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Driver Fatigue Detection: A Survey

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Abstract **– Driver fatigue is an important factor in a large number of accidents. There has been much work done in driver fatigue detection. This paper presents a comprehensive survey of research on driver fatigue detection and provides structural categories for the methods which have been proposed. 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 PERCLOS, 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 – driver fatigue, fatigue detection, driver monitoring system.

I. Introduction

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 [1]. Furthermore, accidents related to driver hypo-vigilance are more serious than other types of accidents, since sleepy drivers often do not take evasive action prior to a collision. For this reason, 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. Probably the only direct measure of fatigue involves self-reports of internal states, however there are a number of problems in using any self-report measure due to the influence of demand effects or motivational influences [2]. 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. Some representative projects in this line are the MIT Smart Car [3], and the ASV (Advanced Safety Vehicle) project performed by Toyota, Nissan [4]. Other techniques monitor eyes and gaze movement using a helmet or special contact lens, which are still not acceptable in the practice [5]. 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 [6]. 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.

The rest of this paper is organized as follows: Section 2 provides a detailed survey of different fatigue detection methods. In Section 3, some typical driver monitoring systems are provided and discussed. Finally, summary and conclusions are presented in Section 4.

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 [2].

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 the driver's direction of gaze, blinking rate and actual eye closure. Other measurements that are capable of measuring driver physiological state are also proposed.

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Examples of these are: mouth shape, head position and EEG recording. A detail presentation is given below.

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, vigilance or attentiveness.

The work done in face and eye detection and tracking can be 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. Generally they consist of two steps: locating face to extract eye regions and then eye detection from eye windows. The face detection problem has been faced up with different approaches: neural network, principal components, independent components, and skin color based methods.

Eriksson and Papanikolopoulos present a system to locate and track eyes of the driver. They use 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 [7]. Singh and Papanikolopoulos propose a non-intrusive vision-based system for the detection of driver fatigue [8]. 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. The system deals with skin color information in order to search for the face in the input space. After segmenting the pixels with skin like color, blob processing is performed in order to determine the exact position of the face. In order to find and track the location of the pupil, they use gray scale model matching; they also use the same pattern recognition technique to determine whether the eye is open or closed. If the eyes remain closed for an abnormal period of time (5-6 sec), the system draws the conclusion that the person is falling asleep and issues a warning signal. Wahlstrom, Masoud, and Papanikolopoulos accomplish a project by using the Framework for Processing Video [9]. 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, Shah, and Lobo present a system for analysing human driver alertness [10], [11]. 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. In addition, the system is able to track both through occlusions due to eye blinking, and eye closure, large mouth movement, and also through occlusion due to rotation.

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. The high contrast between the pupils and the rest of the face can significantly improve the eye tracking robustness and accuracy. Fig.1 shows the pupil detecting result in [12]. Many methods are based the use of infra-red light.

PERCLOS (Percent Eye Closure) methodology, a video-based method that measures eye closure, is a reliable and valid determination of a driver's alertness level. PERCLOS is the proportion of total time that the driver's eyelids are closed 80% or more and reflects slow eyelid closures rather than blinks [13]. The approach obtains two images of the driver. The first image is acquired using an infrared illumination source at 850 nm that produces a distinct glowing of the driver's pupils (the red-eye effect). The second image uses a 950 nm infrared illumination source that produces an image with dark pupils. These two images are identical except for the brightness of the pupils in the image. Dinges, Mallis, Maislin and Powell evaluate the system against a number of different performance measures. PERCLOS shows the clearest relationship with performance on a driving simulator compared to a number of other potential drowsiness detection devices including two electroencephalographic (EEG) algorithms, a head tracker device, and two wearable eye-blink monitors [13]. Grace and other researchers in Carnegie Mellon Research Institute develop a video-based system that measures PERCLOS [14].

Liu, Xu and Fujimura present a real-time eye detection and tracking method that works under variable and realistic lighting conditions [15]. 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. The appearance model is incorporated in both eye detection and tracking via the use of a support vector machine (SVM) and mean shift tracking. Gu, Ji and Zhu propose a active approach for facial feature tracking [16]. First, the active IR sensor is used to robustly detect pupils under variable lighting conditions. The detected pupils are then used to predict the head motion. Furthermore, face movement is assumed to be locally smooth so that a facial feature can be tracked with a Kalman filter. Local graphs consisting of identified features are extracted and used to capture the spatial relationship among detected features. Finally, a graph-based reliability propagation is proposed to tackle the occlusion problem and verify the tracking results.

