Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
Journal of Tianjin University Science and Technology
ISSN (Online):0493-2137
E-Publication: Online Open Access
Vol: 57 Issue: 01:2024
DOI: 10.5281/zenodo.10549104

DEVELOPMENT OF IOT-BASED DRIVER DROWSINESS DETECTION AND WARNING SYSTEM

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Abstract

Drowsy driving is one of the common causes of millions of traffic accidents every year in the world. Many other accidents in industry and transportation are direct result of tiredness or drowsiness. Current drowsiness detection systems do not provide effective solution because of their weaknesses such as bulky design, dependence on road types or illumination. The research is to develop cost-effective and practical system to identify the level of tiredness and drowsiness from physiological condition of the driver. The methods of detecting driver drowsiness state by capturing and calculating the blinking rate, ratio of eye-opening and yawning pattern are developed and analysed by a new developed algorithm. Then, information collected by the camera system are saved in the local and internet database which later can be retrieved for further processing.

Keywords: Internet of things, IoT, Drowsiness, Fatigue, Detection, Viola-Jones

1. INTRODUCTION

Many industries (manufacturing, logistics, transportation, emergency services, and the like) operate 24/7, meaning their employees work in shifts. Working in shifts can lead to a mismatch with the internal biological circadian rhythms of many individuals, causing sleep disturbances, drowsiness, fatigue, mood disturbances, and other long-term health issues.

Driver fatigue can have several causes such as lack of sleep, long journeys, anxiety, alcohol consumption, and mental pressure. Each of these factors can lead to serious disasters. Currently, road rage occurs far more frequently than before, causing stress to drivers. Therefore, previous transportation systems are not sufficient to address road hazards. Many accidents in the industry and transportation are a direct result of fatigue or drowsiness. The National Highway Traffic Safety Administration (NHTSA) in the United States reports that driving while drowsy causes nearly 100,000 traffic accidents and over 1,500 deaths each year [1]. A study conducted in urban areas of West Malaysia identified fatigue levels of 130 drivers. 17.7% were in a state of fatigue, and 34.7% experienced poor sleep [2]. Due to long working hours and a relaxed psychological state while driving, drivers can experience heavy eyelids and fatigue. In many cases, drivers are unaware of their level of drowsiness, creating the possibility that they could fall asleep at any time.

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By incorporating an automatic fatigue detection system into vehicles, some fatal accidents can be prevented.

Driver sleep deprivation is a major reason for accidents. Therefore, technology for driver fatigue detection systems is needed to reduce accidents on the road. Continuous fatigue detection systems to analyse the driver's level of attention and to provide warnings to the driver before a serious threat to road safety emerges. The development of this technology poses a significant challenge for the industrial and research communities. There are various signs of driver fatigue that can be observed while operating a vehicle, such as difficulty keeping the eyes open, frequent yawning, or nodding the head forward. Various measures are used to determine the driver's level of drowsiness. These measures include physiological measures, behavioural measures, and vehicle-based 1easures.

2. LITERATURE REVIEW

Variety of systems were developed to overcome and reduce the number of traffic and industrial accident caused by tiredness and drowsiness. However, those systems traditionally require installation of additional and expensive equipment leading to low utilization in the transportation industry and other sectors. The examples of such systems are Electroencephalography (EEG) and Electrocardiography (ECG), which uses brain signals and heart beat rate to predict drowsiness and tiredness of driver or worker. Such systems also create discomfort and could obstruct the view while driving because they require attachment of sensors to human body or scalp to measure required brain signals and heartbeat. Other common methods of determining level of drowsiness and tiredness are by image processing or by recognizing the driving patterns. The weaknesses of such systems are they are not only bulky and required big space but also dependent on certain factors and conditions when performing measurement. Many systems are not fully utilized by industry and mass public outside the labs because they require stable platform and additional support system, such electricity dan protection system.

There were many attempts and studies to develop effective way of avoiding accidents related drowsy driving [3]. Detecting the state of driver using various techniques such as measuring biological signals, driving patters and image processing are among popular methods. Some methods involving biological signals from driver such as brain waves, heart rate and pulse rate, drivers are required to attach or wear additional sensors, which creates disturbance while driving. The methods involving speed, lateral position and turning angle of vehicle are effective in certain type of drivers, roads, and driving conditions. The last method is by observing face of driver. However, the effectiveness depends on image quality and image processing techniques used. Another weakness of this method is different image quality in different illuminations [3]. Additionally, some developed systems are expensive, big size and uncomfortable to use which hinders industry and public to utilize them 0in mass scale.

