Driver Drowsiness Detection and Monitoring System (DDDMS)

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***Abstract*—The purpose of this paper is to develop a driver drowsiness and monitoring system that could act as an assistant to the driver during the driving process. The system is aimed at reducing fatal crashes caused by driver's drowsiness and distraction. For drowsiness, the system operates by analysing eye blinks and yawn frequency of the driver while for distraction, the system works based on the head pose estimation and eye tracking. The alarm will be triggered if any of these conditions occur. Main part of the implementation of this system will be using python with computer vision, while Raspberry Pi, which is uniquely designed, for the hardware platform and the speaker for alarming. In short, this driver drowsiness monitoring system can always monitor drivers so as to avoid accidents in real time.**

Keywords—Distraction; drowsiness; eye blink; yawn; head pose estimation; eye tracking; computer vision; Raspberry Pi

I. Introduction

Driver distraction and drowsiness are the major public health concerns and have led to road accident that have become one of the major causes of death and injuries in Malaysia. The Bukit Aman Investigation and Traffic Enforcement has reported that in the first six months of 2019, the country reported 281,527 road accidents, an increase of 2.5%, compared to 274,556 in the same period last year. These often stem from peoples' mistakes that occur in different activities related to vehicle driving. The term "drowsy" indicates "sleepy," as in prone to falling asleep. Drowsiness is commonly induced by a lack of sleep, certain medications, and boredom produced by driving a vehicle for extended periods of time. The driver will lose control of his vehicle when sleepy, resulting in an accident. Driver distraction is defined by the National Highway Traffic Safety Administration (NHTSA) as the process through which drivers redirect their attention away from driving duties. Drivers are often distracted by activities taking place around them, such as texting, talking on cell phones, or conversing with others. All these activities divert drivers' attention away from the road, which can lead to accidents that threaten drivers, pedestrians, and even other vehicles on the road.

Many efforts have been made to reduce all these numbers such as developments in computers that can be used to track drivers' conditions with the ability of alerting in dangerous situations [1]. Using physiological measures, ocular measures, and performance measures, a variety of methods have been investigated and applied to describe driver drowsiness and distraction. Despite the effort, since many studies are focused on referring to the non-direct function, driver drowsiness and monitoring systems have not become widespread. Thus, this paper describes the design and development of a Driver Drowsiness and Monitoring System using Raspberry Pi minicomputer with a webcam making the system cost-effective and portable. The objective of the work is to develop driving assistant system that can help driver to stay alert while driving so that numerous accidents can be reduced or prevented. This paper is organized as follows.

In Section II, this paper presents the previous works. Section III presents the proposed Driver Drowsiness and Monitoring System. In Section IV, the paper discusses the results of the experiments to show accuracy of the system. Finally, the conclusion and future work will be explained in Section V.

II. Related Work

A. Driver Drowsiness and Monitoring System

Due to large number of accidents occurring over time, the ability to detect driver's distraction and drowsiness, then alarming them in real time becomes challenging. In order to improve the system development, a few existing systems in the market have been studied and discussed. Majority of the applications are integrated with the single functionalities only. Anti-Sleep Pilot is the dashboard device that will monitor both driver and their driving condition. It will let the driver know when it's time to take a ten-minute rest and pull over. The device continuously calculates the driver's fatigue level once driving started and status displayed. Driver alertness is also maintained and measured through occasional reactive tests in which the device must be touched as soon as indicated. If the combination of variables approaching the limit, the visual and audible signals from the Pilot will be activated to the fact that the driver need to take a break- the system is adaptive to light and sound, so that its monitor and warning automatically change for cabin conditions.

In industry, systems based on near-IR are the most common. The Saab Driver Attention Warning System detects visual inattention and drowsy driving. The system uses two

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miniature IR cameras integrated with Smart Eye technology to accurately estimate head pose, gaze, and eyelid status. When a driver's gaze is not located inside the primary attention zone (which covers the central part of the frontal windshield) for a predefined period, an alarm is triggered. When the cameras detect a pattern of long duration eye-lid closures, indicating the potential onset of drowsiness, a series of three warnings is initiated. This can only be cancelled when the driver presses a reset button in the fascia. The system is then immediately reactivated. [10] In this paper the author provides facts and figures of road accidents due to driver's drowsiness. Study reveals that in United States of America near about ten million fatal accidents occur in a year. In order to find safety precautions and road accident prevention, real time driver's drowsiness monitoring must be done. Author claimed 80% correct results of the suggested structure by focusing on the facial expressions of the driver and to propose a lightweight model using Android application.