Eye blink rate is also used as the measurement of driver fatigue. Ito, Mita, Kozuka, Nakano and Yamamoto develop a

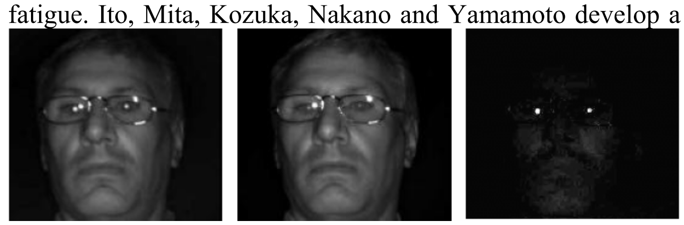

Fig.1 The difference image eliminates all image features except for the bright pupils. (a) bright-eye image (b) dark-eye image (c) difference image.

method for measuring the blinking of a driver in real time by motion picture [17].

Eye-gaze data appears to contain information about micro-sleep events several seconds before the real event takes place [18]. 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. Closer to the micro-sleep event the pupil diameter decreases and the eye-gaze coordinates are drifting until the eyes are closed. Especially interesting is the behaviour of the eye after the second eye closure event, which was cut short by an accident. Immediately after the accident, a sharp increase in the pupil diameter occurred in connection with rapid oscillations in the eye-gaze coordinates. This is the typical pattern for a person who is suddenly aroused by the accident and tries to reorient himself. 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, and put all of these features together to make up an eigenvector as the input of a three-level Bp network, then the output is obtained among three different spirit states [19].

The head position sensor system MINDS (Micro-Nod Detection System) proposed by ASCI is conceptually designed to detect micro-sleep events occurring in association with head nodding by assessing the x, y, and z coordinates of the head through conductivity measurements [20]. Driver's head is tracked in real time. The signal is correlated with the head position of the driver, then the software detector extracts head motion behaviour associated with driving while drowsy. However, micro-sleeps also occur in the absence of obvious head nodding.

There are two methodologies considered have potential for real-world applications. One is PERCLOS, which is mentioned above; another is faceLAB, which is used by Seeing Machines.

FaceLAB is a tool that can be used to measure driver visual behaviour, including fatigue and inattention [21]. It is different from most other measures of eye closure and gaze direction. A passive pair of video cameras is used in faceLAB. 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. The software locates the iris centres, then combining the eye-gaze vectors for each eye with the head pose to determine the eye-gaze direction. FaceLAB also monitors the eyelids, to determine eye openings and blink rates. The faceLAB methodology has been validated in simulated driving situations. 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 electroencephalographic (EEG) algorithm, which is a physiological sleepiness measure, has been studied to detect drowsiness as well. Most of these studies have used EEG to validate the existence of drowsiness when other measures are being evaluated rather than as a fatigue detection measure [22], [23]. A study by Lal, Craig, Boord, Kirkup and Nguyan demonstrates substantial relationships between an EEG algorithm for detecting fatigue and drowsiness under simulated conditions [24]. The biggest drawback associated with EEG as an on-road drowsiness detection device is the difficulty in obtaining recordings under natural driving conditions; making it a somewhat unrealistic option for the detection of fatigue [2].

One group of researchers has evaluated a number of measures of driver alertness in the laboratory, including head position, eye gaze, pupillary change and blink rate [18]. These studies draw the conclusion that no single measure is sufficiently sensitive and reliable enough to quantify driver fatigue. Since alertness is complex phenomenon, a multi-parametric approach needs to be used, if a robust method of fatigue detection is to be developed. Ji and Yang propose a real-time prototype computer vision system for monitoring driver vigilance [25]. The main components of the system consist of a remotely located video CCD camera, a specially designed hardware system for real-time image acquisition and for controlling the illuminator and the alarm system, and various computer vision algorithms for simultaneously, real-time and non-intrusively monitoring various visual bio-behaviours that typically characterize a driver's level of vigilance. The visual behaviours include eyelid movement, face orientation, and gaze movement (pupil movement). The use of multiple visual cues reduces the uncertainty and the ambiguity present in the information from a single source.

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 [26] and [27], 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 and Broggi 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 [28], [29]. Wijesoma, Kodogoda and Balasuriya use two-dimensional ladar sensing and extended Kalman filtering for fast detection and tracking of road curbs [30].

One of the major problems for these approaches is developing a system that can deal with large changes in the characteristics of the roadway, road quality and lighting. 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 [31]. The methodologies are applied in commercial vehicles. Lane tracking device is designed to detect when the vehicle unexpectedly crosses lane markings or the road edge. The driver is warned of the occurrence through vibration of the seat on the side where the lane infringement has occurred.