The objective of this study is to develop effective driver drowsiness detection and warning system. The study aims to design and implement a practical mobile, internet of things (IoT) system to identify the level of tiredness and drowsiness from physiological condition

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of the driver and integrated with notification system to give warning and assisting drivers to nearest rest area if required. The physiological condition of driver will be monitored using camera, which is connected to computer to do image processing using various image processing techniques and algorithms. The camera is to capture images in required quality during night or day conditions. The system utilizes IoT technology to store and transfer data about the drowsiness level of driver, which will make information globally available. The mobile device located near to driver will acquire information about drivers' drowsiness level and then stored it in local or internet database using specially developed application.

3. METHODOLOGY

During this study the drivers fatigue level will be identified by image processing which will analyse following factors: (1) mouth opening, (2) PERCLOS (Percentage of Eye Closure), and (3) head positioning. The effective method of identifying the critical levels of driver's fatigue going to be established through analysing those three factors. Information containing the level of fatigue will be transferred to Internet database using IoT (Internet of Things) communication technology. Mobile application created will use information about drivers' fatigue in Internet database to give appropriate response to warn and assisting driver to locate nearest place to stop for resting.

3.1 Drowsiness detection methods

Drowsiness is first stage of nonrapid-eye-movement (NREM) sleep [4]. There are various methods developed and used to identify the level of drowsiness. The drowsiness detection techniques usually use following three measuring methods: Physiological measure, behavioural measure and visual measure [5].

3.1.1 Physiological measure

Electroencephalography (EEG) and heart rate variability (HRV), pulse rate and breathing are physiological signals that are commonly used to identify the drowsiness level of driver. Since those bio signals closely related level of drowsiness/sleepiness, they give accurate results. For example, frequency domain analysis of heart rate variability (HRV) showed that density ratio of low frequency band (0.04 – 0.15 Hz) to high frequency band (0.15 – 0.4 Hz) decreases and power of high frequency band increases when person changes from waking into drowsiness/sleep stage [4,6-9]. However, these methods require electrode contacts to driver's body and which creates discomfort and annoyance for drivers.

3.1.2 Behavioural measure

These methods focus on evaluating driver's condition from driving patterns. Pilutti and Ulsoy developed a model which input is vehicle lateral position its output and steering wheel position to identify the driver's fatigue. Change in bandwidth and/or parameters of such model can indicate in what condition is driver. Behavioural measure also done by placing sensors to various part of car such as steering wheel, gas pedal to analyse data

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from them. Distance between vehicles is another parameter, which is taken into account to identify drivers' condition. Main drawback of these methods is that they are dependent on road quality and lightening. The drowsiness, which does not affect the driving patterns, also cannot be detected by systems based on behavioural measure [10, 11].

3.1.3 Visual measure

These methods utilize image processing and pattern recognition techniques for detecting drowsiness and fatigue indicators such as yawing, gazing, nodding, and eye closure. PERCLOS (the percentage of time that eyes are closed in a given period) in one of the most common methods used in many studies [12]. The frequency of eye blinking is closely associated with the drowsiness and fatigue state of driver. Figure 1 shows the general method of detecting eyes and PERCLOS.

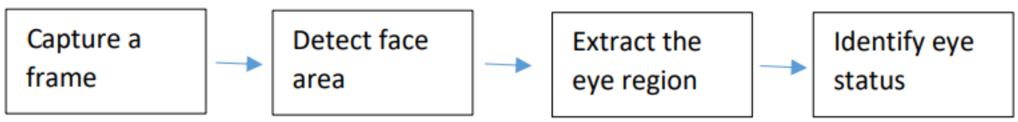

Figure 1: General method of detecting eyes and PERCLOS [12]

As seen from the figure, first stage is to capture the image of the video. After the image is captured, each frame is individually analysed to detect the face region. There are number of methods developed for face detection in recent years. The most widely used method of boosted cascade algorithm using Haar-like features as identification patterns. The algorithm was later enhanced by Lienhart and Maydt. Face and eye detection system developed by Viola and Jones used this boosted cascade algorithm using Haar-like features. Haar-like features make use of difference in averaged intensities of objects such as bridge of nose is brighter than its sides to detect them. Figure 2 below shows the Haar-like features [12].

