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International Journal of Road Safety

Journal homepage: www.ijrs.my

IJRS International Journal of Road Safety

A Critical Review on Driver Fatigue Detection and Monitoring System

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ABSTRACT

This paper reviews existing and future fatigue detection and monitoring systems. Over the past few years, there has been an increase of interest in technologies, systems, and procedures to detect and monitor driver fatigue to reduce the number of road accidents. The driving activity has become more important as this medium is more practical, faster, and cheaper in connecting humans around the world. However, driving activity can cause disasters or deaths to human in daily life as they get fatigued while driving. Driver fatigue is a vital contributor to road accidents. Studies show that 80.6% of road accidents are caused by human error which includes fatigue or drowsiness. Statistics indicate the need for a reliable driver fatigue detection and monitoring system, which could alert or warn the driver before any mishaps happens. Several approaches and methods have been developed to reduce the risk of fatigue among drivers, which uses the following measures: (1) vehicle-based measures; (2) behavioural measures; (3) physiological measures; (4) psychophysical measures; and (5) biomechanical measures. In this paper, the authors briefly review the literature on fatigue detection and monitoring systems. The findings from this review are discussed in the light of directions for future studies and the development of fatigue countermeasures.

ARTICLE INFO

Article History:
Received 20 Sep 2020
Received in revised form
15 Oct 2020
Accepted
28 Oct 2020
Available online
01 Nov 2020

Keywords:
Driver Fatigue
Monitoring System
Detection System
Road Accidents
Road Safety

1. Introduction

Fatigue is a feeling of extreme physical or mental tiredness Physical fatigue is a phenomenon of reduced performance of a muscle after stress. It is characterized by the reduction of muscular power and movement, which contributes to impaired coordination and increase chances of mistakes and accidents. Mental fatigue is associated with a disinclination of effort, reduced efficiency and alertness, and impaired mental performance. Driver's fatigue causes the driver to be discomfort during driving, and reduction of motor control and strength capability that leads to performance decrease (Yung, 2016) and increase the risk of road accidents and human error which contribute to 80.6% of accidents in Malaysia (MIROS, 2015). Based on the recent reports from the Department of Statistics Malaysia (DOSM) and Ministry of Transport Malaysia (MOTM), 6,740 road fatalities and 548,598 road accidents have been reported in 2018 (DOSM, 2019; MOTM, 2019).

Malaysia, along with other countries is now in the exciting rate of urbanization level. The report by Transformasi Nasional 2050, also known as TN50, estimated that almost 60% of the world population will be staying in urban areas by 2025 (Land Public Transport Commission, 2006). As the urbanization level increases, the human population around the world has become more dependent on the transportation systems. Hence, the need for a better vehicle which provide a good systems or technology is much demanded today. The technology or system such as detection and monitoring systems for driver's fatigue is essential for reducing road accidents. As the drivers face the problems and difficulty in detecting fatigue, the vehicle must be installed with the fatigue detection and monitoring system.

In recent years, many researchers and road safety practitioners have shown interest in the development of fatigue detection and monitoring systems. Many mechanisms and measures in detecting fatigue while driving such as vehicle-based, physiological-based, and behaviour-based measures have been used (Srikander & Anwar, 2018; Sahayadhas et al., 2012). In vehicle-based measures, several metrics such as deviations from lane position, movement of the steering wheel, pressure on the acceleration pedal, etc. are monitored and any changes in these that are over the specified threshold shows a significantly increased probability that the driver is fatigued (Forsman et al., 2013; Kang, 2013; Liu et al., 2009). Behavioural measures monitored the behaviour of the driver such as yawning, closing eyes, eye blinking, head pose, etc. through a camera and sensor and the driver acts as an alarm if any of these fatigue symptoms are detected (Forsman et al., 2013; Kang, 2013; Liu et al., 2009).

In physiological measures, the researcher studies the correlation between the physiological signal such as the electrocardiogram

(ECG), electromyogram (EMG), electrooculogram (EoG), and electroencephalogram (EEG) (Yang et al., 2010; Liang et al., 2009; Kang, 2013; Kokonozi et al., 2008; Akin et al., 2008). Besides that, some researchers also used subjective measures by asking the drivers to rate their level of fatigue through a questionnaire or interview, which the evaluation was determined based on the rating (Tremaine et al., 2010; Philip et al., 2005). Hence, there is a need to review existing literatures on fatigue detection and monitoring system in order to understand the current technologies and the effectiveness of these systems for managing driver fatigue.