The authors [12] used a lightweight Convolutional-Neural-Network model to categorize facial sleepiness patterns of drivers while driving on road. With glasses, the accuracy level range between 85% to 88% with and without glasses along with the overall average of 83%. [13] Driver sleepiness is one of the main reasons for road accidents and the number of such accidents can be minimized with the help of driver drowsiness monitoring system. A lot of research has been done and variety of alarm models and frameworks were deployed for this purpose including capturing facial and head movements along with yawn frequency. The paper itself is a survey and it presented a comprehensive comparative analysis for the detection of driver sleepiness and preventive measures adopted. The authors [13] reviewed multiple approaches SVM (Support Vector Machine), HMM (Hidden Markov Model) and CNN (Convolutional Neural Networks) along with their positive and negative impacts and limitations associated with each approach to help researchers in finding gaps. They concluded that SVM is comparatively cheap but doesn't work best with large data sets whereas HMM and CNN has less error ratio, but they are costly. The authors [14] presented a detailed comparison betouren invasive and non-invasive sleepiness detection methods. Invasive method like electrooculogram (by recording eye movements) and non-invasive method like electrocardiogram (by recording heart rhythm and activity) of the driver. The authors used hybrid approach by combining both EOG and ECG, but this strategy has limitations associated with it as there are many other reasons for change in heart rhythm except for drowsiness only.

The authors [15] proposed a framework to estimate in advance about the number of possible road accidents which could happen according to the road condition by using the random variable function and Taylor's series. The authors [16] described another approach by breaking down the proposed model in four steps. Started by capturing movements of the driver from the real time video after then categorizing different sleep conditions by considering other factors like with putting glasses on or off and movements of mouth, head, and eyes. The authors are using any two conditions to get to know the sleepiness state of the driver. Another research based on measuring heart rhythm to detect driver's sleep state as heart-rate-variability (HRV) has already been used to determine the brain disorder [17]. Therefore, the authors recommend using HRV to detect sleep state of the driver as change in sleep state changes the involuntary physiologic process of the man which directly effects HRV. But again, the reason for change in HRV may not be only the drowsiness as presence of other factors can never be ignored and this becomes the limitation of the suggested approach.

Driver's face expressions recorded, and alert sent to the driver when found in drowsy state. It works by extraction of facial expressions and then running an algorithm to check and detect the drowsy position and finally alert sent to driver to make him/her conscious [18].

B. *Eye Blink Detection Method*

For the blink detection, Mandeep and Gagandeep [2] had proposed a method using Mean Shift Algorithm. In this algorithm, eyes are identified in each frame, and each eye blink is compared to a mean value. The system analyzes the eye opening at each blink to a standard mean value, and an alert is generated if the eye opening exceeds this value for a certain number of consecutive frames. Compared to the algorithm in this study, the system does not need to store information from previous frames because eye blinking measurements from a collective number of frames are utilized to assess drowsiness. The algorithm proposed is simple but efficient to detect eye blink. The system monitors the EAR which is the ratio between the height and the width of the eye contour in the real time. This value can represent the level of the eye opening by comparing to threshold value.

The research [11] was focused on capturing eye movement with the help of cameras by using CNN which is used to identify real time patterns in images and videos. The eye movement pattern from the video helps in categorizing sleepy or non-sleepy driver and consequently generates an alarm in order to provide protection from road accidents. Although, the researchers [11] provided more accuracy when compared to conventional CNN but it works with only capturing eye movement and not considering yawning and head movement. [19] This paper covered other factors along with detection of driver's drowsiness by capturing eye-blink. Upon drowsiness detection, the system sends an alarm to make the driver alert. Location monitoring was done by GPS and driver's alcohol, temperature and heat rhythm were measured to monitor health by putting a check on vehicle speed and informing about the current status to other vehicles [19]. The authors [20] advocate to smartly monitor driver drowsiness without conditioning it with other factors like steering-angle, pedal-pressure and electrocardiogram etc. In fact, it used a USB camera to capture video and extract facial traces for sleep pattern monitoring by using iris area and eye closure period. In [31] researchers presented a solution to a challenge normally faced in driver drowsiness detection that is capturing driver's different facial images like frequency of eye-closure and yawning at night or when light is low. To solve this issue, infrared camera was used to capture facial images with adequate visibility. More than 3000 facial images were used for testing purpose and researcher claims the result was more than 90% accurate for both eye-closure and yawn frequency monitoring in low light.