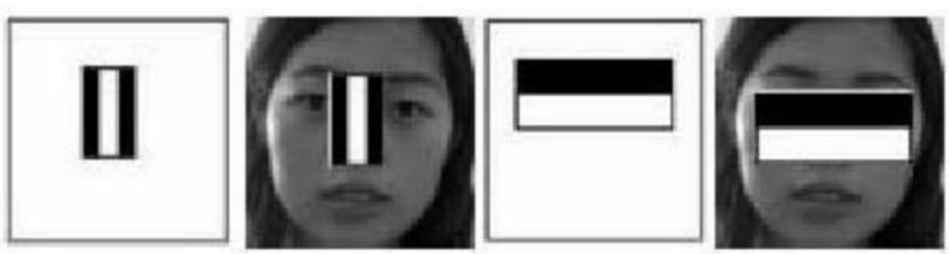

Figure 2: Haar-like features. [12]

These different Haar-like features are grouped under one weak classifier and processed. The learning algorithm chooses and combines these weak classifiers to make strong classifier. Figure 3 shows this process and boosted cascade of the classifiers.

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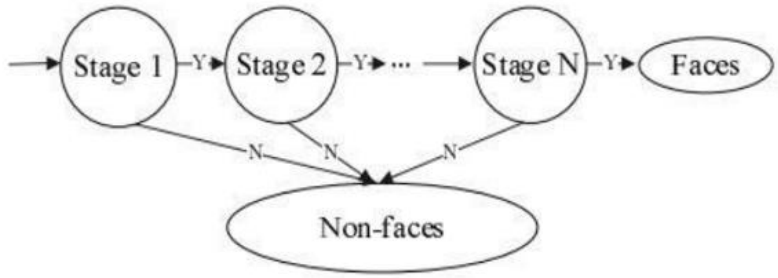

Figure 3: Boosted cascade of the classifiers [12]

Classifier from each stage detects the objects that it is trained to meanwhile rejecting the others. This scheme of cascaded classifiers called AdaBoost. After face and eye region is detected, next stage is extracting it and determining its state. Number of methods were developed in recent years to for detecting state of eye closure. These methods could be grouped in two according to how they identify the eye state. One group focuses on eye characteristics and features of its parts such as eye corners, eyelids and iris, etc. The intensity template, Fisher method, intensity projection, searching of the upper eyelid, detecting of iris through Hough Transform (HT) which could be included in to this group. The second group uses pattern recognition. The algorithms of neural networks, the support vector machines, and the hidden Markov model, etc., belongs to this group of methods [12-22].

In this study IoT technology going is utilized to make information globally available and, in the same time, creating assistance system through transferring and storing information on local and internet database. The information about drowsiness state of driver will be stored in server by computer Raspberry pi 3 using Wi-Fi communication technology. In this arrangement the companies or agencies that operate dozens of vehicles will be able to acquire information about their drivers' state and consequently operate safer, more efficient and effective. Implementation of IoT technology in the system will be especially helpful for transportation and mining companies. The mobile device is located close to driver so it can capture the information using developed application, process and analyse the drivers' state and respond adequately.

4. SYSTEM SETUP AND RESULTS

The study is to develop fatigue detection system, which will identify the drowsiness level of driver and consequently generate adequate response by assisting or warning driver if required. The system will utilize IoT components and new algorithm to capture, analyze and store the information about driver's state.

4.1 System Setup

First stage which is identifying driver's drowsiness condition will be accomplished by method of image processing using camera and raspberry pi 3 minicomputer. The camera will capture driver's image in required quality for image processing to identify the eye

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closure, PERCLOS, yawning patterns and angle of tilt of driver's head. The captured video will be divided into individual frames and will be analysed using appropriate image processing techniques and algorithms in the Raspberry pi 3 minicomputer and send the information to local and internet database using Wi-Fi internet connection. The information will be acquired by application in driver's phone and being analysed. The application, after acquiring the location and state of driver, will warn the driver on his/her condition and assist to locate the nearest possible location for the driver to stop and rest. Figure 4 shows the components of the detection setup and its configuration representation of system.