2. Aim

The main objective of this paper review is to evaluate the current status of research regarding fatigue detection and monitoring system, and at the same time identify any related issues there might be regarding driver fatigue.

3. Method

To identify relevant studies to include into this topic, a systematic scoping review was carried out for each item in the taxonomy. This method scientifically represents the body of literature. There was a schematic approach followed for each review, consisting of the initial search, screening, identifying additional papers, and prioritizing paper for coding.

For the initial search regarding the information on fatigue detection and monitoring system, several relevant literature databases were used such as Google Scholar, Scopus, IEEE Xplore, and Research gate. The well-defined logical string of keywords was used for searching the topic as shown in Table 1 as an example.

Table 1: An example of search terms
(“driver detection and monitoring fatigue”)

Fatigue	“fatigue” OR “tired” OR “drowsy” OR “drowsiness” OR “monotony”
AND	
Detection and monitoring system	“fatigue detection system” OR “fatigue monitoring system” OR “measure”

The keywords with the resulting number of studies were mentioned. The searching results need to be screened to select the potentially relevant studies for further analysis. This was done first by looking at the abstract, before looking at the overall paper. The reference lists of the selected papers were examined to identify any additional relevant papers related to the topics. Next, the papers need to be prioritized based on outcome variables, transferability, recent publication date, language, and publication source.

4. Results and Discussion

Table 2 summarizes the previous studies for driver fatigue detection and monitoring system. This literature’s table is organized in terms of the approach used to detect or monitor fatigue, the name of the device (if applicable), the developers, and a brief description of the distinguishing features of the method/system/device and its state of development. The summarization of this literature is based on the methodology implied to reflect fatigue-related changes. These methodological emphases include measures of the driver’s current state, measures of driver performance, and measures of a combination of the driver’s current state and driver performance.

Many works of literature on the detection of fatigue effects and the driver’s current state has given more attention to changes and movements of the eyes such as changes in the driver’s direction of gaze, rate of blinking, and eye closure. In this measure, there are two popular and commonly used methodologies; percent eye closure (PERCLOS), and electroencephalographic (EEG). PERCLOS is a video-based method that measures eye closure, and its ability has been proved to be a well-established fatigue detection system or device. PERCLOS ability has been tested and evaluated by (Dinges & Grace, 1998) under different performance measures. They found that a satisfactory relationship was obtained between eye closure and lapses in attention, providing some useful evidence to verify the system’s ability in detecting the current state of the driver.

Another popular methodology used as a method of detecting drowsiness is EEG. Some researchers assume that EEG could potentially be one of the most predictive and reliable techniques for detecting changes in alertness and vigilance. However, for an on the real-road experiment, EEG has a weakness in terms of difficulty in obtaining recordings under natural driving conditions. From the author's observations, many researchers used this methodology for a simulator study.

In terms of driver performance measures, many previous studies conducted on the real-road experiment which focuses on monitoring the lane tracking, tracking the distance between the driver’s vehicle with the vehicle or obstacles in front (headway tracking). The level of driver’s alertness can be measured through these studies. By using these approaches, driver performance is also influenced by other factors such as roadway, road quality and condition, lighting, weather, and environment.

Some researchers and previous studies combined these two measures; driver state measures, and driver performance measures. This approach provides direct evidence of driver alertness. Besides that, the European Union (EU) has used this method in the completed System for Effective Assessment of Driver Vigilance and Warning According to Traffic Risk Estimation (AWAKE) project in 2014 (Boverie, 2014). This project measures the driver’s state based on eyelid movement, changes in steering grip and as well as driver behavior (lane tracking), use of accelerator, and brake, and steering position. All these measures were 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.

Further research is required on different approaches to providing a warning to drivers to reduce the number of road accidents. However, one of the positive things about this is the researcher’s awareness of developing driving fatigue detection systems. This is reflected in the amount of research that has been conducted in this area. below:

Table 2: Summary of the fatigue monitoring system

References	Approach/System	Methods
Huda et al. (2020)	Face detection	The study proposed the algorithm to detect the driver's face in the image and estimate the landmarks in the face region. The Local Binary Features for face landmark detection was used for regressing.
Zhou et al. (2020)	Eyelid closure	The study developed the prediction model that was able to predict the fatigue transition at least 13,8 seconds ahead of time using a nonlinear autoregressive exogenous network.
Song et al. (2020)	Electrooculogram (EOG)	This research focuses on a new electrooculogram (EOG) based approach for muscular visual fatigue detection. The author studied the process that causes muscle visual fatigue and deliberately designed an experiment to cause muscle visual fatigue and at the same time the EOG was recorded.

