

On Driver Eye Closure Recognition for Commercial Vehicles

Riad I. Hammoud, Gerald Witt, Robert Dufour, Andrew Wilhelm and Timothy Newman
Delphi E&S

Copyright © 2008 SAE International

ABSTRACT

This paper addresses the issue of driving while drowsy and proposes a passive eye monitoring-based driver eye closure recognition system. It reviews the core algorithmic building blocks of this system along with in-depth analysis of operational test field characteristics. The system operates equally in both day and night-time. It automatically finds the drivers eyes in the images, tracks the eye location in a wide range of head and eye motion, and estimates in real-time the eye state as either open or closed eye, and further infers to driver drowsiness state. This paper reports as well the experimental results on a diverse and challenging set of subjects and environmental driving conditions.

1. INTRODUCTION

Driving while drowsy compromises safe driving! The driving performance of drowsy drivers only gets worse, leading eventually to a loss of control of the vehicle, which in turn inflicts calamities and serious damages. At least 8-10% of single vehicle run-off-the road crashes have been contributed to drivers' drowsiness [3].

Drowsiness (or fatigue) is a kind of neurobiological need forcing drivers to fall asleep (micro-sleep event) at the wheel. These sleep events take place when drivers are sleepdeprived, being behind the wheel for a long while, or have taken some sort of drugs, medicine, or alcohol. Regardless of the cause of drowsiness, there are number of unique behavioral indications preceding the onset of sleep including slow eyelid closures, increased number and duration of eye blinks, reduced pupil diameter, head nodding, excessive yawning, slowdown of breathing and heart rate, decline of muscle tone and body temperature, electromyogram (EMG) shift to lower frequencies and higher amplitude, increase of electroencephalogram (EEG) alpha waves, and struggling to fight sleep and stay awake [5, 8, 9, 32, 26, 15].

1.1. Driver drowsiness - Problem size

For over a decade, driver drowsiness (or driver fatigue) has been widely recognized as a major contributor to highway crashes. The National Highway Transportation Safety Administration (NHTSA) has estimated that driver

drowsiness is the primary cause in 100; 000 police reported crashes, resulting in 76; 000 injuries and 1; 500 deaths annually in the U.S.A. These numbers represent 1-3% of all police reported crashes and approximately 4% of fatalities [22, 37]. Based on the 100-car Naturalistic Driving study sponsored by NHTSA, 22 24% of crashes and near-crashes can be attributable to driver drowsiness [21]. Klauer et al. [21] revealed that driver drowsiness increases the likelihood of crashes or near crashes by 4- 6 fold. In a 2003 interview with 4; 010 drivers in the U.S.A., 37% of the drivers reported having nodded off while driving at some point in their lives and 29% of these drivers reported having experienced this problem within the past year [30]. In a 2006 survey with 750 drivers in the province of Ontario, Canada, nearly 60% of the drivers admitted driving while drowsy or fatigued at least sometimes, and 15% reported falling asleep while driving during the past year [35]. Based on 2001 Crashworthiness Data System (CDS) data, Eby and Kostyniuk [7] reported that 4.4% of crashes are attributed to driver drowsiness. This statistic would be considerably higher if 55.6% of the unknown cases were excluded from the analysis. In Australia, approximately 6% of crashes may be attributable to driver drowsiness and fatigue [10]. In England, up to 16- 20% of police reported vehicle crashes are related to driver drowsiness and fatigue [18].

1.2. Drowsiness detection technologies

Early attempts to detect drowsiness have relied on active sensors. Papadelis et al. showed that some Electroencephalography (EEG) observations indicate changes in brain activities prior to a drowsiness state during night-time driving [27]. Lin et al. [24] proposed an Electroencephalography-based drowsiness detection system for safety driving using independent component analysis. Active sensors are invasive and further they could generate noisy signals and hence they are not easy to interpret.

Passive sensors could be less accurate than active sensors, yet more suitable for the driving environment. Many camera-based systems have been developed to compute eye closure and blink rate from which drowsiness state is inferred [38, 28]. In [4], a fuzzy integral based information fusion technique is proposed to combine drivers' eye closure and eye blinks. Yang et

al. [40] utilized a neural network to fuse eye closures and mouth data.

Such eye-tracking based drowsiness detection systems are promising, yet a number of challenges are still ahead to overcome. Along with the limitations of digital video analytic methods in tolerating the diversity of appearance of the eyes among subjects, researchers and algorithm developers are often constrained to work with a low-cost mono-camera system and an automotive-grade Digital Signal Processor to keep the system cost affordable. The eye appearance varies among subjects due to both individual differences in structure and motion of eyes. The use of cosmetic products and eye-wear including both prescription and sunglasses emphasizes the issues of clutter, partial occlusion, and image noise. Different short/tall car seating positions and eye-gaze directions make the finding of a universal set of eye closure recognition thresholds even more challenging. Further, in the presence of some facial expressions like big smiles, bright sunlight, and near IR source, the eyelids get tight and the iris/sclera contrast changes drastically. These aforementioned driver fatigue product specifications and real-world issues make the development phase a true race in the eye tracking community and automotive industry.