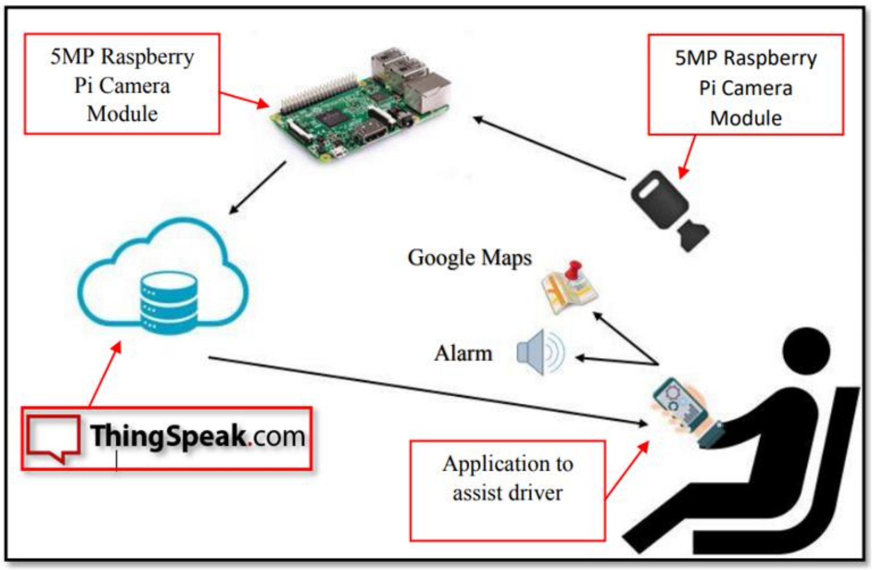

Figure 4: detection setup and its configuration representation of system

4.2 Eye and mouth detection

The Viola-Jones type detector is used for detecting face and eyes from the video frames. This method can obtain high frame rate when it is used to detect objects in grey scale images. The high classification speed is achieved due to three factors: image representation called integral image, method of constructing classifiers that selects number of important features and method of combining successively complex classifiers into cascaded structure [18]. The image processing subsystem is based on Raspberry pi 3 model B microcomputer, which have 1.2 GHZ quad-core ARM Cortex A53 processor. Viola-Jones method of object detection is very suitable for drowsiness detection subsystem due to high frame rate and accuracy of classification in available processing power.

Open-source Computer Vision Library (OpenCv) have a trained Haar cascade classifiers based on Viola-Jones method for face detection that could be used for detecting faces from frames of video. The Haar cascades for face detection detect faces effectively in grey scale images therefore frames are converted to grey images and resized to increase effectiveness. After converting and resizing images, Haar cascade for face detection

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could be applied. After face region is detected, system should identify the eye regions and recognize if eyes are closed or open. Problem arises as each individual have different pattern of eye blinking. It differs in duration of blink, speed of closing and opening or squeezing degree [23]. To identify the eye region of eyes the robust real-time facial landmark detectors going to be used as they can capture characteristic points of human face including eyes. The landmark detectors are trained on "in-the-wild datasets" meaning they preserve same effectiveness and robustness in varying illumination, facial expressions and non-frontal head rotations. Latest developed landmark detectors have error rate less than 5 percent [24]. Open-source C++ toolkit Dlib contains facial landmark detectors that could be loaded and applied to images using Python programming language in Raspberry Pi microcomputers. For each frame of the video the after-face region is detected the facial landmark detector would be applied to identify eye landmarks. Eye aspect ratio (EAR) would be identified using formula proposed in [22] shown in figure below.

$$EAR = \frac{\|p_2 - p_6\| + \|p_3 - p_5\|}{2\|p_1 - p_4\|} \quad \text{.................................. (1)}$$

The value of Eq. 1 remains constant when eyes are open however drops close to zero when they are closed. The Fig. 5 below illustrates how EAR changes when eyes are closed or open. The same methodology could be applied to identify mouth aspect ratio. The facial landmark detector would be applied to identify mouth landmarks. However, mouth-opening ratio would stay close to zero when mouth is closed and increase when mouth is opened.

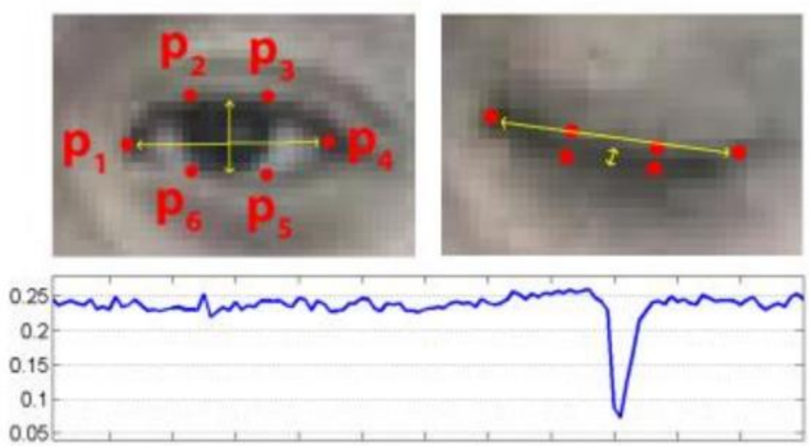

Figure 5: EAR value change [22]