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Table 2: *Continued from previous page.*

References	Approach/System	Methods
Jing et al. (2020)	Electroencephalogram (EEG)	The study monitored the driver's real-time EEG signal which was recorded by field driving fatigue test. Nonlinear and linear methods were used to analyze EEG signals in awake, critical, and fatigue three typical states.
Ani (2020)	Muscle fatigue, handgrip force, whole body vibration, seat pressure distribution force, heart rate, and driving duration.	This study developed a decision support system for detecting driver fatigue. This system provides a systematic analysis and solutions to minimize the risk and the number of accidents associated with driving fatigue. This system used fuzzy logic membership function which defines the input and output variables that correspond to physical measures. The graphical user interface was used to communicate the system with users.
Shin et al. (2019)	The concentration of salivary cortisol and EEG	The study quantifies the level of fatigue by measured a concentration of salivary cortisol using the Smart Fatigue Phone. Smart Fatigue Phone consists of a lateral flow immune sensor and a smartphone-linked fluorescence signal reader. The EEG signal was obtained simultaneously from the participants to confirm a correlation between fatigue status and salivary cortisol concentration calculated by the Smart Fatigue Phone.
Ma et al. (2019)	Electroencephalogram (EEG)	The study presented a novel feature extraction, which was developed by integrating the principal component analysis (PCA) and deep learning model called the PCA network (PCANet). The feature extraction achieved high classification accuracy and efficiency in using EEG for driving fatigue detection.
Ani et al. (2019)	Muscle fatigue, handgrip force, whole body vibration, seat pressure distribution force, heart rate, and driving duration	This study developed the driving fatigue strain index using fuzzy logic to analyze the risk level of driving fatigue. The strain index creation is based on the six risk factors associated with driving fatigue; muscle activity, heart rate, force of handgrip pressure, distribution of seat pressure, vibration of the whole body, and length of driving. For all risk factors, the data is gathered, and then the three conditions or risk levels are described as 'safe',' slightly unsafe' and 'unsafe'.
Wang et al. (2018)	Dry EEG	This study developed a novel real-time driving fatigue detection using dry EEG signals. Two fatigue-related indexes were measured and then fused into an integrated metric to predict the degree of driving fatigue: $(\theta + \alpha) / \beta$ and (θ / β).
Li et al. (2017a)	Steering wheel angles	The study developed the drowsiness on-line detection system for monitoring fatigue levels under real driving conditions. The system is based on the data of steering wheel angles (SWA) collected from the sensors mounted on the steering lever.
Li et al. (2017b)	Steering wheel angles and yaw angles	The study presents a fatigue detection system based on steering wheel angle and yaw angles data obtained by a fixed sensor mounted on the steering wheel.
Mu et al. (2017)	Electroencephalogram (EEG)	This research tests a combination of EEG data processing approach based on entropy to detect driver fatigue. For driver fatigue detection purposes, four types of enthrones (spectrum entropy, approximate entropy, sample entropy, and fuzzy entropy) were used to extract features. The selection method for electrodes and the classification algorithm for a support vector machine (SVM) were also suggested.
San et al. (2016)	EEG measures	The study proposed a hybrid Deep Generic Model (DGM)-based Support Vector Machine (SVM) driver fatigue detection system, which detects the normal and fatigue stages through analysis of large variation of drivers' EEG signal.
Qiao et al. (2016)	Eye blinking, head nod, and yawning	This study developed a fatigue monitoring system that focused on information fusion that is designed and implemented in a smartphone. It detects eye blinking, head nod, and yawning as an indicator of driver fatigue.
Ani (2016)	Muscle fatigue, handgrip force, whole body vibration, seat pressure distribution force, and heart rate	The study developed the regression models based on psychophysical and biomechanical factors that contribute to fatigue. The models predict the relationship between the input parameters and output responses.
Azmin et al. (2014)	Eye closure and yawning	This study presents a non-intrusive fatigue detection system based on the video analysis of drivers which observed the eye closure duration through eye state information and yawning analyzed through mouth state information. The data are further passed to the Fuzzy Expert System that identifies the fatigue state of the driver.
Zhang et al. (2013)	EEG, EOG, and EMG measures	The study proposed a real-time method for automated detection and identification of driver fatigue based on various entropy and complexity measures.
Brookhuis & De Waard (2010)	Physiological measures: ECG and EEG	The study monitored the mental workload based on physiological measures including ECG, and EEG. The study monitored the alertness level of the drivers.
Bundele & Rahul (2009)	Skin conductance and Oximetry Pulse	This study tries to design wearable computing in form of a jacket to be worn by the driver, which the jacket equipped with computing, sensing, and communicating elements. The complex set of non-invasive and non-intrusive sensor compute element integrated with the appropriate e-textile would form the primary part of this wearable computer.
Rogado et al. (2009)	Physiological and biomechanical measures: heart rate variability (HRV) and steering-wheel grip pressure	The study presents a method for detecting the early sign of fatigue while driving. The system determines if the driver can drive based on HRV, steering-wheel grip pressure. The hardware system acquires and processes the parameters, as well as an algorithm to detect the beats and calculate the HRV of the drivers to determine the fatigue level.
Jap et al. (2009)	Physiological measures: EEG	The study investigated four EEG frequency bands; delta, alpha, theta, and beta, and four algorithms (algorithm (i) (h + a)/b, algorithm (ii) a/b, algorithm (iii) (h + a)/(a + b), and algorithm (iv) h/b) to quantify fatigue.
Yutian et al. (2009)	Eye state identification	The study proposed the combined eye state detection algorithm. The study found that 95.67% accuracy of eye state identification algorithm is time-saving and robust to illumination and has reliable for a fatigue detection system for drivers.