C. Yawn Detection Method

On the other hand, the yawn detection in [3] describes a system in which the face is found in a video frame using the Viola-Jones face detection approach. Then, from the face region, a mouth window is generated, and lips are searched using spatial fuzzy c-means (s-FCM) clustering. However, this algorithm has complex classifier, as a result, it is impractical to install the system inside the vehicle with little processing power, and training on datasets with huge samples is required. Compared to the algorithm in this study, the system utilizes some mouth geometrical characteristics to identify yawning which is detected by the ratio of mouth height and width. The authors [21] used an algorithm to record video and trace facial behavior like yawning, eye-closure period and frequency of eye-blink from that recorded video instead of measuring the functioning of any other device attached with the vehicle to simplify the algorithm. In [22] the authors tried to focus on driver drowsiness and to propose such an algorithm which not only detects driver's drowsiness but also finds a safe place nearby to park the vehicle there and inform the transportation authority about the problem to ensure road safety. The authors in [23] tried to enhance their previous work related to detect sleepiness with the help of machine learning. They suggested to capture face expressions and position to detect sleepiness of the driver by using a simple algorithm resulting 88% accuracy with driver wearing no glasses and 85% with driver wearing glasses. The authors also described that their proposed algorithm is more efficient in terms of storage, model-size and complexity than the benchmark-model and is capable of implementing in real time driver's sleep detection vehicle applications.

The authors [24] presented an approach to analyze the magnitude of relation of different facial parts to detect driver drowsiness. These facial parts include movements and changes in eyes, nose, ear, eyebrows, mouth, and face wrinkles. In analyzing the magnitude, relation of all these facial parts, the authors proposed the use of SVM classifier. In this research paper, the authors [25] endorsing the fact that use of images for driver's sleepiness detection is one of the main focus of research nowadays. Images of facial expressions and movements can be the best way to detect driver drowsiness and to ensure road safety. The researchers are using four types of CNN based image recognition and classification methods to process data containing yawn frequency along with variable mouth positioning. In this research the authors [26] proposed a model which needs prior training as it works on two main streamlines. One is to reduce light effect from the face images with the help of contrast limited adaptive histogram equalization and second one is to extract maximum information from the eye images using the 3D SE-blocks. The researchers used 3D-depthwise separable sensing framework instead of 3D image extraction to minimize overall cost. It comes with one limitation that face images may not be always clear as sometimes driver may wear cap or driver's hairs may cover the face resulting in the poor visibility of extracting sleepiness patterns from driver's facial images. In [27] proposed a framework where Support Vector Machine algorithm was used to monitor driver sleepiness by extracting facial expressions like eye-blinking frequency for a specific period of time or mouth opening due to yawning from the pictures captured by a built-in camera in the vehicle. This proposed model sends an alert to driver upon drowsiness detection by using Euclidean-distance function to ceaselessly monitor eyes-mouth space approaching to sleepiness.

In [28] researchers advocated that road accidents can be avoided with driver drowsiness monitoring using MATLAB for image processing. System works on visual concept by using a camera for face recognition and detection. After that it focuses on eye blink and then information about eyes open/close was extracted by MATLAB using Hough-transform and Viola-Jones algorithms. Eye movement observation was recorded continuously using camera and driver was declared sleepy if more than five frames show closed eyes consecutively. It consequently sends alert to the driver with the help of alarm. Authors [29] presented a detailed analysis of recently used techniques and algorithms for driver's drowsiness monitoring/detection as drowsiness is one of the main reasons of road accidents and is more harmful than any other technical fault in vehicle. Authors used the analysis approach by dividing latest drowsiness detection algorithms and techniques into three categories. First one is to analyse the driver's driving style, secondly driver's mental state or psychological patterns are observed. Third and last is the detailed analysis of different visual monitoring systems used to scan and then to extract required information to alert driver and ensure road safety. Specifically focusing analysis on the data sets available to work on for driver drowsiness detection and results found are there is still plenty of attention required to add more driver drowsiness images to comprehensively monitor human yawning patterns. In [30] authors presented an approach to monitor real-time driver's sleepiness with the help of magnitude relation of driver's eye-closure along with yawn frequency and head positioning by observing the mouth and eyes movements. As the proposed model is intended for real-time environment, therefore, to achieve accuracy it runs 15 frames/second which is justifiable. The best results showed accuracy level of eye-movement/blinking was 97% and the results for yawn frequency was 96% and head positioning accuracy level was 63.4% detected.