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, Manstetten, Altmueller, Ladstaetter and Mahler use a range of measures to detect driver fatigue [22]. They use eye-closure, lane tracking and changes in physiological state to predict fatigue-related crashes.

Recently, the European Union has completed an ambitious project called AWAKE (System for Effective Assessment of Driver Vigilance and Warning According to Traffic Risk Estimation) [32]. 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

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.

DAISY (Driver AssIsting System) has been developed as a monitoring and warning aid for the driver in longitudinal and lateral control on German motorways [33]. The warning messages are generated and initiated on the basis of comprehensive system knowledge about the driving situation including the behavioural state and the condition of the driver.

Copilot is a drowsy driver monitor developed by Robotics Institute in Carnegie Mellon University [12]. 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.

DAS (Driver Assistance System) has been developed by the group at the Australian National University [31]. It uses a dashboard-mounted faceLAB head-and-eye-tracking system to monitor the driver, as shown in Fig.2. The Distillation algorithm is used to monitor driver performance. Feedback on deviation in lane tracking are provided to the driver using force feedback to the steering wheel which is proportional to the amount of lateral offset estimation by the lane tracker. This novel approach clearly has some potential problems of conflict with driver intention, and will need to be evaluated very carefully before it can be implemented as a component of a functional on-road fatigue monitoring device.

FaceLAB and AWAKE, which are mentioned above are also the systems having good performance.

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 [34]. 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 mentioned

Fig.2 The Transport Research Experimental Vehicle uses two vision platforms: CeDAR(Cable Drive Active Vision Robot) and faceLAB.

above includes a force feedback component administered through the steering wheel. 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 survey of research on driver fatigue detection and to provide some structural categories for the methods described in many papers. 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.

References

[1] L.M. Bergasa, J. Nuevo, M.A. Sotalo, and M. Vazquez, "Real-time system for monitoring driver vigilance," in *Proc. Intelligent Vehicle Symp.*, Parma, Italy, pp.78-83, 2004.

[2] A. Williamson, and T. Chamberlain, "Review of on-road driver fatigue monitoring devices", unpublished.

[3] J. Healey, and R. Picard, "SmartCar: detecting driver stress," in *Proc. 15th Int. Conf. Pattern Recognition*, Barcelona, Spain, vol. 4, pp. 218-221, 2000.

[4] A. Kircher, M.Uddman, and J.Sandin, "Vehicle Control and drowsiness," Swedish National Road and Transport Research Institute, 2002.

[5] Anon, "Perclos and eyetracking: Challenge and Opportunity," Technical Report, Applied Science Laboratories, Bedford, MA, 1999.

[6] H. Ueno, M. Kaneda, and M.Tsukino "Development of drowsiness detection system," in *Proc. Vehicle Navigation and Information Systems Conf.*, pp.15-20, 1994.

[7] M. Eriksson, and N.P. Papanikotopoulos, "Eye-tracking for detection of driver fatigue," in *Proc .Int. Conf. Intelligent Transportation Systems*, Boston, pp. 314-319, 1997.

[8] S. Singh, and N.P. Papanikolopoulos, "Monitoring driver fatigue using facial analysis techniques," in *Proc. Int. Conf. Intelligent Transportation Systems*, Tokyo, Japan, pp. 314-318, 1999.

[9] E. Wahlstrom, O. Masoud, and N.P. Papanikotopoulos, "Vision-based methods for driver monitoring," in *Proc. Int. Conf. Intelligent Transportation Systems*, vol. 2, pp. 903-908, 2003.

[10] P. Smith, M. Shah, and N. da Vitoria Lobo, "Monitoring head/eye motion for driver alertness with one camera," in *Proc. 15th Int. Conf. Pattern Recognition*, Barcelona, Spain, vol. 4, pp. 636-642, 2000.

[11] P. Smith, M. Shah, and N. da Vitoria Lobo, "Determine driver visual attention with one camera," *Intelligent Transportation Systems*, vol. 4, pp. 205-218, December 2003.

[12] R. Grace, "Drowsy driver monitor and warning system," in *Proc. Int. Driving Symp. Human Factors in Driver Assessment, Training and Vehicle Design*, 2001.

[13] D.F. Dinges, and R. Grace, "PERCLOS: A valid psychophysiological measure of alertness as assessed by psychomotor vigilance," US Department of Transportation, Federal highway Administration. Publication Number FHWA-MCRT-98-006.