4.3 Identifying drowsiness level using EAR and MAR

Eye aspect ratio (EAR) and mouth aspect ratio (MAR) values indicate the state of eye and mouth respectively. EAR was used to identify blinking rate and eye-opening state. The MAR was used to identify yawning. Analyzing those three parameters about driver, system predicts the drowsiness state of driver. Blinking rate is one of the factors that

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changes when driver drowsiness level increases. To identify the blinking rate system needs to identify blink from video. The EAR value will get small during person blink for a short time. Therefore, the duration of small EAR compared to average going to be used as an indication to identify eye blink. The average human blink is around 300 milliseconds [25]. Taking into account this factor system will count EAR value decrease as a blink if its duration is around 300 milliseconds. Average rate of human eye blink is around 15 to 20 times per minute [26]. If driver is drowsy, his blinking most probably will increase. Eye state by itself was used as indication of drowsiness. If eye is closed more than blinking duration, it can indicate that drivers have fallen asleep.

Yawning could be taken as early indication of drowsy driver. MAR value going to be used to predict if driver yawned or not. MAR value increases as mouth opens. However, increase in MAR does not always mean yawning as other actions such as speaking, laughing can give same effect on MAR value. Therefore, system needs to differentiate yawning from other actions that cause MAR value to increase. Yawning can be differentiated using EAR value and duration of MAR value increase. The average human yawning is around 2-3 seconds. Another indication of yawning is decrease in EAR value during the yawning. The blink and yawning detection accuracy of system was tested in three trails with same the subject. The tests procedure was according to following scenario: Subject blinked 10 times and yawned 5 times with varying intervals in between and in different postures. Subject also performed other actions during the test such as speaking, closing eyes for long intervals. The flowing formula was used to calculate the drowsiness level due to eye blinking rate [25].

$$DL' = DL^0 + (NT' + BR^0) \quad \ldots\ldots (2)$$

The DL represents drowsiness value the NT represents interval value and the BR means number of blink rate. If the number of blinking increases next interval (NT) then drowsiness value would be increased. Considering the how yawning indicates the drowsiness the following formula was developed to calculate the drowsiness level due to yawning.

$$DL = \sum_{n=1}^{n=\infty} \frac{EP}{\frac{TP_n - (TP_n mod\, EP)}{EP} + EP} \quad \ldots\ldots (3)$$

DL is drowsiness level of driver due to yawning; EP is effective period of yawning it represents approximate time from yawning until driver drowsy state. As the yawning is considered an early sign of yawning, EP sets how many seconds early we need consider it. TP is Time Period meaning time passes in since the yawning happened and n is number of yawning happened. If yawning happened close to current time then formula gives higher number. If yawning happened long time ago then effect of yawning on drowsiness value decreases, as formula will give smaller number.

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4.4 Internet of Things (IoT) Responses

After detecting the EAR and MOR using Haar cascades and Dlib in Raspberry Pi 3 the system calculates three drowsiness values each representing drowsiness due to indicator. EAR and MAR and three drowsiness values are sent to the ThingSpeak which is an open IoT platform. The values could be fetched from specific channel of cloud in the form of JSON format in android application and necessary pieces of data pierced from JSON format. EAR, MAR and three drowsiness values are fetched from the cloud and showed respective TextViews in android application. The driver or any other individual who is interested in monitoring driver's state, can monitor those values using android application. If the driver drowsiness level increases, then the android application gives warning and opens google maps application to find closest location possible for rest. The application identifies the drowsiness level of driver according to three drowsiness values. Following table represents the logic that system uses to identify if driver's state according to three drowsiness values.

Table 1: The logic used to identify driver drowsiness state

State	Drowsiness value (blinking rate)	Drowsiness value (yawning)	Drowsiness value (eye state)
Sleeping	-	-	1
Drowsy	DV > 0	DV > 1	-
Fresh	DV < 0	DV < 1	0

As table shows the there are two indicators of drowsiness which are blinking rate and yawning. If the any of those drowsiness values exceed the critical level, the application will give a warning and assistance by helping to find closest location to rest. The eye state is used to identify if driver is sleeping or not. If driver is sleeping, the application will behave same as it did in drowsy state.

4.5 EAR and MAR Results

Results were obtained for effectiveness of first stage of drowsiness detection system, which is detection of face and prediction of EAR and MAR values. Figure 6 shows detection process, where face features are being detected and simultaneously calculating eyes aspect ratio (EAR) and mouth aspect ratio (MAR).