Recent effort toward robust detection of drowsiness state consists of fusing multiple sensors data and multiple modalities including, pupil variations, head nodding, EEG data, steering wheel angle, vehicle standard lateral deviation, pulse waves, gaze direction and blink duration [12, 19, 33, 17]. While robustness may be increased, the system becomes more expensive and in some cases less practical to be installed in a motor vehicle.

1.3. Paper contribution

This paper focuses on extended eye closure recognition in near infrared imagery. It proposes a single-camera eye monitoring-based driver eye closure recognition system. It describes the core algorithmic building blocks of this system along with in-depth analysis of operational test field characteristics. The system operates equally in both day and night-time. It automatically finds the drivers' eyes, tracks the eye location in a wide range of head and eye motion, and assesses in real-time the eye state as either open or closed. The proposed system in this paper utilizes a commercial off-the-shelf (COTS) infrared camera, and an automotive grade fixed-point DSP processor. The proposed algorithms have shown a high level of robustness to many eye-tracking challenges mentioned earlier.

1.4. Paper organization

Section 2 highlights different drowsiness measures based on eye closure data and their relation to Delphi AVECLOS based drowsy detection system. Section 3 reviews drivers' drowsiness detection systems along with a general overview of the proposed eye closure

detection system. A summary of the core algorithmic building blocks is provided in section 4. In section 5 we analyze the computational resources our algorithms require. The experimental setup, tracking, eye closure recognition, and extended eye closure recognition and fatigue results are detailed in section 6. Finally, the paper is concluded in section 8 after a short discussion in section 7.

2. EYE CLOSURE BASED DROWSY DRIVER MEASURES

Eye blink detection allows measurement of blink frequency, blinking rate and the rate of eye closures. These measures are often used as indicators of driver awareness while operating a vehicle [25] [34]. Erwin [8] conveyed that slow eyelid closure is the best measure of driver drowsiness. Several field operational studies and laboratory experiments [5, 9, 29, 39, 15] have revealed that among all driving performance and physiological measures that have been tested, PERCLOS is the most reliable and valid measure of driver drowsiness. When a driver becomes drowsy, the eyelids tend to droop and a smaller portion of the eyes remains visible. When the eyes are fully open, the iris and the pupil are clearly visible from the face image. If the eyes are 80% closed, only 20% of the iris or the pupil will be visible from the face image. If the eyes are 100% closed, the iris or the pupil will not be visible from the face image. The key step in the PERCLOS algorithm is measuring the percentage of eyelid closure per frame. To that end, several image processing techniques have been investigated in the literature. The common approach has two phases: (1) identify key eye components like eyelids, pupil and iris and (2) derive statistics from these key eye components including the eyelids spacing and width-height pupil and iris ratio [36] [2] [20] [1] [15].

The computation of PERCLOS often requires high resolution high-quality imagery (i.e. higher cost and narrow head motion field) and calibration, and is very sensitive to noise and drivers' appearances. Instead a simplified version of PERCLOS could be computed: the average eye closure AVECLOS. The eye is simply classified either as open or closed. The correlation between PERCLOS and AVECLOS is shown in figure 1.

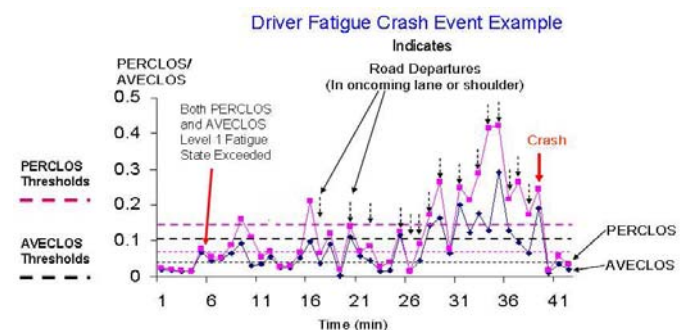


Figure 1. Correlation between Perclos and AVECLOS. Delphi validated AVECLOS measure. High correlation between AVECLOS and PERCLOS (= .95) Enables prediction of fatigue related road departures, crashes, and micro-sleeps. A proven precursor to road departures. AVECLOS will predict drowsiness before lane performance-based systems.

Our image-based eye closure recognition system, detailed in the following sections, explores multiple eye pattern cues to make a robust binary decision about the eye state, and thus it favors AVECLOS driver fatigue measure. Figure 2 illustrates Delphi AVECLOS-based drowsy driver detection system.



