Real Time Eye Detection and Tracking Method for Driver Assistance System

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Abstract Drowsiness and fatigue of automobile drivers reduce the drivers' abilities of vehicle control, natural reflex, recognition and perception. Such diminished vigilance level of drivers is observed at night driving or overdriving, causing accident and pose severe threat to mankind and society. Therefore it is very much necessary in this recent trend in automobile industry to incorporate driver assistance system that can detect drowsiness and fatigue of the drivers. This paper presents a nonintrusive prototype computer vision system for monitoring a driver's vigilance in realtime. Eye tracking is one of the key technologies for future driver assistance systems since human eyes contain much information about the driver's condition such as gaze, attention level, and fatigue level. One problem common to many eye tracking methods proposed so far is their sensitivity to lighting condition change. This tends to significantly limit their scope for automotive applications. This paper describes real time eye detection and tracking method that works under variable and realistic lighting conditions. It is based on a hardware system for the real-time acquisition of a driver's images using IR illuminator and the software implementation for monitoring eye that can avoid the accidents.

Keywords Vigilance level · Eye tracking · Deformable template · Edge detection · Template-based correlation · IR illuminator

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1 Introduction

The increasing number of traffic accidents due to a drivers' diminished vigilance level is a serious problem for the society. Drivers' abilities of vehicle control, natural reflex, recognition and perception decline due to drowsiness and fatigue, reducing the drivers' vigilance level. These pose serious danger to their own lives as well as lives of other people. According to the U.S. National Highway Traffic Safety Administration (NHTSA), drowsiness and falling asleep while driving are responsible for at least 100,000 automobile crashes annually [1, 2]. An annual average of roughly 40,000 nonfatal injuries and 1,550 fatalities result from these crashes. These figures only present the casualties happening during midnight to early morning, and underestimate the true level of the involvement of drowsiness because they do not include crashes during daytime hours. Vehicles with driver intelligence system that can detect drowsiness of the driver and send alarm may avert fatal accidents.

Several efforts to develop active safety systems have been reported in the literature [3–11] for reducing the number of automobile accidents due to reduced vigilance. Among deferent techniques, measurement of physiological conditions like brain waves, heart rate, and pulse rate [10, 12] yields maximum detection accuracy. However these techniques are intrusive as the sensing elements (electrodes) for measurement require physical contact with drivers causing annoyance. Less intrusive techniques like eyelid movement or gaze or head movement monitoring techniques [13] with head-mounted devices as eye tracker or special contact lens also deliver good results. These techniques, though less intrusive, are still not practically acceptable. A driver's state of vigilance can also be characterized by the behaviors of the vehicle he/she operates. Vehicle behaviors including speed, lateral position, turning angle, and moving course are good indicators of a driver's alertness level. While these techniques may be implemented non-intrusively, they are, nevertheless, subject to several limitations including the vehicle type, driver experiences, and driving conditions [4].

Fatigue in people can be easily observed by certain visual behaviors and changes in their facial features like the eyes, head, and face. The image of a person with reduced alertness level exhibits some typical visual characteristics that include slow eyelid movement [14, 15], smaller degree of eye openness (or even closed), frequent nodding [16], yawning, gaze (narrowness in the line of sight), sluggish in facial expression, and sagging posture. To make use of these visual cues, increasingly popular and non-invasive approach for monitoring fatigue is to assess a driver's vigilance level through visual observation of his/her physical conditions using a camera and state-of-the-art technologies in computer vision. Techniques using computer vision are aimed at extracting visual characteristics that typically characterize a driver's vigilance level from his/her video images. In a recent workshop [17] sponsored by the Department of Transportation (DOT) on driver's vigilance, it is concluded that computer vision represents the most promising non-invasive technology to monitor driver's vigilance.