D. Gaze Detection Method

Lastly, the gaze detection in [4] explained that the face detection was done using the Viola-Jones algorithm. The eye area is next localized using the integral projection function, followed by pupil detection and gaze classification. The pupil position and eye corner location information are utilized to identify the direction in which the subject is looking. The distance from pupil boundary to eye corner line segment is measured to find whether the driver is distracted or not. Compared to the algorithm in this study, the system is able to handle the head movement while this algorithm is done only for frontal face images. In [32] researchers proposed a framework to optimize gaze detection using data transfer learning with the help of deep-learning models. It used a small camera to capture images of eyes and mouth and then extract the required information from the centre of the eyes and mouth.

In [33] researchers proposed a framework for eye gaze detection with the use of Convolutional-Neural-Network model and claimed better accuracy results when it comes to road safety. Along with this claim, the paradigm for the possible execution of proposed algorithm, real time eye gaze controlled autonomous vehicle can be used. The authors [34] described that real time road safety applications must deal with some challenges, like driver drowsiness, glass, and lighting reflections. Therefore, chance to get false result may increase when driver does not move his head and gaze an object with only eyes movement and gaze detection based only on head movement will not be sufficient and accurate. It presented a deep learning gaze detection without prerequisite of driver standardization with the help of an infrared small sensor.

III. Proposed System

Fig. 1 shows the flowchart of the operation of Driver Drowsiness and Monitoring System in detecting drowsiness and distraction among the drivers. This system will be split into three modules which are blink detection, yawn detection and gaze detection. For all the module to operate, the system must successfully detect driver face. If there is any face detected, then it will go through each module simultaneously and begin the detection. If the driver shows any sign of drowsiness or distraction, the system will immediately sound the alarm to alert the driver.

Driver Drowsiness and Monitoring System is an automobile application that have the purpose to alert the driver when signs of drowsiness or distraction are detected. Based on Fig. 2, this system comprises a camera-based driver drowsiness and monitoring system aimed at the driver's face, which enables a real-time evaluation of the driver's presence and state. For the hardware part, the system will use Raspberry Pi 4 as the main component to make a compact embedded system. All the algorithms will be implemented in it. Webcam is installed on the car dashboard for video feed purpose to track features of the driver (8FPS). Portable speaker will be used as an alarm device. When the system detects drowsy or distracted driver condition, it makes a sound alert from the speaker. Image's processing algorithm is developed in Python and OpenCV to detect the drowsiness sign based on rate of eye blinking, eye closing period and rate of yawning while gaze detection to estimate where the driver is looking for the distraction sign.

A. Face Detection using Dlib Library

To detect the face in the image, HOG + LinearSVM face detector from dlib library will be used. The function that had been used for face detection is: dlib.get_frontal_ face_detector(). This function will return the pre-trained HOG + Linear SVM face detector which is used for obtaining the face bounding box (i.e., the (x, y)-coordinates of the image's face). Given the face region in the face bounding box, the key facial structures in the face region can be detected. Facial landmark detection will be applied using pre-trained facial landmark detector inside the dlib library. This method is used to localize and labels mouth, right eyebrow, left eyebrow, right eye, left eye, nose and jaw. Each facial structure on the face has its own specific (x, y)-coordinates.

There are 68 coordinates (shown in Fig. 3). Those coordinates represent each facial structure mentioned above. These coordinates can be used to detect eyes, nose, mouth and left and right eyebrow and will be used for the next section.