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Figure 6: Detection of Face, EAR and MAR

Figure 6 shows the eyes and mouth landmarks are indicated with green line and mouth aspect ratio and eye aspect ratio values are illustrated in top right side of figure. Face region is detected using Viola-Jones type detector. Eyes and mouth are detected using facial landmark detectors from Open CV library. Eye aspect ratio (EAR) and Mouth aspect ratio (MAR) were calculated similar to formula proposed in [23] shown in Figure 5. Figure 7 shows the graph of values of EAR during testing of the program

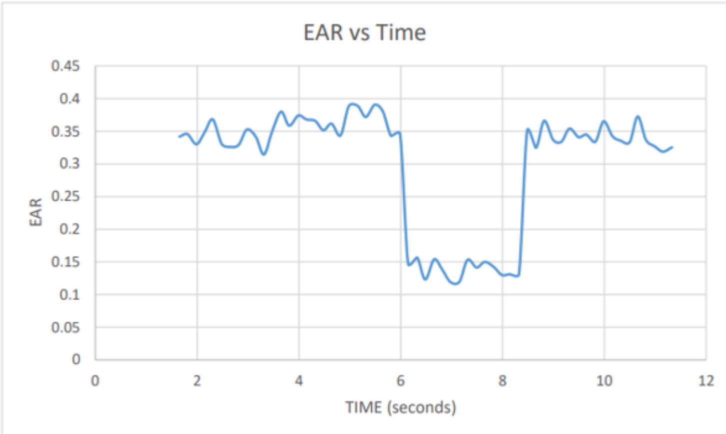

Figure 7: EAR vs Time

As Figure 7 shows, the EAR value stays constant with small ripples when eyes are open until sixth second. When eyes are closed value decreases to closer value to zero and stays the same with small ripples until eyes are opened again. Another value that the program calculates is MAR value. Figure 8 shows the MAR value during testing of the program.

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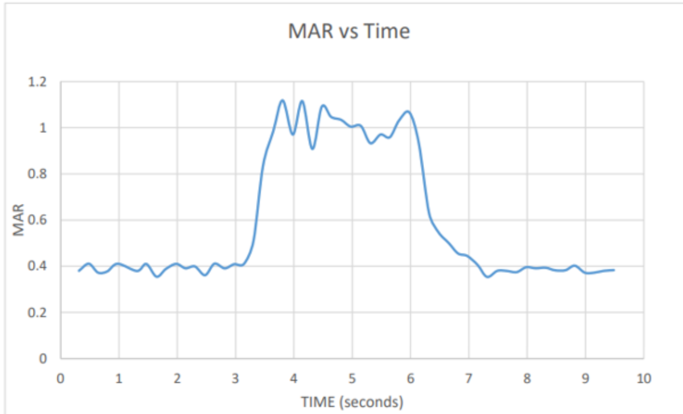

Figure 8: MAR vs Time

MAR value in the figure 8 stays constant when mouth is closed with small ripples to some value close to zero because distance between upper and lower landmark points of mouth have small difference. When mouth opens the MAR value increases and stays same until mouth is closed again with small ripples. Changes is EAR and MAR values when state of eyes or mouth changes respectively would be used to identify the drowsiness of driver as blinking and yawning rate are good indicators of driver drowsiness.

4.6 Identifying drowsiness level using EAR and MAR

Three indicators of drowsiness were used in this project: yawning, blinking rate and closed state of eyes. As stated before, number of blinking rate, yawning and state of eyes would be identified using MAR and EAR values. Figure 9 shows the EAR value during human eye blink.

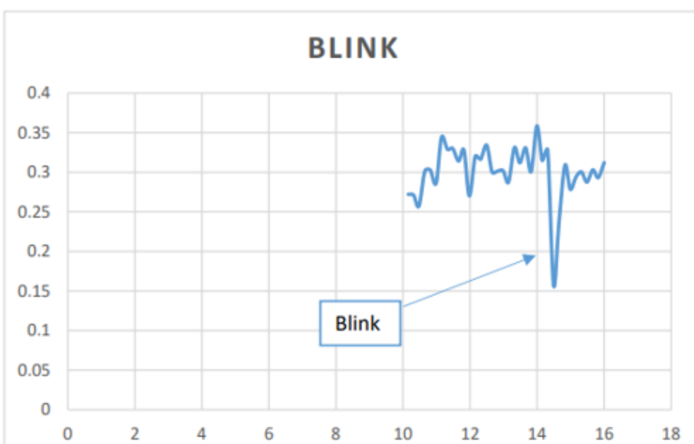

Figure 9: EAR value during the eye blink

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As the graph shows the EAR value drops to half for approximately 300-400 milliseconds when blink happens. The EAR and MAR values were analyzed during yawning. Figure 10 shows how EAR and MAR values change during yawning process

