Driver Drowsiness Detection Techniques: Review

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***Abstract*—This document is a review report on the research conducted in the field of computer engineering to develop a system for driver drowsiness detection to prevent accidents from happening because of driver fatigue and sleepiness. The novel proposed the results and solutions on the limited implementation of the various techniques that are introduced in the thesis-es on the topic. The document discusses the many solutions available for detecting fatigue and their efficacy in preventing accidents in the current state of traffic. Furthermore, the paper states the overview of the observations made by the authors in order to help further optimization in the mentioned field to achieve the utility at a better efficiency for a safer road.**

***Keywords*—Driver drowsiness; eye detection; yawn detection; blink pattern; fatigue.**

I. INTRODUCTION

Humans have always invented machines and devised techniques to ease and protect their lives, for mundane activities like traveling to work, or for more interesting purposes like aircraft travel. With the advancement in technology, modes of transportation kept on advancing and our dependency on it started increasing exponentially. It has greatly affected our lives as we know it. Now, we can travel to places at a pace that even our grandparents wouldn't have thought possible. In modern times, almost everyone in this world uses some sort of transportation every day. Some people are rich enough to have their own vehicles while others use public transportation. However, there are some rules and codes of conduct for those who drive irrespective of their social status. One of them is staying alert and active while driving.

Neglecting our duties towards safer travel has enabled hundreds of thousands of tragedies to get associated with this wonderful invention every year. It may seem like a trivial thing to most folks but following rules and regulations on the road is of utmost importance. While on road, an automobile wields the most power and in irresponsible hands, it can be destructive and sometimes, that carelessness can harm lives even of other people on the road. One kind of carelessness is not admitting when we are too tired to drive. In order to monitor and prevent a destructive outcome from such negligence, many researchers have written research papers on driver drowsiness detection systems. But at times, some of the points and observations made by the system are not accurate enough. Hence, to provide data and another perspective on the research conducts, in order to improve their implementations and to further optimize the solution, this review is being written.

Our current statistics reveal that just in 2015 in India alone, 148,707 people died due to car related accidents [1]. Of these, at least 21 percent were due to fatigue causing drivers to make mistakes [1], [2], [3]. This can be a relatively smaller number still, as among the multiple causes that can lead to an accident, the involvement of fatigue as a cause is generally grossly underestimated. Fatigue combined with bad infrastructure in developing countries like India is a recipe for disaster.

Fatigue is a safety problem that has not yet been deeply tackled by any country in the world mainly because of its nature. Fatigue, in general, is very difficult to measure or observe unlike alcohol and drugs, which have clear key indicators and tests that are available easily. Probably, the best solutions to this problem are awareness about fatigue-related accidents and promoting drivers to admit fatigue when needed. The former is hard and much more expensive to achieve, and the latter is not possible without the former as driving for long hours is very lucrative. When there is an increased need for a job, the wages associated with it increases leading to more and more people adopting it. Such is the case for driving transport vehicles at night. Money motivates drivers to make unwise decisions like driving all night even with fatigue. This is mainly because the drivers are not themselves aware of the huge risk associated with driving when fatigued. Some countries have imposed restrictions on the number of hours a driver can drive at a stretch, but it is still not enough to solve this problem as its implementation is very difficult and costly.

Driver fatigue is a real-world problem and needs ample resources to be properly taken care of. It is in human nature to overestimate our abilities. When our body experiences more fatigue, we tend to underestimate it, endangering all the people on the road. Since fatigue is very common among people, it is easily ignored, thus, becoming an almost impossible problem to tackle. As the severity of this problem is becoming common knowledge in the past few decades, people have now started coming up with a wide range of solutions to tackle this problem which plagues our roads. Various studies have been done on identifying the key biological indicators, vehicle behavior and face indicators that commonly occur when a person is fatigued [4].

Biological indicators include brain waves, heartbeat, and breathing pattern. Since they are all very intrusive, therefore they have a very less adoption rate by the drivers. Vehicle behavior includes, the speed of the vehicle, the angle of the vehicle when turning, lateral position in the lane and braking patterns. These can be implemented successfully and are non-intrusive but are lesser accurate as they do not account for human behavior.

Face analysis brings the best of both worlds, accuracy, and non-intrusiveness. It can be used independently of the vehicle, the journey, and the driver experience. Although it is limited by lighting conditions, it is still very reliable even from a sub-quality camera. With face analysis parameters like pupil movement, the distance between eyelids, eyelid closure time per blink, blinking rate, yawning rate, head movement, etc. are all considered when measuring the fatigue of the driver.

