Yawning Detection for Driver Drowsiness Measurement: A Review

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Abstract: Sleep deprivation is one of the major causes of driver's drowsiness that leads to severe road accidents. Hence, it is necessary to develop systems to detect driver's drowsiness and prevent many accidents, physical injuries and economic losses. Lane position monitoring, vehicle pattern monitoring, behavioral and physiological measures have been explored to detect whether the driver is drowsy or fatigued. Behavioral measures such as eye blinking frequency, PERCLOS (percentage of eye lid closure), Head tilting, driver's direction of attention and yawning detection are mostly used in drowsiness detection and alert systems. This paper presents a thorough review of yawning detection techniques as yawning is not only useful in driver fatigue detection system but also in operator attentiveness detection, human well-being assessment and studying the intentions of people with a tongue disability. Yawning detection consists of three principle steps that are face detection, mouth detection and yawning observation. Viola Jones algorithm is widely used for face and mouth detection. A vast number of techniques have been examined to detect yawning in the past. The current growth of deep learning requires that these algorithms or techniques be revisited to evaluate their accuracy in detection of yawning. Efficient and accurate yawning measurement is needed to develop robust and reliable systems. This paper will discuss recent techniques and algorithms for yawning detection based on ANN, computer vision, machine learning and deep learning. It also lists various publicly available databases used for yawning detection.

Index Terms- **Yawning detection, driver drowsiness, machine learning, neural networks, computer vision**

I. INTRODUCTION

The Global status report on road safety 2013 (conducted every five years) had estimated that more than 231000 people are killed in road traffic crashes in India every year [1]. National Sleep Foundation's Sleep in America poll has shown that the percentage of Americans who have felt sleepy while driving is 60% and 37% admit to having fallen asleep while driving, in the past year [2]. The main cause of drowsy driver is prolonged driving hours, or night time driving especially in the case of heavy transportation vehicles. Finally, the driver not getting enough sleep will lead to a great risk of a meeting an accident. There are several signs that can tell a driver to stop and rest. These signs are difficulty focusing, frequent blinking, or heavy eyelids, wandering/disconnected thoughts, missing exits or traffic signs, yawning repeatedly or rubbing your eyes, trouble keeping your head up, drifting from your lane, tailgating, feeling restless. A few studies recommend countering drowsiness by taking naps between trips, consuming caffeine (coffee, energy drinks etc.), or driving with company [3] [4].

Considering the advancements in the field of science and technology, it is very important to develop efficient systems that can detect these signs and alert the driver or give warnings about his or her drowsiness levels. There are various measures that can be used to detect driver's drowsiness which are classified into three categories:

1. Behavioral measures
2. Physiological measures
3. Vehicle based measure

Behavioral measures [5] [6] [7] include the observation and study of various factors related to the face such as frequent eye blinking, yawning, head tilting, drooping eyelids, PERCLOS etc. These are non-intrusive in nature and are most popular method of detecting drowsiness. Physiological measures refer to the study of brain activity. Electro cardiogram (ECG), electromyogram (EMG), electro encephalogram (EEG) and electooculogram (EOG), heart rate (HR) and eye movements are possible measures for physiological signals [8] [9]. Out of these EEG signals are the most used, which have different frequency bands namely alpha, theta, beta that depict the sleeping levels of the driver. Though physiological measures are direct and much accurate but they are invasive in nature because many electronic devices and wires are involved in the process. In vehicle based method [10] [11] [13], a number of metrics like steering wheel movement, accelerator or brake pattern, vehicle speed, lateral acceleration, deviations from lane position etc. are monitored continuously. Comparing these measures, the physiological measures are much precise as they cannot be influenced but are very intrusive in nature and costly due to the equipment required. On the other hand, behavioral measures are less expensive.

A general framework for yawning detection is described in Section II. Section III provides a review a few decision-making techniques. Section IV. gives meta-analysis results and lists publicly available datasets which can be used as benchmarks for drowsiness detection task. Finally, conclusions are provided in section V.

