factor in many transportation accidents. This problem has increased the need of developing active safety systems that can reduce road accidents by warning the drivers of their poor driving condition.

In fact, there have been many attempts to achieve reliable fatigue detection in the past last decade[3]-[6]. According to the information sources, these possible techniques for detecting fatigue in drivers can be broadly divided into three major categories as follow:

1) Drivers' physiological parameters- based fatigue detection. The best accurate detection techniques are based on drivers' physiological parameters like brain waves, heart rate, pulse rate and respiration [7]-[10]. But these techniques are intrusive as electrode attachment to the driver is required. To the driver, this usually proves to be an annoyance and is in most situations impractical. However, physiological measurements serve as a good benchmark when evaluating other techniques.

2) Fatigue detection based on driving performance. Driver fatigue can also be characterized by the behaviors of the

vehicle. Signs of driver fatigue can be found by monitoring the transportation hardware systems, such as the changes of the steering wheel, vehicle lateral position [11], driver's grip force on the steering wheel [12], acceleration, vehicle speed, acceleration, braking and turning angle, etc. While these methods may be implemented non-intrusively as opposed to Drivers' physiological parameters- based measurements. They are subject to the vehicle type, driver experience and general driving conditions. Additionally, long time driving would result in perspiration on the sensors, diminishing their ability to monitor accurately.

3) Fatigue detection from visual cues. Monitoring eyelid movement and gaze by using a video camera is an established technique for driver fatigue detection [13]. People in fatigue exhibit certain visual behaviors that are easily observable from changes in facial features. Visual behaviors that typically reflect a person's level of fatigue include slow eyelid movement, smaller degree of eye openness, frequent nodding, yawning, sluggish in facial expression, and sagging posture. Much research effort has been dedicated to develop these techniques. Using a video camera to monitor the driver is also non-intrusive and become more and more practical and popular with the rapid development of camera and computer vision technologies. These techniques however do tend to be sensitive to external factors such as luminance or appearance of the driver (e.g. whether the driver is wearing glasses or not).

On the whole, eye behaviors provide significant information about a driver's fatigue and that if such visual behavior can be detected then it will be feasible to predict a driver's state of drowsiness or vigilance. But, it is difficult to predict the driver fatigue accurately or reliably based only on a single driver behavior. And, it may fail to predict the driver's true state if the eyes are not detected due to varying lighting conditions or vibrations experienced in real driving scenario. Hence, it cannot be denied that an approach depending on different visual facial features will work more effectively than the one depending on just one feature. For this reason, our proposed system incorporates yawning feature along with the eye state analysis to determine the fatigue level of driver in real time.

The rest of this paper is therefore organized as follows: In the next Section, a real-time driver fatigue detection system is presented. Section 3 describes the overall algorithm architecture, explaining its main modules. Experimental results are shown in section 4 and finally we present the conclusions and future studies in Section 5.

2. SYSTEM MODEL

By monitoring the eyes and mouth, it is believed that the symptoms of driver fatigue can be detected early enough to avoid a car accident. The complete block diagram representation of the proposed system based on eyes closer count and yawning count of the driver is as shown in Figure 1.

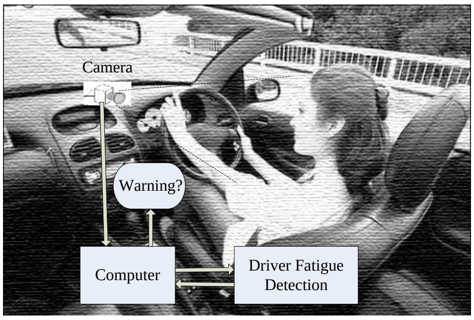


Figure 1. Block diagram representation of the driver fatigue monitoring system

A person's level of fatigue can be determined by his eyelid movement. In order to analyze a person's eyelid-movement, eye detection and tracking are necessary. The approaches detecting eyes based on active IR illumination utilize the special red-eye effect. It's a simple and effective approach for pupil detection based on differential infrared lighting scheme. The IR-illuminator used in this system is as show in Figure 2.