There are many literatures reporting the fatigue monitoring systems based on active real-time image processing technique [3–7, 9, 10, 15, 18–21]. Detection of driver fatigue is primarily focused in efforts. Characterization of a driver's mental state from his facial expression is discussed by Ishii et al. [9]. A vision system from line of sight (gaze) to detect a driver's physical and mental conditions is proposed by Saito et al. [3]. A system for monitoring driving vigilance by studying the eyelid movement is described by Boverie et al. [5] and results are revealed to be very promising. A system for detection of drowsiness is explained at Ueno et al. [4] by recognizing the openness or closeness of driver's eyes and computing the degree of openness. Qiang et al. [18] describes a real-time prototype computer vision system for monitoring driver vigilance, consisting of a remotely located video CCD camera, a specially designed hardware system for real-time image acquisition and various computer vision algorithms for simultaneously, real-time and non-intrusively monitoring various visual bio-behaviors typically characterizing a driver's level of vigilance. The performance of these systems is reported to be promising and comparable to the techniques using physiological signals. This paper focuses an effort to develop a low cost hardware system that may be incorporated at dashboard of vehicles to monitor eye images movements pertaining to drowsiness of driver. The paper is organized with background theory describing various processes of eye detection, followed by proposed scheme and implementation. Finally experimental observations and results are tabulated and discussed.

2 Background Theory

To analyze the eye movement and tracking, image processing technique is employed which treats images as two dimensional signals while applying already set signal processing methods. It is a type of signal dispensation in which input is image, like video frame or photograph and output may be image or characteristics associated with that image. The images from camera are converted into digital form that are thereby enhanced and performed some filtering and logic operations on them, to extract some useful and desired information.

Methods used for eye detection and tracking rely on various prior assumptions of the image data and in general two classes of approaches exist. One common and effective approach is to exploit active illumination from infrared (IR) light emitters. Through appropriate synchronization schemes and by using the reflective properties of the pupil when exposed to near infrared light (dark or bright pupil effects) the eye can be detected and tracked effectively. In addition to controlling the light conditions, IR also plays an important role for some gaze estimation methods. Other approaches avoid the use of active illumination, and rely solely on natural light. But eye detection much difficult in absence of active illumination as some assumptions on the image data is to be made. A method based on active light is the most predominate in both research and in commercial systems. Ebisawa and Satoh [22] use a novel synchronization scheme in which the difference between images obtained from on axis and off axis light emitters are used for tracking. Kalman filtering, the Mean shift algorithm, and combinations of Kalman and mean shift filtering are applied for eye tracking. The success of these approaches is highly dependent on external light sources and the apparent size of the pupil. Efforts are made to focus on improving eye tracking under various light conditions. Sun light and glasses can seriously disturb the reflective properties of IR light.

Eye tracking and detection methods fall broadly within three categories, namely deformable templates, appearance-based, and feature-based methods. Deformable template and appearance-based methods are based on building models directly on the appearance of the eye region while the feature-based method is based on extraction of local features of the region. In general appearance models detect and track eyes based on the photometry of the eye region. A simple way of tracking eyes is through template-based correlation. Tracking is performed by correlation maximization of the target model in a search region. Grauman et al. [23] uses background subtraction and anthropomorphic constraints to initialize a correlation-based tracker. Matsumoto and Zelinsky [24] present trackers based on template matching and stereo cameras. Excellent tracking performance is reported, but the method requires a fully calibrated stereo setup and a full facial model for each user. The appearance of eye regions share commonalities across race, illumination and viewing angle. Rather than relying on a single instance of the eye region, the eye model can be constructed from a large set of training examples with varying pose and light conditions. Based on the statistics of the training set a classifier can be constructed for detection purposes over a larger set of subjects. Eye region localization by Eigen images uses a subset of the principal components of the training data to construct a low-dimensional object subspace to represent the image data. Recognition is performed by measuring distances to the object subspace. The limitations of the methods, which are purely based on detection of eyes in individual frames, are that they do not make use of prior information from previous frames which can be avoided by temporal filtering.