II. FACTORS CAUSING DROWSY DRIVER

Humans tend to ignore fatigue as a constraint of their under-performance. This can lead to many dangerous situations especially when drivers are responsible for their life as well as the life of other people on the road. Driver drowsiness is a dangerous mixture of driving while fatigued and sleepy.

Some of the factors that lead to fatigue are:

1) Driver fatigue generally happens when the driver has not slept well in the past 24 hours. An average human should sleep at least 7 hours every day for better health.
2) Other factors such as sleep disorders like insomnia, Sleep Apnea and Shift work sleep disorder (SWSD) which can occur because of irregular hours at work [5].
3) Too much work pressure can cause stress and anxiety which often leads to loss of sleep during normal hours.
4) According to a study, people who drive commercial vehicles especially trucks suffer from drowsy driving more regularly than non-transport drivers [5]. This is mainly because of increased demand for workers and higher pay for greater work hours at odd times of the day.
5) The human brain is trained to relate to sleep and night hours. However, this is the time when most transport vehicles are on the move. This leads to an increase in the number of cases of drowsy driving as the drivers fall asleep easily while driving at night compared to the day.
6) Another factor is medication, alcohol and drugs. Consumption of these in many cases can cause even a perfectly healthy person to fall asleep in front of the wheel and cause an accident [5].

III. METHODS

Various techniques have been advised by different authors of various research papers for detecting fatigue in drivers effectively. OpenCV library from Python can be used to detect face and eyes accurately for detecting fatigue. This makes the system very easy to implement however, it makes the process of detecting faces very slow. Various techniques like comparing changes in consecutive frames to detect face and eyes can make this process at least twenty times faster [6]. A method for detection of human eye that uses Circular Hough Transform (CHT) for accurate iris detection can make the whole drowsiness detection process much more reliable [7]. CHT is used to calculate the center and radius of the iris which is important for calculating the gap between eyelids.

Another system uses video input to analyze both the eyes and mouth for eye tracking and mouth to better predict the drowsiness of the driver. Since faces with different complexions is distinguished by only brightness, YCbCr which is made of two components Luminance (EyeMapL) and Chrominance (EyeMapC) can help in detecting faces with different complexions better as after the removal of luminance from the Eye Map faces with different complexions can easily be identified. Color space like HSV graph is used to identify the state of eyes i.e. open or close which can be used for calculating PERCLOS parameter to judge drowsiness.

Structural Similarity Measure (SSIM) can be used for eye detection as it has better performance than any of the conventional measures. Combining yawn detection with this result gives insight that helps to decide if the alarm should be triggered by checking drowsiness levels [8].

IV. DROWSINESS DETECTION TECHNIQUES

In order to counteract the effects of drowsiness, modern technologies need to be used in ways that are not intrusive and yet accurate for better adoption rate. There exist a lot of research for implementing such techniques.

There exists a lot of software like TensorFlow and OpenCV which can help in the identification of faces and its different components making the fatigue detection easier to implement. There are techniques like monitoring distance between eyelids over a period to judge drowsiness. Others include factors like blinking rate and gaze detection. The next is to monitor mouth to detect fatigue in people if there are multiple instances of yawning. Other techniques include monitoring car data to detect drowsiness in the driver. It includes irregular steering movement, steep turning angle, sudden acceleration or sudden deceleration, lateral position in the lane, etc.

The detailed explanation of the techniques and their respective results used for the drowsiness detection purpose are:

1) Eyelid movement-based technique
2) Eye state analysis using Circular Hough Transform (CHT)
3) Yawning and Eye Closure
4) Open/Closed Eye Analysis

A. *Eyelid Movement based technique*

Eyelid movement-based technique can detect eyes and faces faster than normal means thus, in turn making the whole fatigue detection process faster [9]. Using the motion information to trace the face along with, mask matching technique and diamond searching procedure make the eye and face detection twenty times faster than when the same is done through OpenCV. This technique focuses on the movements of the eyelids of the drivers to determine their fatigue level. In two contiguous frames, there can only be one of four eyelid state of the driver.

