Driver Fatigue Detection Technology in Active Safety Systems

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***Abstract* – Driver fatigue and sleep deprivation have been widely recognized as critical safety issues that cut across all modes in the transportation industry. FMCSA, the trucking industry, highway safety advocates, and transportation researchers have all identified driver fatigue as a high-priority commercial vehicle safety issue. There has been much research work done in driver fatigue detection. This paper presents a comprehensive review of driver fatigue detection technologies in recent decades. The methods of fatigue detection mainly focused on measures of the driver's state, driver performance and the combination of the driver's state and performance. The measures of driver's state included eye state, mouth shape and head position; the measures of driver performance included lane tracking and tracking of distance between vehicles. These approaches are presented and discussed in detail. Some typical driver monitoring systems are also introduced in this paper. Finally, summary and conclusions are presented.**

Index Terms – active safety, fatigue detection, driver monitoring system.

I. Introduction

Fatigue affects mental alertness, decreasing an individual's ability to operate a vehicle safely and increasing the risk of human error that could lead to fatalities and injuries. Sleepiness slows reaction time, decreases awareness, and impairs judgment. Fatigue and sleep deprivation impact all transportation operators (airline pilots, truck drivers, and railroad engineers, for example) [1].The increasing number of traffic accidents due to a diminished driver's vigilance level has become a serious problem for society. Statistics show that between 10% and 20% of all the traffic accidents are due to drivers with a diminished vigilance level [2]. Developing systems for monitoring a driver's level of vigilance and alerting the driver, when he is drowsy and not paying adequate attention to the road, is essential to prevent accidents. The prevention of such accidents is a major focus of effort in the field of active safety research.

Fatigue measurement is a significant problem as there are few direct measures, with most measures of the outcomes of fatigue rather than of fatigue itself. These characteristics of fatigue measurement present a real problem for road safety. In the last decade many researchers have been working on the development of the monitoring systems using different techniques. The best detection accurate techniques are based on physiological phenomena like brain waves, heart rate, pulse rate and respiration. These techniques are intrusive, since they need to attach some electrodes on the drivers, causing annoyance to them. Other techniques monitor eyes and gaze movement using a helmet or special contact lens, which are still not acceptable in the practice [3]. A driver's state of vigilance can also be characterized by indirect behaviours of the vehicle like lateral position, steering wheel movements. Although these techniques are not intrusive, they are subjected to several limitations as the vehicle type, driver experience, geometric characteristics and state of the road [4]. People in fatigue show some visual behaviours easily observable from changes in their facial features like eyes, head and face. Computer vision can be a natural and non-intrusive technique to monitor driver's vigilance.

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II. Fatigue Detection Technology

The process of falling asleep at the wheel can be characterized by a gradual decline in alertness from a normal state due to monotonous driving conditions or other environmental factors; this diminished alertness leads to a state of fuzzy consciousness followed by the onset of sleep. The critical issue that a drowsiness detection system must address is the question of how to accurately and early detect drowsiness at the initial stage.

Possible techniques for detecting drowsiness in drivers can be broadly divided into three major categories:

- methods based on driver's current state, relating to the eye and eyelid movements and physiological state changes;
- methods based on driver performance, with a focus on the vehicle's behaviour including position and headway;
- methods based on combination of the driver's current state and driver performance [5].

A. Methods Based on Driver State

There has been much literature on detection of fatigue effects and the driver's current state specifically focussed on changes and movements in the eye. This includes assessing changes in visual features, such as actual eye closure, blinking rate, the direction of gaze, mouth shape. Other measurements that are capable of measuring driver physiological state are EEG and EOG recording.

Eye behaviours provide significant information about a driver's alertness and that if such visual behaviour can be measured then it will be feasible to predict a driver's state of drowsiness or attentiveness.

The work done in eye detection and tracking can be

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classified into two categories: passive appearance-based methods and the active IR (Infra-red) based methods. The former approaches detect eyes based on their different appearance from the rest of the face. Eriksson et al. present a symmetry-based approach to locate the face in gray image, and then eyes are found and tracked. Template matching is used to determine if the eyes are open or closed [6]. Singh et al. propose a non-intrusive vision-based system for the detection of driver fatigue [7]. The system uses a color video camera that points directly towards the driver's face and monitors the driver's eyes in order to detect micro-sleeps.

Wahlstrom et al. accomplish a project by using the Framework for Processing Video [8]. The monitoring software works by first finding the lips on the driver's face using color analysis. Then, the skin color of the driver can be sampled and a face region is generated. The largest holes in this region are the lips and eyes. Once the eyes are found, the software finds the darkest pixels in the eyes and marks these as the pupils. The software uses the relative positions of the eyes and pupils to make statements about the gaze direction.