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Table 2: *Continued from previous page.*

References	Approach/System	Methods
Saradadevi & Bajaj (2008)	Mouth and yawning tracking	The study proposed a method to locate and track the driver's mouth using a cascade of classifiers. The support vector machine (SVM) is used to train the mouth and yawning images, which then classify the mouth and to detect yawning then alert fatigue to the driver.
King et al. (2006)	EEG measures	The study developed a driver fatigue detection system using an Artificial Neural Network (ANN) from 20 EEG data sampled of a professional driver and 35 EEG data sample of nonprofessional drivers.
Lin et al. (2005)	EEG measures	The study developed a drowsiness estimation system based on EEG by combining independent component analysis (ICA), power spectrum analysis, correlation evaluations, and linear regression model. The study estimates the driver's cognitive state while driving. This study is carried out in virtual reality (VR)-based dynamic simulator.
Zhu & Qiang (2004)	Tracking of eye gaze	The image of the driver's face was captured using video cameras. The eye gaze direction is used to identify the driver's fatigue state.
Wijesoma et al. (2004)	Lane tracking	The study used the 2D radar sensing and Kalman filtering for fast detection and tracking of road curbs.
Boverie (2004)	AWAKE project: eyelid change and steering grip change	This study detects the real-time hypo vigilance and drowsiness while driving based on eyelid change and steering grip change. The driver behaviour such as lane tracking, use of accelerator and brake, and steering position is observed. The data is marched together with the data on traffic risk including information from digital navigation maps, a positioning system, anti-collision radar, odometer, and driver gaze direction sensor. If the risk is detected, a driver warning system is activated.
Perez et al. (2003)	Tracking of eye gaze	Tracking based on head movement using the eye camera that detects the pupil-glint vectors.
Wahlstrom et al. (2003)	Tracking of eye gaze	Eye detection using human skin color properties and using the infra-red light burst to identify the pupil and track movement.
Lal et al. (2003)	EEG measures	The validation of EEG is used as a tool for assessing fatigue. The study was conducted using the simulator study.
Apostoloff & Zelinsky (2003)	Lane tracking	The study used the Distillation Algorithm to combine several available visual cues that have been captured by a video camera. The algorithm estimates the location of the vehicles in the lane.
Broggi (2003)	Lane tracking	This lane tracking system is based on geometrical transform and morphological processing. The system can detect roadway lines on flat and structured roads.
Chang et al. (2003)	Vision-based vehicle behavior monitoring and warning system	Video cameras collect information on lane tracking and preceding car tracking. Based on the information, the fuzzy neural network is used to determine the risk of accidents.
Fletcher et al. (2003)	Driver Assistance system	Use FaceLAB to monitor the driver. While the distillation algorithm used to monitor the driver performance based on lane tracking and obstacle detection and tracking.
Ayoob et al. (2003)	User-centered drowsy driver detection and warning system	This system will alert drivers and encourage safe behaviour while driving. A drowsiness warning was developed through a qualitative assessment of usability, which was evaluated by experts and drivers.
Chieh et al. (2003)	Steering grip force	The study detects driver fatigue by monitoring the driver's grip force on the steering wheel, which is based on the variation in steering grip force due to fatigue or losing alertness.
Liu et al. (2002)	Tracking of eye gaze	Tracking the eye gaze using the infra-red light and appearance-based object recognition.
Gu et al. (2002)	Tracking of facial	Predict the facial feature; pupils and head motion. The changes in eye and head motion are analyzed using the predictive analysis.
Parmar & Hiscocks (2002)	Eye closure	Detection of eye closure using face imaging. The image from the video is used to determine whether the eye is open or closed.
Ito et al. (2002)	Eye blinking	Detection of fatigue based on the rate of eye blinking.
Longhurst (2002)	Eye closure, eye gaze, and eye blinking rate - faceLAB	The twin video cameras detect eye closure, gaze, and blinking. The PERCLOS method was used.
Heitmann et al. (2001)	Multiple measures: head position, eye gaze, pupillometry, and mayo pupillometry	Using multiple measures such as head position sensor (MINDS system), eye gaze system, pupillometry measures safety scope, and mayo pupillometry system. This study is carried out using a simulator and the author found that there is no single measure was reliable for quantifying driver fatigue.
Rimini et al. (2001)	Multiple measures: lane tracking, eye closure, and physiological state	Using physiological measures such as ECG, EEG, EOG skin temperature and impedance, pulse and oxygen saturation in blood, respiration frequency and head movement, eye closure, and lane tracking to predict accidents in a simulation study. The study found that lane tracking gives a significant effect on predicting accidents.