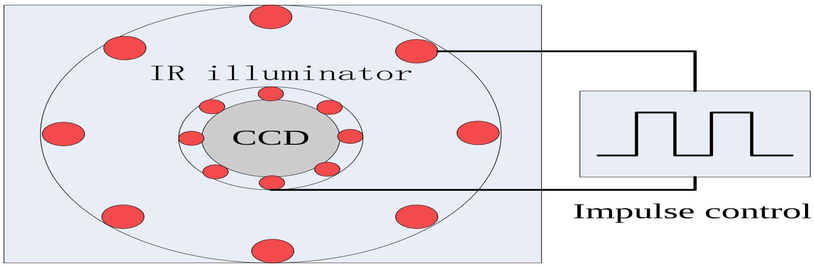


Figure 2. The structure of the IR-illuminator (a) and the real IR-illuminator for proposed system

To obtain a bright pupil image, the inner LEDs are turned on and to obtain a dark pupil image, the outer LEDs are turned on. Once the bright and dark pupil images have been obtained, the eye detection process can be started. It can be seen that both images share the same background and external illumination, with only the pupil being significantly different. By subtracting the dark pupil image from the bright pupil image, the background can be eliminated and the external light illumination can be reduced. The result of the subtraction is a difference image.

The eye blink frequency increases beyond the normal rate in the fatigued state. In addition, micro sleeps that are the short periods of sleep lasting 3 to 4 seconds are the good indicator of the fatigued state, but it is difficult to predict the driver fatigue accurately or reliably based only on a single driver behaviour. Additionally, the changes in a driver's performance are more complicated and not reliable. Therefore, a yawning count is considered as the second parameter in this system.

3. GENERAL ALGORITHM

An algorithm flowchart that detects driver fatigue by analyzing changes in eye state and mouth is shown in Figure 3. The algorithm proposed can be divided into four phases: Image Acquisition, Face Detection, Eye Detection and Process, eye state analysis and Yawning analysis, Mouth Detection and Yawning Analysis, Driver State Analysis.

3.1. Image Acquisition

The first stage is acquiring video images of driver's face for fatigue detection. A robust image acquisition system consists of a charged coupled device (CCD) micro camera and a near-IR illuminator was used. The video is 24-bit true color image and frame rate is 25fps.The distance between the CCD camera and the driver is about 50cm. We use the infrared illumination to reduce the impact of environmental light and it will not cause any interference with subjects for infrared beam is invisible to the human eye. The infrared wavelength was selected as 850nm. The advantage of using near-IR illumination is threefold. Firstly the impact of different ambient light conditions is minimized. Secondly, the bright/dark pupil effect can be produced. This is the basis for eye detection and tracking. Thirdly, near-IR light [13],[14] is barely visible to humans and will therefore not interfere with normal driving operations.

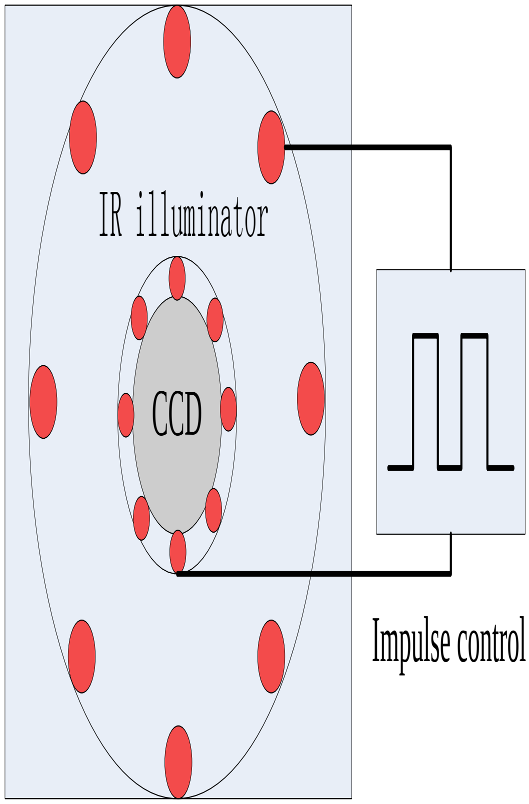


Figure 3. Algorithm flowchart of driver fatigue detection

3.2. Face and eye Localization

The face pose can be used for detecting fatigue or distraction behaviors among the categories defined for inattentive states. The normal face orientation while driving is frontal. If the driver's face orientation is in other directions for an extended period of time, it is due to distractions, and if it occurs frequently, it is a clear symptom of fatigue. Accurately detecting the driver's face and eye is the key to a driver fatigue detection.