II. YAWNING DETECTION PROCESS

Yawning is the most suitable and reliable feature to detect sleepiness and drowsiness. Some of the researchers have developed real time detection software using webcams, embedded hardware and others have used databases consisting video sequences to analyze the algorithms proposed by them. Most researchers follow a common process to extract facial characteristics from the camera feed. After obtaining these features, further processing is applied to determine the level of drowsiness, typically by applying various techniques. Prominent steps of yawning detection are shown in the flowchart.

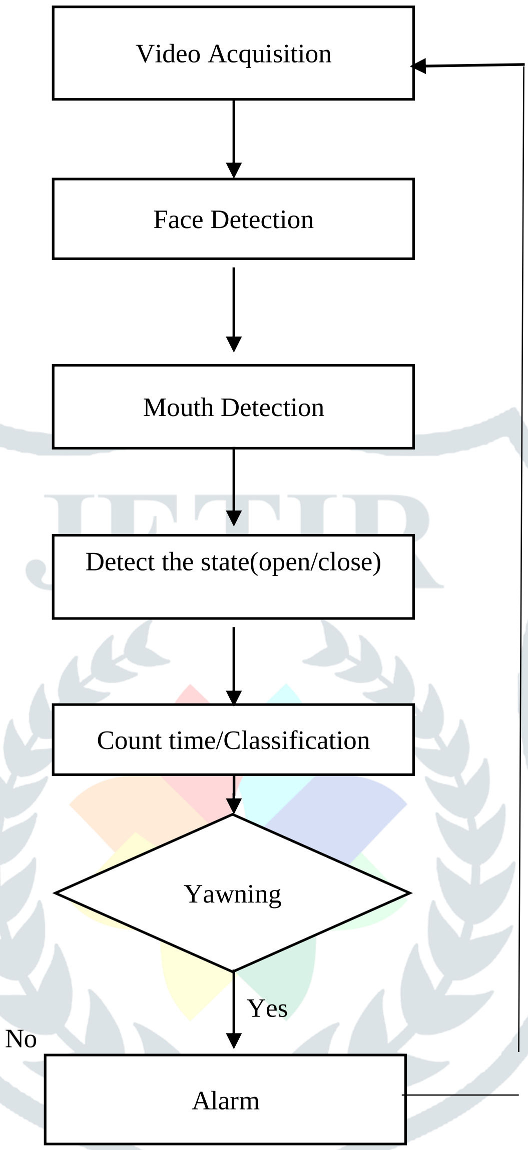

Fig 1. General Yawning Detection Process

2.1 Video Acquisition

Videos of drivers are captured using a webcam or a smartphone installed on the dashboard or side mirror. The extracted video is then converted into a series of images resulting in an image array. Images are then read at regular gaps.

2.2 Face Detection

The goal of the second stage of the yawning detection process is to identify the face of the subject. Face extraction is a vital step to reduce the search space and the computational cost. Viola jones algorithm is widely used for the detection of face [14]. [15] used support vector machine for face detection. The basis of this method is to run an observation window at all positions, and orientations in the image. A nonlinear SVM is applied to decide if a face is contained in the observation window. The nonlinear SVM operates by comparing the input patch to a set of support vectors (SV) which can be considered as face and anti-face models. The SV is scored by a nonlinear function against the observation window. A face is detected if the resulting sum exceeds threshold. However, when CNNs are used, the whole image is typically fed to a network that have multiple filters and features are automatically extracted. CNNs combine the two stages of detecting the face and feature extraction. [16] has used skin segmentation to extract the face area.

2.3 Mouth Detection

This step consists of extracting and the features that are to be analyzed. To detect or measure the yawning frequency efficiently, mouth region extracted instead of performing the operations on the whole face region. Histogram of oriented gradients(HOG), Local binary pattern, Landmark localization, Facial geometry color space conversions are different methods used for extracting out the features. Extracted features are then processed as is the case of PERCLOS for eye analysis and mouth based features for yawning analysis.