The four states of eyelid are:

1) Completely closed state
2) Completely opened state
3) Partially opened state
4) Partially closed state

An eye is made up of three parts, sclera, iris and eyelid. When two contiguous frames are observed, and the temporal difference image is constructed each of these parts can easily be distinguished. And thus, the latter two eyelid states can be differentiated by tracking the movement of eyelids either from closed to an opened state or from opened to closed state based on the change in color gradient around iris from dark to light (Ncnt) or light to dark (Pcnt) respectively [6]. During an eyelid movement, if a dark peak occurs before a bright peak then, it signifies that the eye changed state i.e. eyes first opened from a closed state and then closed. The following formula can be used to figure out the current state of the eye.

$$g(x,y) = \begin{cases} -127 & Ic(x,y) - Ip(x,y) > th \\ 127 & Ic(x,y) - Ip(x,y) < -th \\ 0 & otherwise \end{cases} \quad (1)$$

Eye State Indicator

Different parameters to judge the drowsiness of the person is based on the eyelid state. These parameters are:

1) *Duration of the closure of eyelids*: It is calculated by different peaks of Pcnt and Ncnt curves. It is used in the calculation after comparing it to a certain threshold.
2) *Groups of continuous blinking of eyes*: They are also calculated by the different peaks of Pcnt and Ncnt curves. The driver may be fatigued if there are more than two continuous groups.
3) *The frequency of eyelid closure*: It is a very important criterion as a driver exhibits drowsiness the most by the frequency of eye blinks. If the driver recently became drowsy then they might try to flutter eyes faster to awaken. But, if the driver is feeling fatigued for a longer period, they might blink slower because of the tiredness.

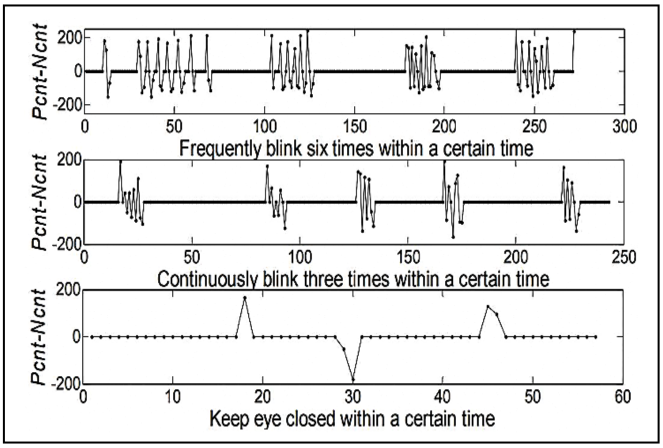

Figure 1. Types of drowsiness [9].

For a normal human, blinking every 6-10 seconds for 0.15 to 0.30 seconds is common with at most 2 blinks at any instance at most. If a person, violates any of these conditions there is a high chance of drowsiness for them.

This is a very fast technique and can be used in practical applications because of its simplicity and speed. But there is no mention of accuracy in the paper and the same cannot be judged without detailed experiments because of the glaring holes in the thesis itself. This process doesn't account for the driver's mouth movement which can cause a lot of inconsistencies. With different head orientations, the accuracy of the results will reduce. Also, any kind of movement in the background may result in false positives. Further work needs to be done on this method for better drowsiness detection as it uses a very good algorithm for eye detection but not for face or mouth detection. To attain the objective of a perfect driver drowsiness detection system, work needs to be done to solve the mentioned limitations.

B. Eye state Analysis using Circular Hough Transform (CHT)

Circular Hough Transform (CHT) was developed to perform analysis of state of eyes at different movements which can be implemented on any video capturing devices such as a driver-cam and even a webcam. This technique proposes the use of Circular Hough Transform to more accurately detect eyes [10]. In this procedure, firstly, the face is extracted using face detection techniques like SVM technique [11] which was developed by Blake and further optimized by Bakir [12]. Secondly, the eyes are localized to avoid confusion between the movement in other features of the face. This is done by highlighting the edges using the gradient image. Now, horizontal and vertical projections are made to detect upper, lower, left and right limit of the face and the eyes are now separated [7].

Alioua proposed a new edge detection technique that respects the eye's morphology [7]. It detects the eye using color variance between the pupil, iris and the sclera. The Sclera is a very dark region surrounded by iris which is very bright. This helps in the exact detection of eyes. A threshold pixel value is selected which is grey enough to stay in the boundary of the difference in pixel intensity inside the sclera while maintaining a large difference with the pixel intensity of iris. Now, the pixels to the left and right of the detected sclera pixels are checked to confirm if they are bright or not i.e. if they belong to iris or not. If all the conditions are met, the selected pixel forms the left or right edge of the sclera.