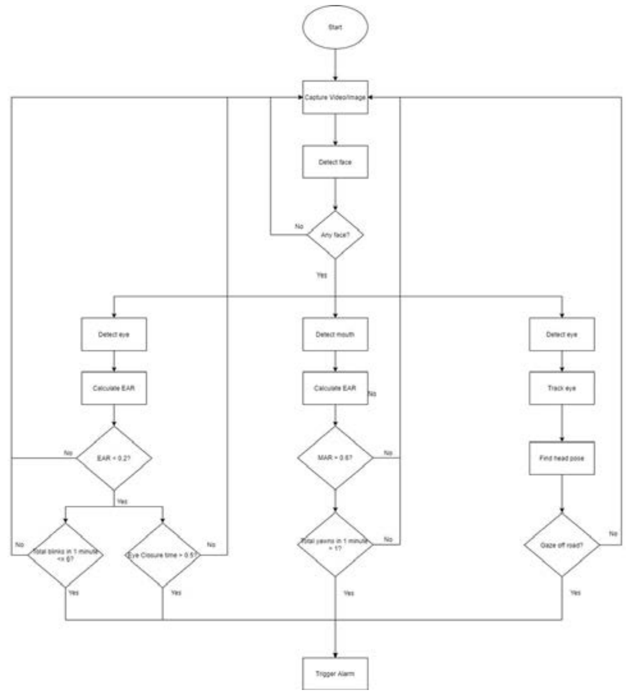

Fig. 1. Flow Chart of Driver Drowsiness and Monitoring System.

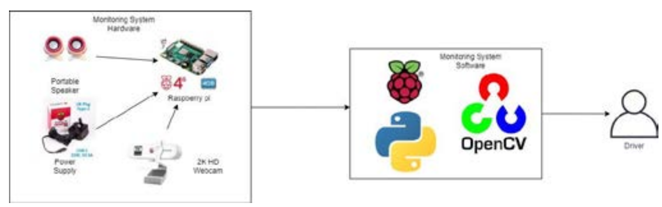

Fig. 2. System Architecture Diagram.

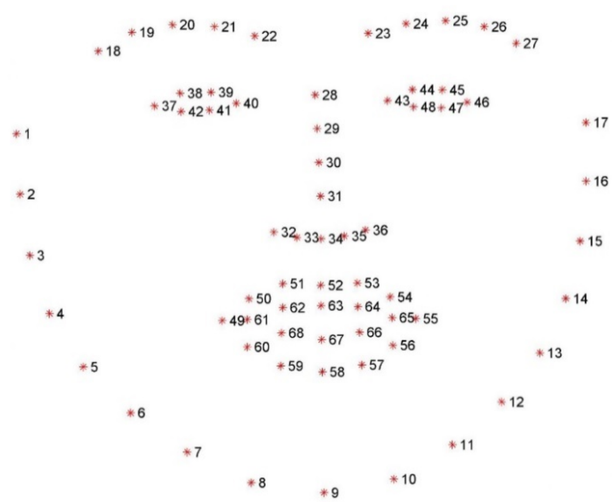

Fig. 3. 68 Facial Landmark Coordinates.

B. Blink Detection System

For the blink detection method, Eye Aspect Ratio (EAR) algorithm will be used. EAR is defined as the ratio of the height and width of the eye. First, extraction of the eye region from a set of facial landmarks. Based on Fig. 3 there are six coordinates for each eye. These six coordinates (as shown in Fig. 4) will be used for calculation of EAR value. The calculation is done for both left and right eye.

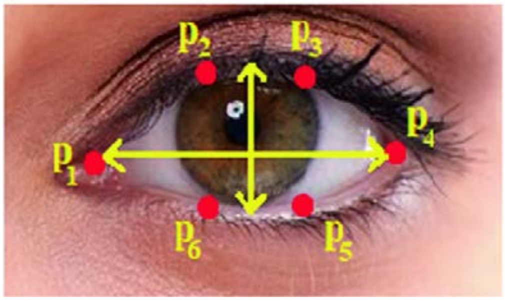

Fig. 4. The 6 Coordinates of an Eye represent in P1, P2, P3, P4, P5 and P6.

According to [5], the equation for EAR can be derived as the following:

$$EAR = \frac{|P2-P6|+|P3-P5|}{2\,|P1-P4|} \quad (1)$$

Where, P1, P2, P3, P4, P5 and P6 are the facial landmark coordinates that have been obtained before. Next, the system calculates the average of two EAR together (assumption that a person blinks both eyes at the same time). EAR value will be compared with the threshold value (Te) taken as 0.2 [5]. If the EAR value is below than Te, the eye will be considered as closed. When eye is closed, the two types, which are eye closure and eye blink will be differentiated. When the duration of eye closed is more than 0.5 seconds, it will be considered as eye closure or else as eye blink.

$$EyeState = \begin{Bmatrix} Closed, EAR < Te \\ Open, EAR > Te \end{Bmatrix} \quad (2)$$

Alarm will be triggered in two conditions. Firstly, when the eye is closed for more than 0.5 seconds. This is because the typical duration of a single blink for the human eye is 0.1 to 0.4 seconds [6]. If it more than 0.5 seconds, then it is considered as eye closure. When the EAR value remains less than Te for more than 0.5 seconds, it can consider that the driver is drowsy or tired. Secondly, when the total number of blinks per minute is equal or less than six. This is because the typical blink rate for a normal individual is 10 blinks per minute, whereas it is 4-6 for a sleepy person [7].