Deformable template-based method relies on a generic template which is matched to the image. In particular deformable templates, an eye model is constructed in which the eye is located through energy minimization. The system is to be robust to the variations of the template and the actual image for analytical approximations. Yuille et al. [25] uses statistical measures in a deformable template approach to account for statistical variations. The method uses an idealized eye consisting of two regions with uniform intensity. One region corresponds to the iris region and the other the area of the sclera. Ivins and Porrill [26] describe a method of tracking the three-dimensional motion of the iris in a video sequence. A five-parameter scalable and deformable model is developed to relate translations, rotation, scaling due to changes in eye-camera distance, and partial scaling due to expansion and contraction. The approximate positions of the eyes are then found by anthropomorphic averages. Detected eye corners are used to reduce the number of iterations of the optimization of a deformable template. This model consists of parabolas for the eyelids and a subset of a circle for iris outline. A speedup is obtained compared to Yuille et al. [25] by exploiting the positions of the corners of the eye. This method requires the presence of four corners on the eye, which, in turn, only occur if the iris is partially occluded by the upper eyelid. When the eyes are wide open, the method fails as these corners do not exist. Combination of deformable template and edge detection is used for an extended iris mask to select edges of iris through an edge image. The template is initialized by manually locating the eye region along with its parameters. Once this is done the template is allowed to deform in an energy minimization manner. The position of the template in an initial frame is used as a starting point for deformations that are carried out in successive frames. The faces must be nearly frontal-view and the image of the eyes should be large enough to be described by the template. The deformable template-based methods seem logical and are generally accurate. They are also computationally demanding, require high contrast images and usually needs to be initialized close to the eye. While the shape and boundaries of the eye are important to model so is the texture within the regions. For example the sclera is usually white while the region of the iris is darker. Larger movements can be handled using Active Appearance Models for local optimization and a mean shift color tracker. These effectively combine pure template-based methods with appearance methods. This model shares some of the problems with template-based methods; theoretically it should be able to handle changes in light due to its statistical nature. In practice they are quite sensitive to these changes and especially light coming from the side can have a significant influence on their convergence.

Feature-based methods extract particular features such as skin-color, color distribution of the eye region. Kawato et al. [27] use a circle frequency filter and background subtraction to track the in-between eyes area and then recursively binaries a search area to locate the eyes. Sommer et al. [28] utilize Gabor filters to locate and track the features of eyes. They construct a model-based approach which controls steerable Gabor filters: The method initially locates particular edge (i.e. left corner of the iris) then use steerable Gabor filters to track the edge of the iris or the corners of the eyes. Nixon demonstrates the effectiveness of the Hough transform modeled for circles for extracting iris measurements, while the eye boundaries are modeled using an exponential function. Young et al. [29] show that using a head mounted camera and after some calibration, an ellipse model of the iris has only two degrees of freedom (corresponding to pan and tilt). They use this to build a Hough transform and active contour method for iris tracking using head mounted cameras. propose the Fast Radial Symmetry Transform for detecting eyes in which they exploit the symmetrical properties of the face. Explicit feature detection (such as edges) in eye tracking methods relies on thresholds. In general defining thresholds can be difficult since light conditions and image focus change. Therefore, methods on explicit feature detection may be vulnerable to these changes.

In this paper real time eye detection and tracking method is presented that works under variable and realistic lighting conditions which is applicable to driver assistance systems. Eye tracking is one of the key technologies for future driver assistance systems since human eyes contain much information about the driver's condition such as gaze, attention level, and fatigue level. Thus, non-intrusive methods for eye detection and tracking are important for many applications of vision-based driver-automotive interaction. One common problem to many eye tracking methods is their sensitivity due to lighting condition change. This tends to significantly limit the scope for automotive applications. By combining image processing and IR light the proposed method can robustly track eyes.

3 Proposed Scheme

To detect and track eye images with complex background, distinctive features of user eye are used. Generally, an eye-tracking and detection system can be divided into four steps: (i) Face detection, (ii) Eye region detection, (iii) Pupil detection and (iv) Eye tracking.