Now, three edge pixels are selected randomly and repeatedly from a region such that they are not collinear [7]. Now, the coordinates for the radius of the circle they can form is calculated using the three pixels. If the radius and center of the circle formed matches a certain threshold, the distance between the remaining edge pixels and the center is calculated. If they are also higher than the threshold, then the circle is used as the circle representing the iris. Otherwise, it is kept as a candidate circle. After all the iteration is done, circle with the largest radius is assigned to be the circle representing the iris.

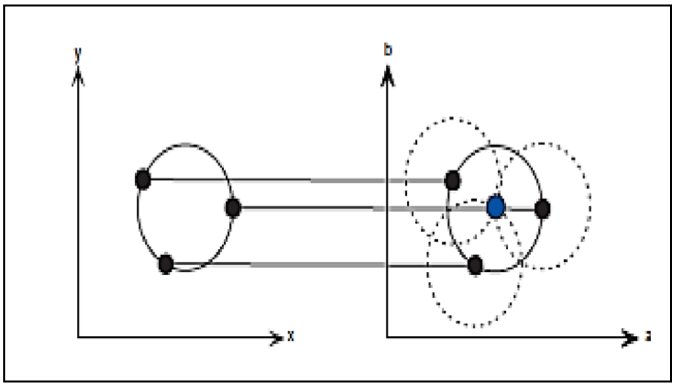

Figure 2: Circular Hough Transform to the parameter space from the Cartesian space [7].

This proposed technique for eye state analysis is very accurate in detecting eyes as well as different parts of the eye. This technique if used for drowsiness detection can help in decreasing the number of false positives. However, as this technique is camera based it is highly reliable only in an environment with enough light or with equipment with a decent low-light camera. Since, it is a camera based different head orientations will further reduce accuracy in the results. Also, this technique is complex and thus, requires a lot of computational power to work. But with enough light and processing power, it has very high accuracy according to Kappa Statistic, Confusion Matrix and Correct Classification Rate than most of the classic methods for detecting eye state [13]. The average accuracy according to Kappa statistic is 88% and according to Confusion Matrix is 99% [7]. The results indicate the consistency in face detection however, for preventing accidents due to fatigue this algorithm is insufficient because of the mentioned limitations.

C. Fusion of yawning and Eye Closure

This part includes combining two factors to correctly decide on the level of drowsiness of the driver. As the above-mentioned techniques only analyze the factors independently, therefore there is lesser accuracy in the detection of drowsiness state of the driver. But by combining multiple factors, it is natural to assume that the certainty of the driver's state [8]. This technique increases the certainty of the drowsy state of the driver by detecting and combining two factors, i.e. eye closure rate and yawning rate, in the repeated successive frames. This leads to an even more accurate conclusion for drowsiness state as yawning along with increased eye closure signifies fatigue.

There are three separate phases of applying fusion in a recognition system;

1) Feature recognition system
2) Similarity scoring stage
3) Decision stage

After completion of the decision process, ON or OFF state of the state alarm is decided which depends upon the result of the detection process [8]. The whole procedure includes decision making.

This technique works on three levels of detection classification;

1) *Level 1 - ALERT*: There is no sign of yawning, and the eye blinks at the minimum frequency rate. The facial features are normal and eye closure doesn't last for more than for 1 second.
2) *Level 2 - SEMI DROWSY*: Some amount of yawning is observed and there is an increase in the frequency rate of eye-blinking.
3) *Level 3 - DROWSY*: Closed state of eyes is detected, and the yawing rate is high. This is a high alert zone.

This technique uses human bodies' subtle movements to detect fatigue using various parameters like eye closure detection and yawning. However, the complexity of the method makes it inefficient to implement and since, it is a camera-based technique head rotation and bad lighting may further reduce accuracy. Also, combining factors may lead to processing redundant data of the combined input, which further leads to inconsistency, but can lead to higher accuracy compared to other techniques mentioned in this paper. M. Omidyeganeh doesn't mention accuracy of the technique using the various standards however, using a database of 450 images of 27 different people the accuracy is found to be at 98%. Since, the images used were of people looking straight in the camera the mentioned limitations are not checked by M. Omidyeganeh. The highly accurate result signifies that using this technique the detection of drowsiness is better than most of the technique currently being used at least for people looking straight in the camera. To have a system with almost no uncertainty in drowsiness detection further work needs to be done.