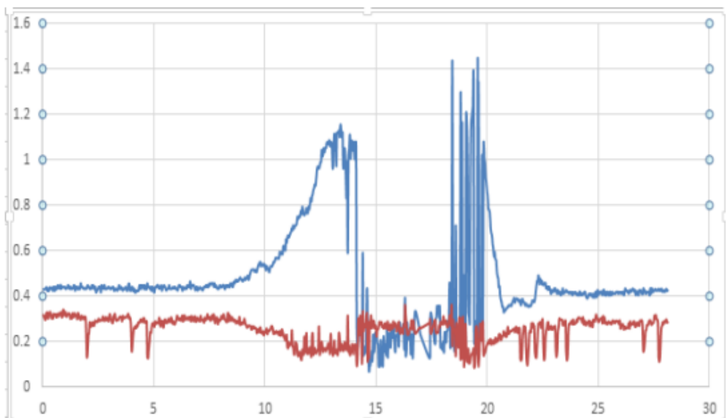


Figure 10: Simultaneous values of EAR and MAR

As illustrated in the graph the EAR value decreases and MAR value increases for duration of more than 2 seconds during yawning. Although the duration could vary person-to-person observed behaviour of EAR and MAR values were used to detect the yawning. The blink and yawning detection accuracy of system was tested in three trails with same the subject. The tests procedure was according to following scenario: Subject blinked 10 times and yawned 5 times with varying intervals in between and in different postures. Subject also performed other actions during the test such as speaking, closing eyes for long intervals. Following table 3 shows the results of the test.

Table 2. Test results for blink and yawning detection

Trail	*Detected blinks out of 10*	*Detected yawning's out of 10*	*BLINK detection Accuracy*	*YAWNING detection accuracy*
1	7	5	70%	100%
2	9	4	90%	80%
3	9	5	90%	100%
Total	25	15	83%	93.3%

Test results showed that system have 83 % accuracy in blink detection and 93.3% accuracy in yawning detection. System showed ability to differentiate between the yawning and speaking or blinking and sleeping. The drowsiness values using eye blinking rate and yawning were calculated using formulas stated before separately. The change of drowsiness due to yawning is showed in following Figure 11.

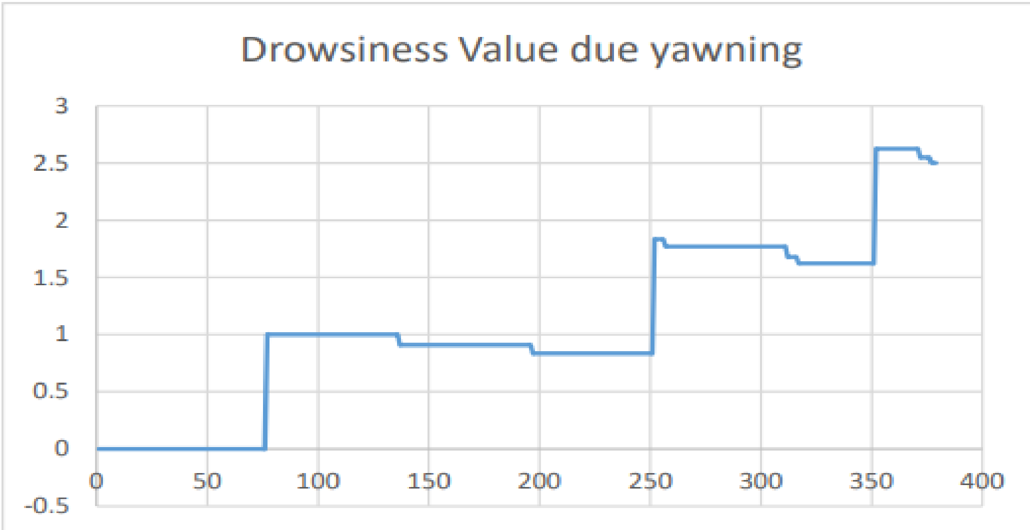
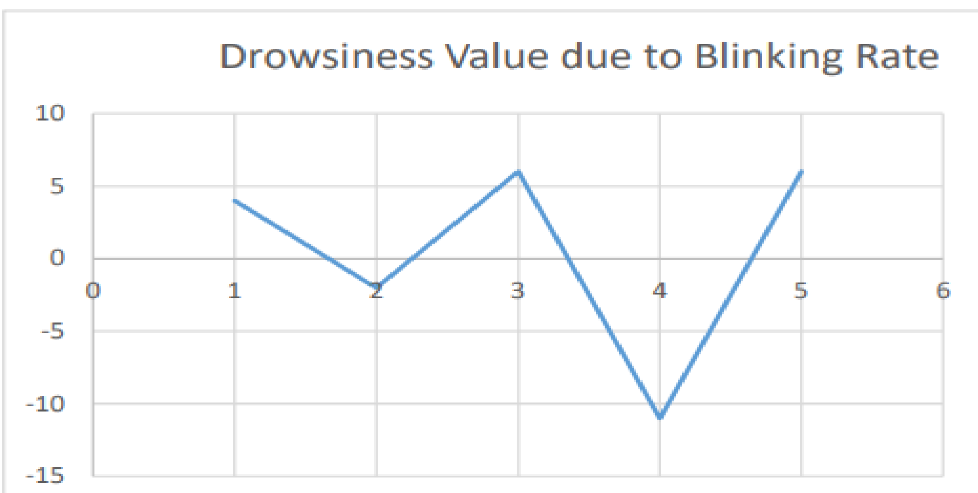