Smith et al. present a system for analysing human driver alertness [9]. The system relies on estimation of global motion and color statistics to robustly track a person's head and facial features. The system classifies rotation in all viewing directions, detects eye/mouth occlusion, detects eye blinking and eye closure, and recovers the 3D gaze of the eyes.

The approaches tracking eyes based on active IR illumination utilize the special bright pupil effect. It's a simple and effective approach for pupil detection based on differential infrared lighting scheme. Many methods are based the use of infra-red light. PERCLOS methodology, a video-based method that measures eye closure, is a reliable and valid determination of a driver's alertness level [10]. Liu et al. present a real-time eye detection and tracking method that works under variable and realistic lighting conditions [11]. By combining imaging by using IR light and appearance-based object recognition techniques, the method can robustly track eyes even when the pupils are not very bright due to significant external illumination interferences. Gu et al. propose an active approach for facial feature tracking [12]. The active IR sensor is used to robustly detect pupils under variable lighting conditions.

Eye blink rate is also used as the measurement of driver fatigue. Ito et al. develop a method for measuring the blinking of a driver in real time by motion picture [13]. Fabio propose an eye blink detector which has been developed according to the Class 1 specifications of IEC 60825-1 standard on the safety of Laser and LED products in order to work until 8 h in a safety condition for the user [14].

Approximately 10 seconds before the micro-sleep event occurs, the pupil diameter shows a slowly fluctuating pattern correlated to no change in the eye-gaze coordinates. Eye-gaze data appears to contain information about micro-sleep events several seconds before the real event takes place [15]. However, it is inconvenient to get the pupil diameter so that this method is difficult to be employed in real driving conditions.

When a driver drives in a normal, talking or dozing state, his/her mouth opening degree will be quite different. According to this fact, Chu et al. use the Fisher classifier to extract the mouth shape and position, then uses the mouth region's geometry character as the feature value, then use a three-level Bp network to obtain three different spirit states [16]. Lu et al. recognize the drivers' yawn by calculating the vertical distance between them [17].

Researchers at Rensselaer Polytechnic Institute have developed a prototype computer vision system for monitoring driver vigilance [18]. The main components of the system include a remotely located CCD video camera, a specially designed hardware system for real-time image acquisition and for controlling the illuminator and alarm system, and various computer vision algorithms for simultaneous, real-time non-intrusive monitoring of various visual bio-behaviors that typically characterize a driver's level of vigilance.

The EEG algorithm which is a physiological sleepiness measure has been studied to detect drowsiness as well. A study by Lal et al. demonstrates substantial relationships between an EEG algorithm for detecting fatigue and drowsiness under simulated conditions [19]. Noguchi et al. demonstrate the possibility of assessing driver's arousal level by using the results of EOG waveform to analyse blinking image sequences [20].

B. Methods Based on Driver Performance

Studies on driver performance have mainly employed lane tracking alone or in combination with tracking of the distance between the driver's vehicle and the car in front.

In [21], driver state assessment is considered in the context of a road departure warning and intervention system. A system identification approach, using vehicle lateral position as the input and steering wheel position as the output, is used to develop a model and to continually update its parameters during driving. Driving simulator results indicate that changes in the bandwidth and/or parameters of such a model may be useful indicators of driver fatigue. Bertozzi et al. develop a lane tracking device based on geometrical transform and morphological processing. The system can detect roadway lines on flat and structured roads under low lighting conditions [22]. Wijesoma et al. use two-dimensional ladar sensing and extended Kalman filtering for fast detection and tracking of road curbs [23]. A group at the Australian National University has developed a more sophisticated approach using multiple roadway cues to detect the location of the vehicle in the lane under varying roadway conditions [24]. Hardzeyeu et al. propose a video-based Hough-Transform driven objects detection algorithms and their applications for lane departure warnings [25]. Kim et al. propose a driver's fatigue detection system which uses the driver's pedal controlling pattern with respect to the driver's front view situation. The driver's fatigue level can be obtained t based on the response patterns [26].

Generally, the measure of driver performance is promising as driver fatigue detection devices. These methods are not attempting to detect driver fatigue directly, but the effects of changes in the driver's state that are significant for road safety. One problem is micro-sleeps: when a drowsy driver falls asleep for some seconds on a very straight road section without changing the lateral position of the vehicle. Such happenings would not be detectable by a system only based on lane-position measure.

C. Methods Based on Driver State and Performance

According to the analyses above, the approaches that combine driver state and driver performance will improve the sensibility and reliability in fatigue detection. Rimini-Doering et al. use a range of measures to detect driver fatigue [27]. They use eye-closure, lane tracking and changes in physiological state to predict fatigue-related crashes. Chang et al. propose a new safety determination criterion that combines the data of eyes detection and lane detection [28].