Human face localization is a very important step in this system. Complexion is one of the most important features of human being in color images. Human's skin-color distributing is different from others.Skin-color still has good assembling character when the brightness information is removed. A large number of experiments show that Cb and Cr of skin color in YCbCr space is in the specific range [2]. We useto represent image pixel in $YCbCr$ space, then skin color pixel $S(i, j)$ satisfy $108 \le P_{Cb}(i, j) \le 123$ and $135 \le P_{Cr}(i, j) \le 156$ $P(i, j)$. Similarity degree can be used to calculate the similarity degree of all element points in color face images and skin-color can be separated from other part, then calculates grey scale, get grey images which was detected before, then use maximal varieties variance threshold dividing method to make the grey image binarization. Each pixel in the image calculated as (1). Hence, we can remove a large number of background regions rapidly and get the binary image of skin color. In order to enhance the regional connectivity, we merge the region which is too small to reduce the computation. We use morphological image processing method corrosion and dilation to realize it.

$$S(i,j) = \begin{cases} 255, & \begin{array}{l} 108 \le P_{Cb}(i,j) \le 123 \\ 135 \le P_{Cr}(i,j) \le 156 \end{array} \\ 0, & \text{others} \end{cases} \qquad (1)$$

After skin color classification, we locate driver's face from large number of skin color regions according to the area characteristics of every connected region and the ratio of the region's length and width. So that computer can get the areas of skin color and non skin-color, and uses white to instead of the area of face, uses black to instead of background, at last separate area of skin-color from the image.

To improve the accuracy of face localization, we also present one statistical learning method for building face recognition classifiers which is based on Ada-Boost. The face and eye is detected by means of using the Ada-Boost classifiers[15], which is widely used in the area of pattern recognition especially in the digital camera application of capturing an individual face feature. Our face detection modules is a rather standard Ada-Boost face and eye detector, trained using 50,000 near-IR face and eye examples. This design is accurate and real time for face detection and eye localization.

A driver's picture is detected by the face of classifier. Then the eye is detected successfully by Ada-Boost classifiers. But we can see that some errors could find out, for example eyebrows, nares, mouth, larger or smaller eyes. Then we should need to choose the right rectangle which contains eyes accurately. By limiting the conditions, the eye is detected accurately.We can find out the effect is good and the Ada-Boost classifiers enables accurate and fast detection of faces and eyes. we take color segmentation which is divided in $YCbCr$ color space. This method is better to retain the characteristics of face and conforms the position of eye. Then the picture element is skin element.

As we known, the eye's color is different with skin's color. So we can easy to divide the eye from the background. By retaining the black pixels and processing the picture, Eye regional and some inference such as eyebrows, the isolated small point and glitch regional value is 255 and the background region is 255.

3.3. Eye state analysis

After we have been process the eye above, we should calculate the height H and width W of the eye, then we get the rate μ . The formula is

$$\mu = \frac{H}{W} * 100\% \tag{2}$$

The eye-height H and eye-width W is marked in Figure 4. We find the first white pixel point from the left and right respectively, then we get the coordinate of these two point and connect them. If the size of the middle pixel is 0, we can judge that the upper eyelid is concave, else the upper eyelid is convex.

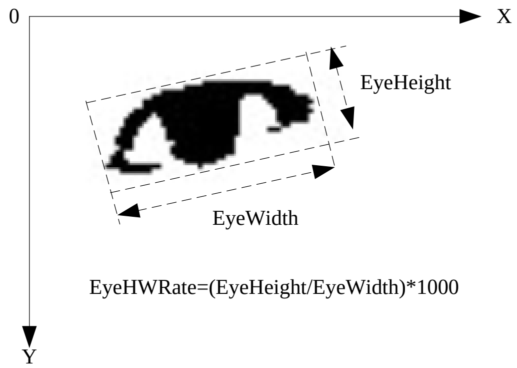


Figure 4. The ratio of eye-height and eye-width

If $\mu < 27\%$, the eye is identified as close. Then if $27\% \le \mu \le 45\%$, we should identify the eye state by the state of the eyelid. Else when the eyelid is concave, and $\mu < 40\%$, we should identify the eye is close or squint. When the eyelid is convex, and $\mu \ge 40\%$, we should identify the eye is open.

Eyelid movements are some of the visual behaviors that reflect a person's level of fatigue. There are several ocular measures to characterize eyelid movements such as eye closure duration, blink frequency, fixed gaze, eye closure/opening speed, and the PERCLOS [14], [15]. The last measure indicates the accumulative eye closure duration over time, excluding the time spent on normal eye blinks. It has been found to be the most valid ocular parameter for characterizing driver fatigue [9]. By recording the times of the eyes of open and close ,and the time of start and ending to calculate the PERCLOS which we can detect yawning.