C. Yawn Detection System

For the yawn detection method, Mouth Aspect Ratio (MAR) algorithm will be used. MAR is defined as the ratio of the height and width of the mouth. First of all, extraction of the mouth region from a set of facial landmarks. Based on Fig. 3, there total 20 coordinates for both outer and inner mouth. To calculate the MAR, only those coordinates will be used at which are at the outer mouth [8]. There are 12 coordinates (as shown in Fig. 5).

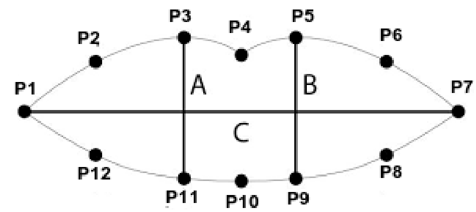

Fig. 5. The 12 Coordinates of Mouth Represent in P1, P2, P3, P4, P5, P6, P7, P8, P9, P10, P11 and P12.

According to [8], the equation for MAR can be derived as the following:

$$MAR = \frac{|P3-P11|+|P5-P9|}{2\,|P1-P7|} \quad (3)$$

Where, P1, P2, P3, P4, P5, P6, P7, P8, P9, P10, P11 and P12 are the facial landmark coordinates that this study obtained before. MAR value will be compared with the threshold value (Tm) taken as 0.75. The value of Tm was established by trial and error, with several values of Tm being tested to ensure that the algorithm accurately classifies an instance of yawning and closed mouth. It shows that if the MAR value is bigger than Tm, the mouth will be considered as yawning. Every time MAR value exceeds the Tm, total threshold will be increased by 1 and will be reset back to 0 after 1 minute.

$$MouthState = \begin{Bmatrix} Close/Talking\,, MAR < Tm \\ Yawn, MAR > Tm \end{Bmatrix} \quad (4)$$

Alarm will be triggered when the total number of yawns per minutes is more than 1. This is because a driver becomes tired when he or she begins to yawn more than once per minute [9].

D. Gaze Detection System

For yawn detection method, the system will combine both head pose estimation and eye tracking. This combination will allow the system to detect whether the driver eyes are off the road or not. Drivers have a habit of changing their head position while driving. To determine which direction the driver is looking, 3D head pose estimation is necessary. In head pose estimation, it is typical to predict relative orientation and position with respect to camera, in calculating the Euler angles. Euler angles can be represented as roll (tilt), pitch (up and down) and yaw (left and right) as shown in Fig. 6.

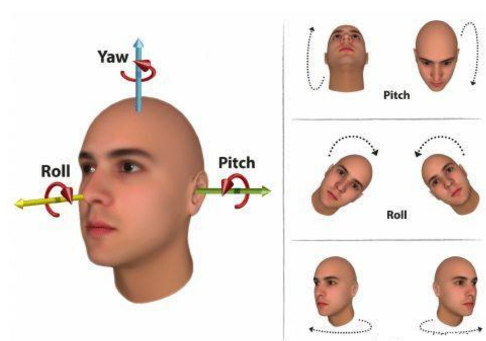

Fig. 6. Roll, Pitch, and Yaw of Euler Angles.

Out of three Euler angles, the system only extracted and used yaw angle only. This is due to the system's sole concentration on determining the left and right direction of the driver's gaze. After that, initializing the frontal face angle will be done. Frontal face is a face with a head yaw angle ∈ [-15°; 15°]. If the yaw angle is in between -15° and 15° it means that the driver is looking at the centre while if the yaw angle is less than -15°, it will be considered as looking in left direction and if it more than 15°, it will be considered as looking in the right direction. Eye tracking is needed because during driving, the driver's eye look is continuously shifting, based on the surroundings. As a result, identifying eyes is insufficient. Real-time tracking of eyes is required by isolating the eyes from the face using facial landmark detection mentioned. Then, detection of the iris by using image processing method such as blurring, eroding, thresholding and contour will be done. After getting the iris, the coordinate and calculate, the horizontal distance will be found to determine which direction driver is looking. The direction of the driver's gaze is determined by a combination of eye tracking and head pose estimation algorithms. Alarm will be triggered when the driver is looking other than centre for more than two seconds. This is because drivers should never move their gaze away from the road for more than two seconds at a time.