Figure 2. Illustration of Delphi Drowsy Driver Detection system

3. OVERVIEW OF THE PROPOSED SYSTEM

In this paper, the onset of driver drowsiness is detected through continuous monitoring of the eye closure state using a video-based driver assistance system. The rationale behind it is that a positive correlation has been found between eye closure/blink rate and drowsiness. The proposed driver assistance system (see figure 3) includes two major components: (1) a driver state sensor, and (2) a countermeasure system.

Driver state sensor. A driver state sensor gathers and processes the eye closure data and infers the drowsiness level. Our performance objective is that the sensor component shall have a high degree of reliability and validity in assessing the driver drowsiness levels. Otherwise, if the sensor has many false negatives (misses) or false positives (false alarms), the driver will not interact properly with the system.

A countermeasure component. The counter-measure component of the proposed driver assistance system determines whether or not the current drowsiness level warrants the delivery of an alert to the driver, and further how the alert should be delivered (e.g., with visual, audio, haptic, or olfactory alerts). Heeding the warnings, the driver will take certain countermeasures (e.g., taking a short nap) to reduce the drowsiness level and restore alertness. Recently, several automotive manufacturers have evaluated drowsiness mitigation systems with encouraging results [23] [36].

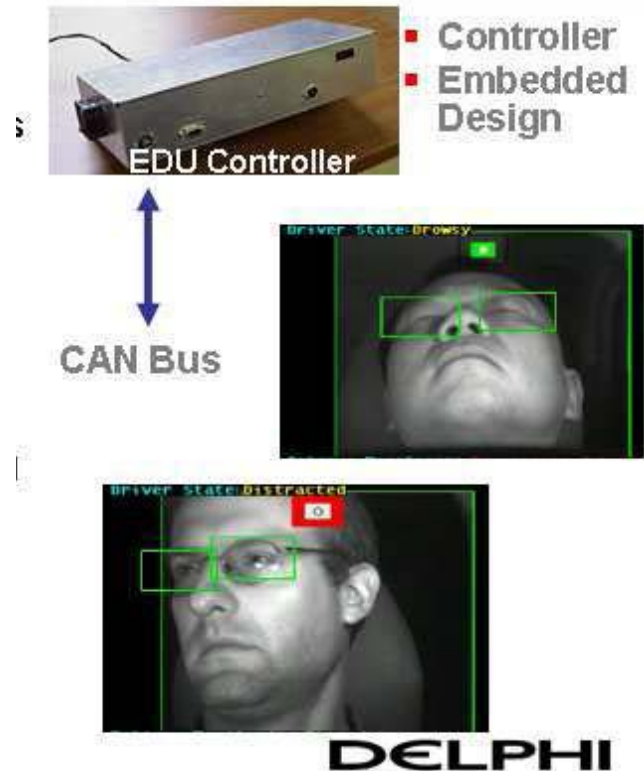
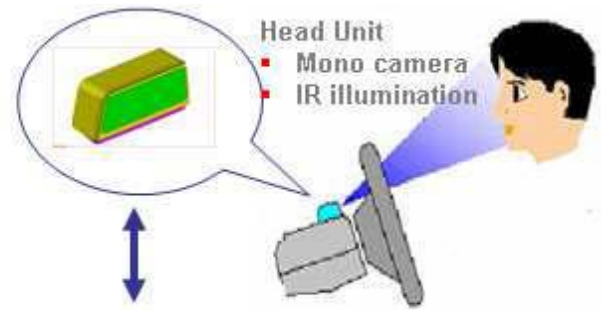


Figure 3. Integrated Driver State Monitor (Distraction & Fatigue)

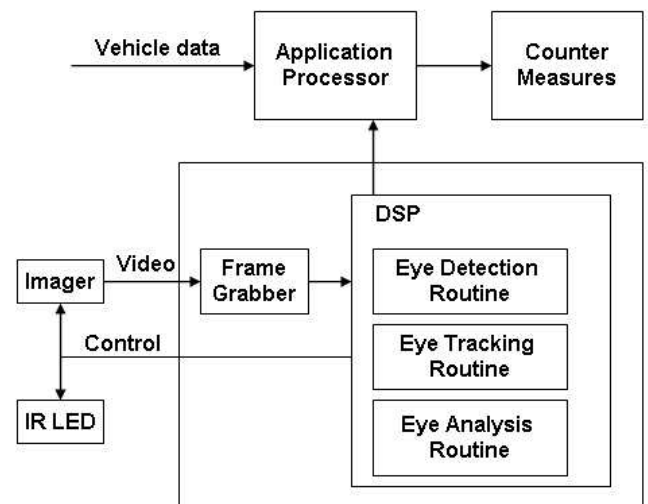


Figure 4. Block diagram of the proposed system