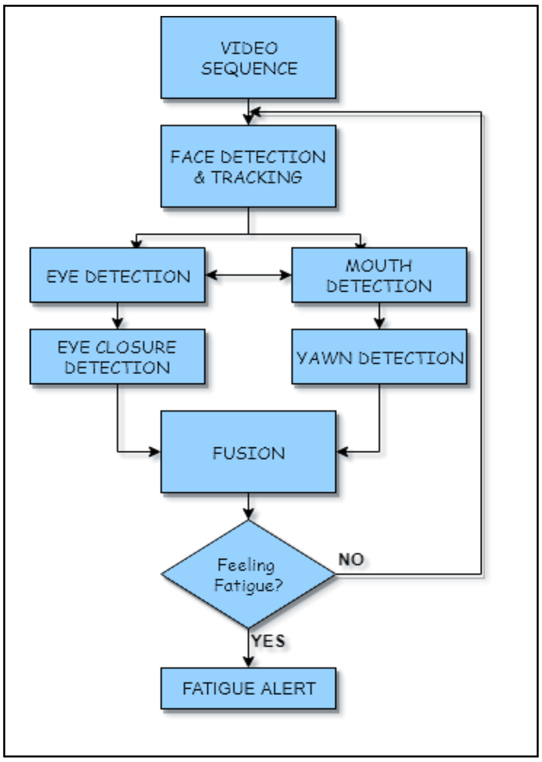

Figure 3: Driver drowsiness system using yawning and eye closure [8].

D. *Open/Closed Eye Analysis*

Open/Closed eye analysis proposed by Pooneh is a three-step system for drowsiness detection. It first detects the eye region using Eye Map. Orthogonal color space like YCbCr is preferred for detecting face because of its ability to remove luminance which is the parameter responsible for different complexions of the drivers in the image [14]. It is used because it can detect faces of different complexities with greater accuracy than RGB because different complexions have the same chrominance components and differ only in luminance. And, since RGB do not support luminance to a degree like YCbCr, it is tougher to detect faces with RGB [15]. Now, eyes are detected using face analysis and pupil center and iris boundary localization is done using Eye Map theory. This can all be implemented with any basic camera. Eye Map is made by clubbing Eye Maps of two different types, EyeMapC for Chrominance and EyeMapL for Luminance. EyeMapC can be formed using:

$$EyeMapC = \frac{1}{3}\left\{C_b^2 + (\widetilde{C_r})^2\left(\frac{C_b}{C_r}\right)\right\} \quad (2)$$

Chrominance Eye Map formula

Here, C_b and C_r represents the chrominance component of the YC_bC_r curve. $(\widetilde{C_r})$ represents 255-C_r and all the different components are reduced to be in the range of [0,255]. The other Eye Map called EyeMapL is of luminance which when multiplied with EyeMapC produces the required Eye Map which is used to detect eyes. This process is not time-consuming as it requires some basic calculations [16]. After the eye region is detected Top Hat filter [17] is applied and then the intensity image is converted into a binary image using N. Otsu's method [18]. Now, the needed EyeMapL can be constructed using:

$$EyeMapL = \frac{Y(x,y) \oplus se(x,y)}{Y(x,y)\ \Theta\ se(x,y) + 1} \quad (3)$$

Luminance Eye Map formula

Pupil centers are detected by performing localization in the upper two-quarter of the Eye Map. To increase its accuracy searching is done using a color gradient for the circle having the maximum level of grey pixels. The radius of the pupil is calculated by taking one-tenth of the distance between the two eyes detected from observations from the experiments. Now, using this radius, different pupil circles are formed having slightly different centers until the region where the sum of grey pixels is the largest [16].

For eye state analysis i.e. to detect if the eyes are closed or open, saturation channel of HSV color space is used. In HSV saturation varies from 0 to 1 (black to white, respectively). For the driver to properly see anything the distance between eyelids should at least be equal to the radius of the pupil. Since iris cover the largest area of the eyes, therefore the saturation value should be nearer to 1 than to 0 for open eyes. Saturation channel gives lower value when the color blends more with white and vice versa. When the eyelids come closer the saturation value decreases as more and more part of the iris is hidden. If the value falls below 0.5, then the eyes are considered closed. For this technique to properly work, the center of the pupil needs to be calculated accurately which is the case because of the color gradient searching done in the previous step.