The PERCLOS (Percentage of Eyelid Closure Over the Pupil Over Time) principle is used to eye state analysis. PERCLOS is the mean of in the unit time the eye closed time occupies proportion. PERCLOS has been validated and found to be the most valid ocular parameter for monitoring fatigue [2]-[6]. The eye closure opening speed is a good indicator of fatigue. It’s defined as the amount of time needed to fully close the eyes or to fully open the eyes. Our previous study indicates that the eye closure speed of a fatigue person is distinctively different from that of an alert person. The degree of eye opening is characterized by the shape of pupil. It is observed that as eyes close, the pupils start getting occluded by the eyelids and their shapes get more elliptical. So, we can use the ratio of pupil ellipse axes to characterize the degree of eye opening. The cumulative eye closure duration excluding the time spent on normal eye blinks is used to compute PERCLOS. To obtain a more robust measurement for these two parameters, we compute their running average (time tracking). To obtain running average of PERCLOS measurement, for example, the program continuously tracks the person's pupil shape and monitors eye closure at each time instance. We compute these two parameters in 30 seconds window and output them onto the computer screen in real time, so we can easily analyze the alert state of the driver. Figure 5 illustrates the measurement principle of the PERCLOS: t_1 to t_4 are used to measure the value of PERCLOS. The formula is:

$$\eta = \frac{t_3 - t_2}{t_4 - t_1} * 100\% \tag{3}$$

The η is the value of PERCLOS, t_1, t_2 are the time that eyes closed from the largest to 80 percent, from 80 % to 20 %; t_3 is the time from 20% closed to 20% open, t_4 is the amount of time spent that that eyes open from 20% to 0%. When used this method to measure state of eyes we use camera to get the image of driver's face, then we position eyes through image processing methods, at last we analysis and identify the image to confirm that the eyes are open or closed. Define that eyes pupil level with greater than 20% is open state.

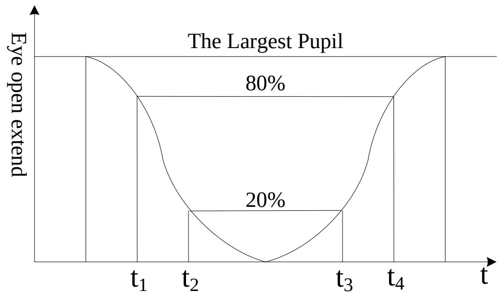


Figure 5. PERCLOS principle

3.4. Mouth texture detection using edge detection and yawning analysis

Yawning is also an important feature that can provide a visual clue in order to detect driver fatigue. When yawning, mouths open widely and the geometric features of the mouth change obviously. In this system, we propose a Gabor wavelet feature based texture detection approach for mouth feature selection [16].

There are three states of mouth: close, open normally and yawning. Basically, driver's mouth is in close state during the normal driving processing. Driver's mouth opens normally when driver talks. And driver's mouth opens widely when the driver is yawning. Therefore, we can detect yawning according to the openness of mouth. If the ratio of mouth height and width is above 0.5, we think the driver is yawning. And if the ratio is above 0.5 in more than 6 frames, we think the driver is fatigued.

In order to verify the effect of driver fatigue detection, we simulate the driver fatigue in the laboratory. There are 10 peoples are in different light conditions (morning, afternoon, evening) and on the different states (awake, fatigue), which are detected 10 times. The PERCLOS results are quite good. It has been found to be a robust ocular parameter for characterizing driver fatigue.

Because of its utility in easily characterizing the texture differences in the images using its frequency and orientation representations, Gabor wavelets filters [17] have been found to be particularly appropriate for texture representation and discrimination. The Gabor filters-based features, directly extracted from gray-level images, have been successfully and widely applied to texture segmentation, handwritten numerals recognition and fingerprint recognition. Use of Gabor filter in solving edge detection problem was experimented based on the assumption that an edge map should have both intensity and texture edges. As we know, texture edge is defined as image locations with a sudden change in the textural properties. In order to get information of yawning, we apply a 2-D Gabor filter for mouth texture detection, which has been a popular tool in medical image classification, texture analysis and discrimination. In using Gabor filter the challenge is to optimally capture texture information in the intermediate responses and eventually compute the significant edge information using global texture properties.