Image processing technique is incorporated for detection of these. Figure 1 illustrates the scheme. Camera is incorporated in the dashboard of vehicle which takes the images of the driver regularly at certain interval. From the images first the face portion is recognized from the complex background. It is followed by eye region detection and thereafter the pupil or eyelid detection. The detection algorithm finally detects the eyelid movement or closeness and openness of eyes. In the proposed method, eye detection and tracking are applied on testing sets, gathered from different images of face data with complex backgrounds. This method combines the location and detection algorithm with the grey prediction for eye tracking.

The accuracy and robustness of the system depends on consistency of image acquisition of the driver face in real time under variable and complex background. For this purpose the driver's face is illuminated using a near-infrared (NIR) illuminator. It serves three purposes:

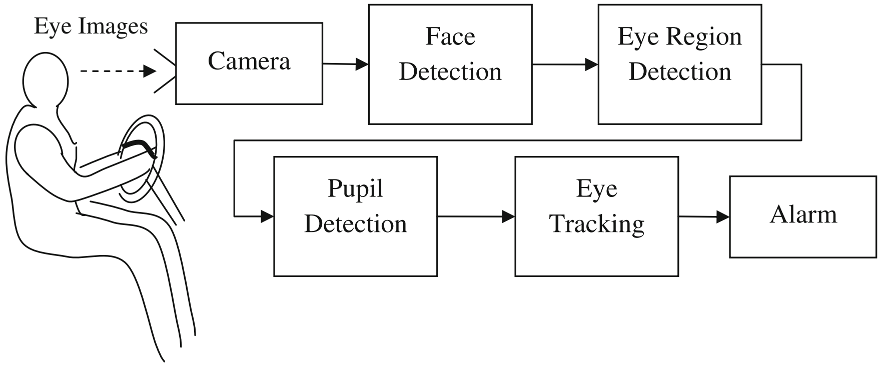

Fig. 1 Image acquisition scheme

- It minimizes the impact of different ambient light conditions, and hence the image quality is ensured under varying real-world conditions including poor illumination, day, and night;
- It allows producing the bright pupil effect, which constitutes the foundation for detection and tracking the visual cues.
- As the near-infrared illuminator is barely visible to the driver, any interference with the driver's driving will be minimized.

If the eyes are illuminated with a NIR illuminator at certain wavelength beaming light along the camera optical axis, a bright pupil can be obtained. At the NIR wavelength, almost all IR light is reflected from the pupils along the path back to the camera. Thus bright pupil effect is produced which is very much similar to the red eye effect in photography. The pupils appear dark if illuminated off the camera optical axis, since the reflected light will not enter the camera lens which is called dark pupil effect. It is physically difficult to place IR light-emitting diodes (LEDs) as illuminators along the optical axis since it may block the view of the camera, limiting the camera's operational field of view. Therefore quite a few numbers of IR illuminator LEDs are placed evenly and symmetrically along the circumference of two coplanar concentric rings, the center of both rings coincides with the camera optical axis as shown at Fig. 2. In the proposed scheme, the camera acquires the images of face of the driver at certain interval. Every time the image is analyzed and bright pupil effect is detected. Whenever dark pupil effect is detected i.e., eyelid is at closed condition at prolonged time, it may be assumed that driver's vigilance level has been diminished. Subsequently alarm is activated to draw the attention of the driver.

Fig. 2 IR illuminator with camera

4 Implementation

A laboratory model has been developed to implement above scheme. A web camera with IR illuminators has been employed focusing the face region of a person (driver) to acquire the images of face. The acquired image signal is fed to Data Acquisition Card and subsequently to a microcontroller. The microcontroller analyses the images and detects the pupil characteristics. If the eyelid is closed for several seconds, it may be assumed that the drowsiness occurred to the person and alarm is activated by the microcontroller. The circuit scheme is shown at Fig. 3. Microcontroller ATMEGA 8 is employed here in association with voltage regulator IC 7805 and driver IC L2930 for buzzer.