The European Union has completed an ambitious project called AWAKE (System for Effective Assessment of Driver Vigilance and Warning According to Traffic Risk Estimation) [29]. The aim of this project is to demonstrate the technological feasibility of driver vigilance monitoring systems and to look at the non-technical issues that can influence the use of such systems. The project employs driver state measures including eyelid movement, changes in steering grip and driver behaviour including lane tracking, use of accelerator and brake and steering position. These measures are then combined and evaluated against an assessment of current traffic risk obtained from digital navigation maps, anti-collision devices, driver gaze sensors and odometer readings. The project has produced a series of design guidelines for the assessment of driver vigilance and warning signals. These guidelines are comprehensive and will have considerable impact on the implementation of fatigue detection devices in the future.

III. DRIVER MONITORING SYSTEM

Research work on driver fatigue detection has yielded many driver monitoring systems. All of these systems focus on providing information to drivers that will facilitate their driving and increase traffic safety. Some typical systems are given below.

Copilot is a drowsy driver monitor developed by Robotics Institute in Carnegie Mellon University [30]. The Copilot is a video-based system for measuring slow eyelid closure as represented by PERCLOS. The monitor is small and easy to use, providing an effective research tool for the field or in the laboratory.

FaceLAB is a tool that can be used to measure driver visual behaviour, including fatigue and inattention [31, 1]. The video images from the camera pair are processed in real-time by optimised software that matches specific features from left and right images to determine the 3D position of each feature. A least squares optimisation is performed using the set of matched features to determine the exact 3D pose of the head. The faceLAB software also processes the images of eyes in parallel to determine eye gaze measurement data, and monitors the eyelids to determine eye openings and blink rates. It has the apparent advantage of being able to cope with low light conditions, head movement and tracking of gaze direction while the driver is wearing sunglasses. The PC-based version of faceLAB is shown in Fig.1. The two-camera system installed in a vehicle for road testing is shown in Fig.2. The two cameras and the IR illuminator are clearly visible mounted on the dashboard above the steering wheel. The newest version is faceLab5.

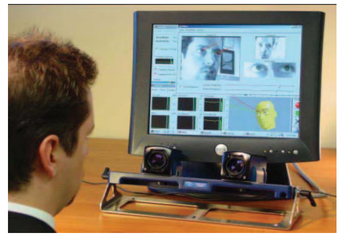

Figure 1. faceLAB

Figure 2. faceLAB installation in vehicle

SensoMotoric Instruments GmbH (SMI) develop InSight, an advanced, non-invasive, computer-vision-based operator monitoring system that measures head position and orientation, gaze direction, eyelid opening, and pupil position and diameter [1]. Fig. 3 shows the InSight system setup for in-vehicle driver monitoring.

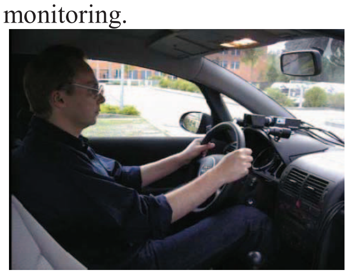

Figure 3. SMI InSight Driver Monitoring System

In the main, the road safety problems for these systems are the same, relating mainly to when and how the information is sent to the driver. Work by a group of researchers at Carnegie Mellon University has looked at the attitudes of experts and users towards fatigue detection devices and the type of information that will be most readily accepted by users [32]. The findings suggest that warning devices should be able to be turned off or have their volume modified significantly, clearly reducing their effectiveness. The AWAKE project conclude that drivers should be trained in appropriately responding to warning devices, especially if they occur infrequently as this may result in the problem of startle effects which can negatively affect driver safety. Further research is needed on different approaches to providing warning to drivers of increased safety risk. Other approaches to driver assistance and warning signals which have been evaluated include vibration of the seat and force feedback through the steering wheel in response to lane deviations. DAS (Driver Assistance System) includes a force feedback component administered through the steering wheel [33]. The degree of vibrotactile stimulation given is proportional to the extent of lateral deviation of the vehicle which provides both a warning to the driver and encourages them to correct the lane deviation.

IV. SUMMARY AND CONCLUSIONS

This paper attempts to present a comprehensive review of research work on driver fatigue detection. The goal of fatigue detection technologies for drivers is to provide effective methods to improve driving safety. The fatigue monitoring devices have to be more accurate than drivers' own self reports if they are going to be used in vehicles to improve driving safety. If drivers learn to rely on the technology for they believe it is accurate, then the failure of warning may be a catastrophe for drivers. If the driver believe that the device is misleading them it will be ignored totally, even if an unsafe fatigue is detected, which also can cause an accident. Furthermore, if the warning occurs early enough in the development of fatigue, such devices can enhance driver alertness sufficient to avoid a collision, although many of the devices currently under development.

Some of the problems with the fatigue detection systems currently under development include the stage of drowsiness being detected and the combination of different measures. More research and development is needed before effective fatigue monitoring systems are standard features in on-road vehicles.

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