A Gabor function in the spatial domain is a sinusoidal modulated Gaussian. The impulse response for the imaginary part of Gabor filter [18] is given as

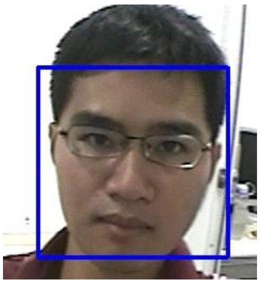
$$
\begin{gathered}
h(x,y)=\frac{1}{2\pi\cdot r\cdot g}\exp\left\{-\frac{1}{2}[\frac{x_\theta^2}{r^2}+\frac{y_\theta^2}{g^2}]\right\}\cdot\exp(j\cdot 2\pi\cdot f_0\cdot x_\theta)\\
x_\theta = x\cdot\cos\theta + y\cdot\sin\theta\\
y_\theta = -x\cdot\sin\theta + y\cdot\cos\theta
\end{gathered} \tag{4}
$$

where f_0 is the central frequency of a sinusoidal plane wave, θ is the anti-clockwise rotation of the Gaussian and the plane wave, r is the sharpness of the Gaussian along the major axis parallel to the wave, and g is the sharpness of the Gaussian minor axis perpendicular to the wave.

4. Experiment Results

CCD color camera and computer (EC3-1698 Industrial Computer board, G084SN03 8.4 inch SVGA Color TFT LCD Module, 256memory, and 30 G Hard disk) are used. There is an IR illuminator in the experiment room. It deals with real-time videos in the experiment. After acquiring the video file, it is converted into consecutive frames of image which is as show in Figure 6(a). The skin color based algorithm is implied to detect the face portion of the face which is as shown in Figure 6(b) and (c). Figure 7 is the results of the face detection and eye localization using Ada-Boost classifier. Figure 8 illustrates the bright/dark pupil effect.

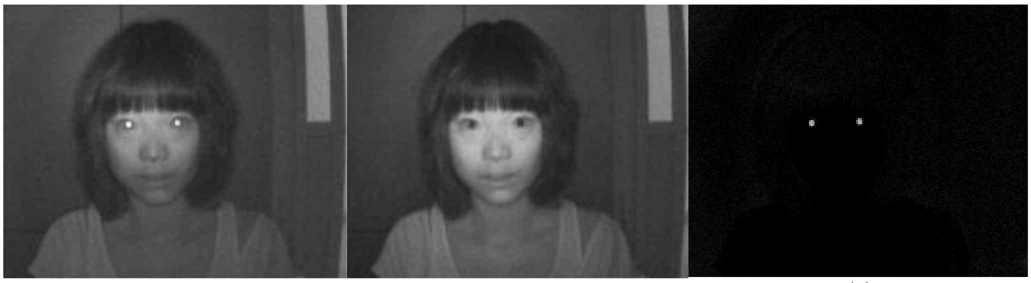
Figure 6.Face Localization using the skin color based algorithm



(a)

(b)

Figure 7.Face detection (a) and eye localization (b)using AdaBoost classifier



(a) (b) (c)

Figure 8.The bright pupil image(a) dark pupil image (b) and difference image (c) of the red-eye effect

In this experiment, the result can prove that a way through η and concave or convex of the eyelid to judge the fatigue diction is feasible. What's more, the algorithm is simple, a short calculation and high accuracy. It can meet the real-time, non-contact, sensitivity and reliability. In order to test the proposed driver fatigue monitoring system and the algorithm, different people and their different state are tested. The experiment results are indicated in table I.

Table I. Experiment results

Number of People	**300 Fatigue driver**		**300 conscious driver**		**Total**	
State of identify	Successful	Failure	Successful	Failure	Successful	Failure
Number of People	272	28	280	20	552	48
Ratio	90.67%	9.33%	93.33%	6.67%	92%	8%

5. DISCUSSION

In this paper, a real time monitoring system that makes use of eye state analysis and yawning to measure the level of inattentiveness of driver is proposed. First, skin color classification and Ada-Boost classifiers are used for face and eye localization in our driver fatigue detection system. Then the red-eye effect and texture detection method are proposed to detect the character of eyes and mouth. At last, we judge the state of the driver according to some guidelines such as PERCLOS and the ratio of eye-height and eye-width. With the use of IR illuminator, the system works robustly in low light level environments. Experiment results demonstrated that the proposed system and algorithm can achieve good performance. However, results can be improved. Some technique must be incorporated to solve this problem such as the driver is wearing dark glasses, the driver puts hand on his mouth while yawning and so on.

Acknowledgments

This work was supported by The Natural Science Foundation of Fujian Province, China under Grants 2009J05155. It was also supported by “211 Project” on information technology of Xiamen University, National Natural Science Foundation of China (Grant No.61001142 and No.61071150), Natural Science Foundation of Fujian Province, China (Grant No.2009J05155) and Fundamental Research Funds for the Central Universities. The authors would like to thank the unknown reviewers for their valuable suggestions and critique.

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