To find the position of pupil, first, face region must be separated from the rest of the image using *boundaries* function, which is a process of segmentation. This will cause the images background to be non-effective. *Region prop* technique is used to separate a region from total face and the region containing eyes and eyebrow. This will result in decreasing the computational complexity. Finally, in proposed method points with the highest values are selected as the eye candidate's using *centroid* function. The eye region is well detected among these points. If eye is detected then the next frame is simulated, and if the eye is not detected then a signal is passed to the micro controller for raising the alarm. The indicator also turns red. And when the eye is detected the indicator turns green with raising no alarm. This is how the system can awake the driver in long drive or in fatigue condition. The implementation flow chart is given at Fig. 4.

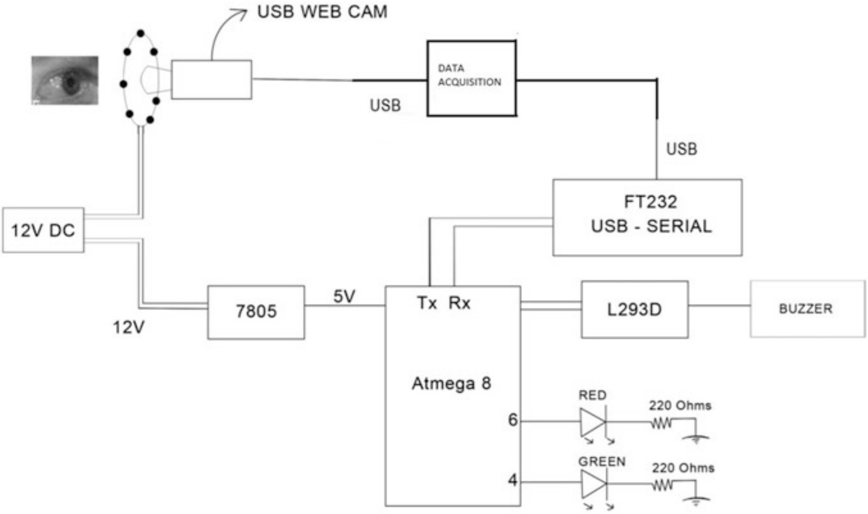

Fig. 3 Circuit scheme

Fig. 4 Flow chart

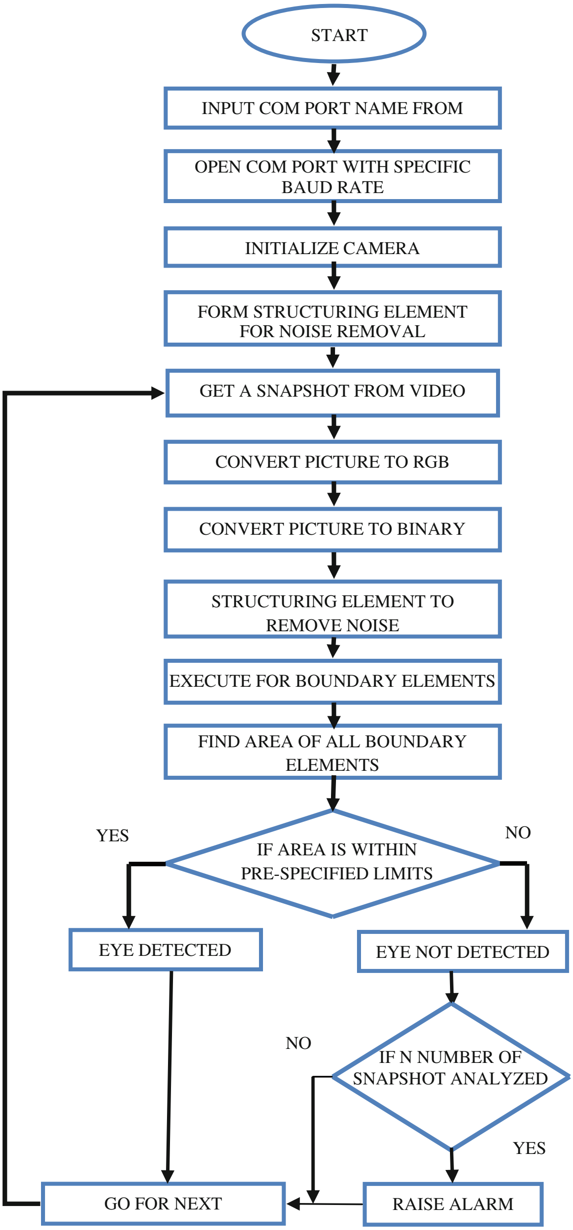

Fig. 5 Experimental results

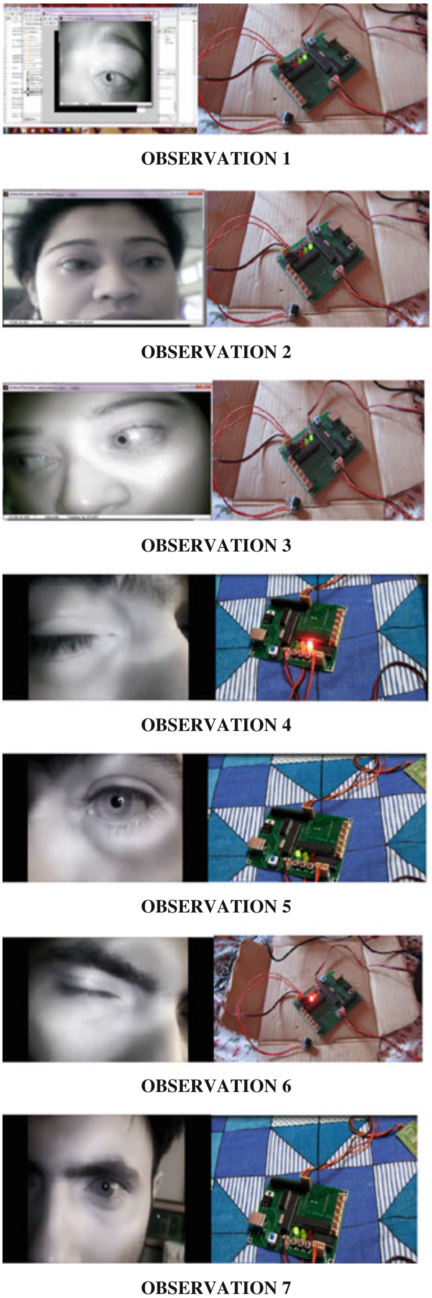

Table 1 Observations on alarm conditions with respect to the eye condition

	Eye condition	Alarm condition
Observation 1	Open	Green LED is ON. No buzzer
Observation 2	Open	Green LED is ON. No buzzer
Observation 3	Open (at night)	Green LED is ON. No buzzer
Observation 4	Closed	Red LED is ON. Buzzer raise the alarm
Observation 5	Open	Green LED is ON. No buzzer
Observation 6	Closed	Red LED is ON. Buzzer raise the alarm
Observation 7	Open	Green LED is ON. No buzzer

5 Observations

Experiments have been carried out on different person and different time. These indicate the high correct detection rate which is indicative of the method's superiority and high robustness. In the experimental set up two different colors of LEDs —Red and Green are used to indicate fatigue condition (closed eyes) and normal condition (open eyes) respectively. A buzzer is also incorporated whenever fatigue condition is detected. The experimental results for image sequence of eye tracking are given at Fig. 5, and observations on alarm conditions with respect to the eye condition are also tabulated at Table 1. It may be noticed that at closed eye condition the Red LED glows as well as buzzer is activated. These observations show that the model can track eye region robustly and correctly and can avoid the accident as well.

6 Discussions

The experimental model as developed in the laboratory is of minimum complexities. Experiments and observations have been carried out at different time, person and environmental condition that prove its good robust performance. It is helpful in driver vigilance and accident avoidance system. However the performance and effectiveness of the project depends on the quality of the camera and finding out the threshold while removing noise from the acquired picture.

In this model the alarming system is only to alert the driver. The system can be integrated with brake and accelerator system of the vehicle. Also this alarming system may be attached with the front end and the back end light indicator with good audible sound to alert other drivers and passer-by on that road to minimize the fatal rate.

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