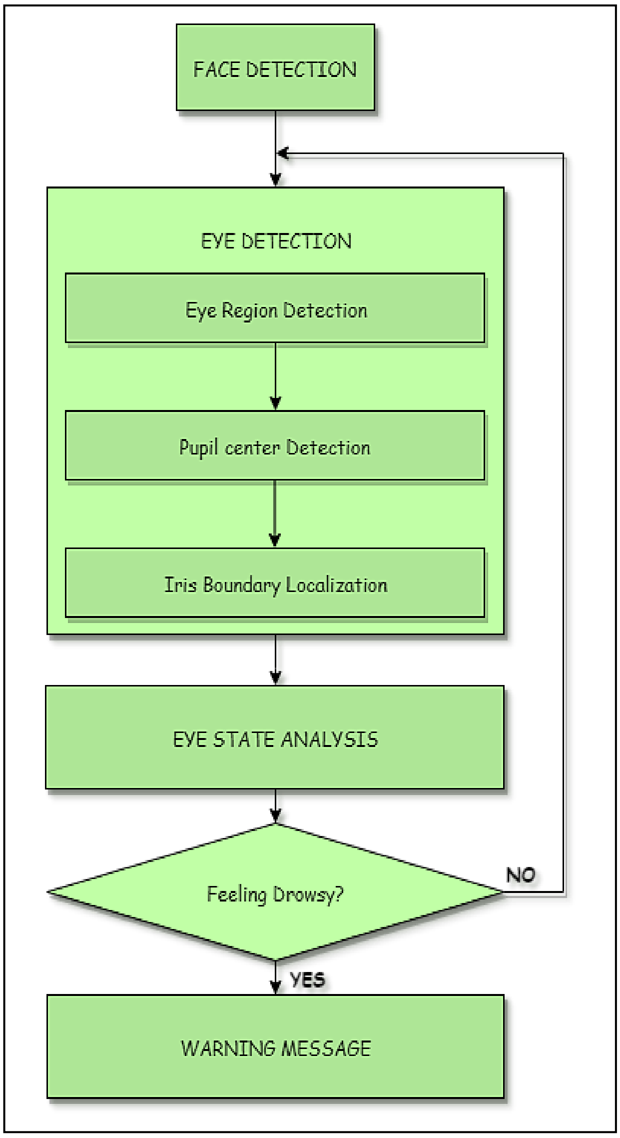

Figure 4. The mentioned system for drowsiness detection [16].

After all the data is collected, drowsiness is judged. Eyelid movement is a distinguishable feature for detecting fatigue. One of the best parameters to judge it is called PERCLOS, it refers to the eye closure percentage over time. A high PERCLOS parameter is closely related to drowsing [4]. A normal person when not tired blinks for at most 0.3 s, 9-10 times in a minute. But when a person is fatigued, the eyes involuntarily try to extend eyelid closure time to signal sleepiness. This leads to an increase in the PERCLOS percentage. Based on the experiment over 5 people, Pooneh found that if the PERCLOS moves above 40%, a drowsy warning should be sent.

This technique doesn't require training data to judge drowsiness accurately. Even without a training period, it is swifter and more accurate than eyelid distance-based technique as the calculations take very less time [19]. The accuracy of this technique is very high, compared to other techniques as it identifies eyes and its different regions with great accuracy. It is 98.8% accurate for detecting open eyes [16] and 96.4% for detecting closed eyes, which is better compared to many of the classical techniques. These results make it a very good candidate for widespread implementation for a driver drowsiness detection system. This technique is almost at par with Circular Hough Transform in terms of accuracy with the added benefit of faster processing. However, as this technique is based on camera equipment, it requires decent lighting conditions or a good night camera to be able to form different color spaces for detecting faces. This technique doesn't account for different head orientations and dark glasses. Since this technique uses human skin color and doesn't consider the movement to distinguish eyes and faces, it can give out wrong results for drowsiness if there is an image of a face in the perspective of a camera. Thus, for the perfect driver drowsiness detection system work needs to be done to solve the mentioned limitations.

V. CONCLUSION

In this paper, we studied different techniques that can be implemented for eye-state analysis for driver drowsiness detection. This paper briefly explains the step-by-step process of all the novel mentioned techniques used for detecting eyes. Also, it explains the upsides and downsides of the different techniques based on the accuracy of results and real-world problem. Since there is no dataset present currently for the different techniques it is almost impossible to truly compare the results of different techniques for the real world. This paper described the significance of the results mentioned by various authors and how they are related to this paper's objective of finding a perfect drowsiness detection technique.

As this is an actual problem and not a perceived one, henceforth it requires a working solution. As described throughout the paper, there are some technologies that exist to detect driver fatigue, but they have their own weaknesses. So, in order to have an improved solution for this, which has a better implementation of driver drowsiness detector with high accuracy research needs to be done.

As for the future, we plan to further research in this field in order to have a solution that will help to minimize and further eliminate this problem. Thus, devising an affordable device which can detect drowsiness for better road safety.

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