Figure 11: Drowsiness value due to yawning

As the graph illustrates the drowsiness value starts from zero and when yawning happens it increases to one. However, with time the drowsiness value decreases gradually indicating that effect of yawning on drowsiness drops over time. When second yawning happens the value to approximately 1.7-1.8 and start dropping again for both yawning's happened. If the yawning happened long time ago the drowsiness will continue approaching zero. The separate drowsiness value was calculated using blinking rate over a certain period. The change of drowsiness value is shown in the following Figure 12.



12: Figure Drowsiness value due to blinking rate

The drowsiness value higher than zero indicates that driver have blinked more than average and driver drowsiness is increasing.

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4.7 Application design

The application was developed in Android Studio development environment. It receives the EAR, MAR and three drowsiness values and gives appropriate response and assistance according to the logic presented in table 1. The following Figure 13 illustrates the User Interface of the final version of application.

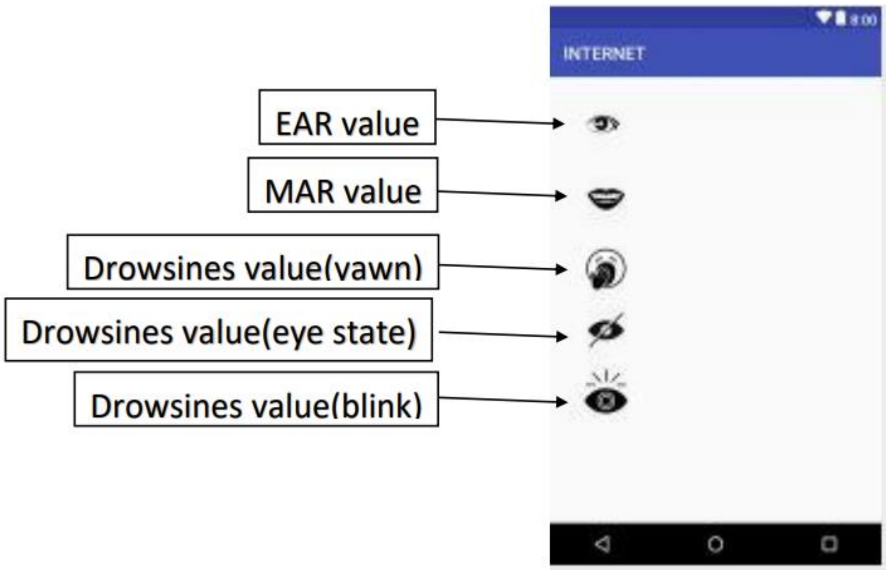

Figure 13: User Interface of the Mobile Application

5. CONCLUSION

Drowsiness while driving has caused fatal accidents and serious injuries to thousands of people each year. This research has developed a mobile, cost effective and practical system to identify the level of tiredness and drowsiness from physiological condition of the driver and given warning and assisting drivers if required. The method of detecting driver drowsiness state by using image processing techniques to analyse video captured by camera. The aspects such as blinking rate, sleeping and yawning patterns are analysed by system and for each of them drowsiness level is calculated. A new algorithm is developed to calculate the drowsiness level due to yawning. The information about the drowsiness state of driver is stored in internet database, which will make information globally reachable.

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