Reasonably simple systems are currently commercially available and are intended to measure fatigue through vehicle-based performance. However, their efficacy in terms of reliability, sensitivity and validity is uncertain (i.e. systematic validation studies were either not carried out or at least not made available to the scientific community). More complicated systems are being rigorously tested and developed and appear to be potentially very effective, but are not yet commercially available. Therefore, the authors do not recommend any of the existing systems for immediate use in transportation. Equally, it is difficult to comment on the role of such innovations in relation to other enforcement and regulatory mechanisms before more complex systems are explored and validated.

Therefore, based on the critical review, learning the methods of fatigue detection with high precision, real-time and strong anti-interference is significantly important. One single form of parameter is not sufficiently accurate to assess driver's fatigued condition. Methods of fatigue detection based on data fusion technologies measure fatigue driving by fusion of vehicle and driver related parameters. This is an important path for research; in addition to that, fatigue detection techniques can obtain more robust detection results by analysing fatigue state by deep learning. This is a trend research field; the "Internet of Vehicles" is essentially the trend of intelligent transportation growth. Combining the “Internet of Vehicles" and driver fatigue identification may lead to successful solutions. The powerful data transmission and analytical capabilities can make a significant contribution to fatigue driving detection accuracy and real-time efficiency.

5. Conclusion

The driver fatigue monitoring system aims to provide the driver with information that his or her alertness is below the level compatible with the safe operation of the vehicle. There is evidence that such warnings are useful to drivers who may be aware that drowsiness is on the rise, but unaware of the impact drowsiness has on their driving capacity. These systems may have additional benefits for the driver. For example, if the warning occurs early enough in the development of fatigue, such devices could increase the driver's alertness in avoiding a collision. Many of the devices currently under development, in particular the driver's state measures, will detect later stage fatigue, which is unlikely to be overcome by a short time of stimulation, such as a warning signal.

Some of the problems with the fatigue monitoring system currently under development include the level of somnolence being detected, the focus of the measure on the driver status (associated with the above difficulties) or the effects on driver performance (which may not be sensitive to driver fatigue only) and the timing and nature of the warnings used. More research and development are needed before efficient fatigue monitoring devices are standard features in on-road vehicles.

Acknowledgments

The authors would like to acknowledge the Universiti Teknikal Malaysia Melaka (UTeM), Tokushima University Japan, Universiti Sains Islam Malaysia (USIM), and Politeknik Kuching Sarawak (PKS) for technical, educational, and financial supports.

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