IV. Result and Discussion

The Driver Drowsiness and Monitoring System is tested in a variety of conditions that a driver would encounter in real life. The factors considered when developing test conditions are as follows:

- Appearance: With and without spectacles

The average frame rate of image capture throughout testing ranged between seven and eight FPS. All the people will be captured for one minutes on each function. Table I show final interpretation of the test performed on the system in terms of accuracy.

$$Truepositive = \frac{Nooframescorrectlydetected}{Totalnumbersofframes} X100 \quad (5)$$

The testing result in Fig. 7, Fig. 8 and Fig. 9 show that the system performs quite well under different condition that have been considered. Based on Fig. 7, the use of spectacles by driver has affected a lot in terms of accuracy. As a result, blink detection suffers from the problem of detecting false positive. This may be because system miscalculated the EAR value of the driver when he/she is wearing the spectacle. While based on Fig. 8, the system utilizes some mouth geometrical characteristics to identify yawning by detected by the ratio of mouth height and width. On the other hand, based on Fig. 9, gaze detection had lower accuracy on the spectacles driver because the system cannot track the eye properly.

TABLE I. System Accuracy Calculated from Testing

	Blink/Eye closure	**Yawn**	**Gaze**
Person 1	68.3%	95%	48.3%
Person 2	91.7%	98.3%	90%
Person 3	67%	91.7%	46.7%
Person 4	96.7%	100%	93.3%
Average	80.9%	96.3%	69.6%

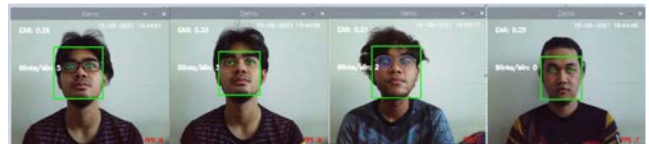

Fig. 7. Samples Testing of Eye Blink and Eye Closure.

Fig. 8. Samples Testing of Yawn.

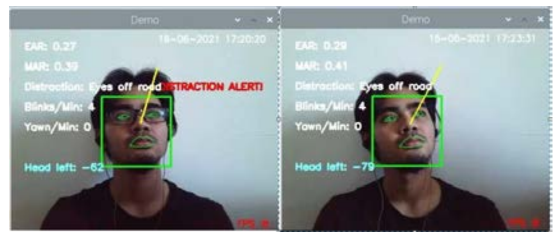

Fig. 9. Samples Testing of Gaze.

V. Conclusion and Future Work

Driver Drowsiness and Monitoring System is all in one software application for driver that can perform many functionalities in one application. This Driver Drowsiness and Monitoring System provides significant benefits to driver for them to track their behavior while driving. I really hope that this project can give benefit to driver so that driver can avoid fatal accident caused by driver negligence and sleepiness. The proposed method easily detects eye blink, yawn and gaze. Image processing provides a non-invasive method of detecting drowsiness and distraction that is free of irritation and interference. Whenever the system meets the requirement, it will set off the alarms. As a result, in this study the system is dependable, efficient, and cost-effective. The detection of drowsiness and distraction in its early phases not only assists the system in delivering timely warnings, but also warns the driver ahead of time, potentially saving lives from tragic mishaps.

In future, this Driver Drowsiness and Monitoring System could be upgraded even further when more systematic functions will be added to give ease to the vehicle driver while driving their vehicle. For instances, implementation of night vision to avoid the effect of poor detection due to insufficient light will obtain a better result that is unaffected by lack of brightness. Besides, the face detection algorithm must account for head movements and detect the face in all conceivable face orientations. So, that the system can be extended to include non-frontal face images. Then, to improve the accuracy of the system, the algorithm should include classifier that is trained on set of sample images. Lastly, to deliver a more comfortable driving experience, the system providing the function such as tire pressure monitoring, lane change assistant, etc. In a nutshell, this system will be useful to the driver by making their journey safer, more engaging, more convenient, and more fun.

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