[14] R. Grace et al., "A drowsy driver detection system for heavy vehicle," in *Proc. 17th Digital Avionics Systems Conference*, Bellevue, USA, vol. 2, pp. I36/1-I36/8, 1998.

[15] X. Liu, F.L. Xu, and K. Fujimura, "Real-time eye detection and tracking for driver observation under various light conditions," in *Proc. Intelligent Vehicle Symp.*, Versailles, France, pp. 344-351, 2002.

[16] H. Gu, Q. Ji, and Z.W. Zhu, "Active facial tracking for fatigue detection," in *Proc. Workshop on Application of Computer Vision*, Orlando, pp. 137-142, 2002.

[17] T. Ito, S. Mita, K. Kozuka, T. Nakano, and S. Yamamoto, "Driver blink measurement by the motion picture processing and its application to drowsiness detection," in *Proc. Int. Conf. Intelligent Transportation Systems*, Singapore, pp. 168-173, 2003.

[18] A. Heitmann, and R. Guttkuhn, "Technologies for the monitoring and prevention of driver fatigue," in *Proc. Int. Driving Symp. Human Factors in Driver Assessment, Training and Vehicle Design*, pp. 81-86, 2001.

[19] J.W. Chu, L.S. Jin, B.L. Tong, S.M. Shi, and R.B. Wang, "A monitoring method of driver fatigue behavior based on machine vision," in *Proc. Intelligent Vehicle Symp.*, Parma, Italy, pp.351-356, 2004.

[20] P.W. Kithil, R.D. Jones, and M. Jone, "Development of driver alertness detection systems using overhead capacitive sensor array," SAE Technical Paper Series, 982292, SAE International, 1998.

[21] G. Longhurst, "Understanding driver visual behaviour," Seeing Machine Pty Limited, 2002.

[22] M. Rimini-Doering, D. Manstetten, T. Altmueller, U. Lasdstaetter, and M. Mahler, "Monitoring driver drowsiness and stress in a driving simulator," in *Proc. Int. Driving Symp. Human Factors in Driver Assessment, Training and Vehicle Design*, 2001.

[23] U. Svensson, "Blink behaviour based drowsiness detection," Linkoping University, Swedish National Road and Transport Research Institute, 2004.

[24] S.K.L. Lal, A. Craig, P. Boord, L. Kirkup, and H. Nguyen, "Development of an algorithm for an EEG-based driver fatigue countermeasure," Journal of Safety Research, pp. 321-328, 2003.

[25] Q. Ji, and X.J. Yang, "Real-time eye, gaze, and face pose tracking for monitoring driver vigilance," *Real-Time Imaging 8*, pp. 357-377, 2002.

[26] T. Pilutti, and A.G. Ulsoy, "On-line identification of driver state for lane-keeping tasks," in *Proc. American Control Conference*, Seattle, Washington, vol. 1, pp. 678-681, 1995.

[27] T. Pilutti, and A.G. Ulsoy, "Identification of driver state for lane-keeping tasks," *IEEE Trans. Systems, Man, and Cybernetics*, Part A, vol. 29, pp. 486-502, 1999.

[28] M. Bertozzi, and A. Broggi, "Real-time lane and obstacle detection on the GOLD system," in *Proc. Intelligent Vehicles Symp.*, Tokyo, Japan, pp. 213-218, 1996.

[29] M. Bertozzi, and A. Broggi, "GOLD: a parallel real-time stereo vision system for generic obstacle and lane detection," *IEEE Trans. Image Processing*, vol. 7, pp. 62-87, 1998.

[30] W.S. Wijesoma, K.R.S. Kodagoda, and A.P. Balasuriya, "Road boundary detection and tracking using ladar sensing," *IEEE Trans. Robotics and Automation*, vol. 20, pp. 456-464, 2004.

[31] L. Fletcher, N. Apostoloff, L. petersson, and A. Zelinsky, "Vision in and out of Vehicles," *IEEE Trans. Intelligent Transportation Systems*, pp. 12-17, 2003.

[32] S. Boveris, "Driver fatigue monitoring technologies and future ideas," in *Proc. AWAKE Road Safety Workshop*, Balocco, Italy, 2004.

[33] R. Onken, "DAISY: an adaptive knowledge-based driver monitoring and warning system," in *Proc. Vehicle Navigation and Information Systems Conf.*, pp.3-10, 1994.

[34] E.M. Ayoob, R. Grace, and A. Steinfeld, "A user-centred drowsy-driver detection and warning system," ACM, 2003.