2.4 Classification

Various classifiers such as Haar classifier, Support vector machine, Convolution neural networks have been used to decide about the open and closed state of the mouth and to determine the drowsiness level of the driver. These classifiers usually increase the computational cost and complexity. Hence, these would be difficult to implement in real time embedded systems.

III YAWNING BASED DRIVER DROWSINESS DETECTION TECHNIQUES

Yawning is the most suitable metric that can prove that a person is fatigued or drowsy. Yawning analysis mainly refers to the process for differentiating between the open and closed state of the mouth. Many techniques have been used for yawn analysis which are classified into following categories:

1. Feature based approach
2. Appearance based approach
3. Model based approach

3.1 Feature based approach

Features like color, pixel intensities, texture, edges can represent the actions of the mouth. Commonly, movement of lips is tracked and width and height of the mouth is calculated using these features. In [18], the authors have proposed a system which is based on a two-agent expert system. Face is detected using skin segmentation, for all the skin area detected, the boundaries are defined. The lower half is the mouth region. The existence of yawning is shown by a black blob in the mouth area of the binary image. Histogram of the blob is obtained and the sun and length of the histogram is compared with the threshold values. If the calculated value exceeds the threshold then yawn count is obtained and driver is declared drowsy. This method also deals with occlusions like covering the mouth by hand during yawning. [19] also follows the same approach for yawn analysis. The mouth is extracted using the difference between the lip color and the face color. A refined version of viola jones algorithm [14] is implemented in [20] for face and mouth detection using Open CV detector [22]. Back projection theory is used for defining the threshold of converting the grayscale image of the mouth into binary image. Non-yawning frame is taken as reference frame and each consecutive frame is compared to the reference frame. If the ration of the black pixels in current and reference frame is greater than a threshold value, the driver is considered to be yawning. This threshold is calculated experimentally. Contour Activation algorithm is used by [21] to locate the contour of lips. If the mouth is open, the inside of the mouth is dark which is roughly segmented out. After segmentation contour of the mouth is obtained and height of the mouth is calculated. Height being greater than the threshold for several consecutive frames, means the person is yawning. Mouth and yawning detection in [25] is based on the color difference between lips and skin and inside of the mouth and mouth’s internal contour is extracted. T. Azim et al [23] uses spatial fuzzy c-means clustering to find the lips and other mouth features to determine yawning state. Instead of color and pixel values edges can also be useful in detection the mouth state. In [24] N. Alioua et al. proposed an algorithm based on Circular Hough transform (CHT). It is basically a method of finding circles in an edge image. The authors have also compared different edge detection techniques. To obtain edge images of the mouth a wide-open mouth edge detector is proposed, suitable to the mouth morphology. Then CHT is applied on the edge and the radius of the open mouth is obtained and finally it is decided whether the mouth is wide open. A consolidated list of feature based yawning detection is shown in Table I.

3.2 Appearance based approach

In this approach, different features are extracted and algorithms are trained on the basis of these features. Mostly statistical machine learning algorithms are applied. Ibrahim et al. [26] proposed a method for yawning detection based on widest area of darkest region between the lips and occlusions due to mouth covered with hand during yawning. Then classification of local binary patterns (LBP) features extracted from the mouth when covered by a hand and evaluated using neural network classifier. In [27] mouth aspect ratio, HOG (Histogram of oriented gradients), LBP (linear binary pattern) are the various features extracted and linear SVM is used for classification for yawn analysis. In [28] features like EAR (eye aspect ratio), MOR (mouth opening ratio), and NLR (nose length ratio for head bending) are extracted. Three classifiers namely, SVM, FLDA (fisher’s linear discriminant analysis) and Bayesian classifier are used for classification. As a result, it was observed that FLDA and SVM outperform Bayesian classifier. In [29] viola jones algorithm is applied to detect face and mouth and then SVM is trained with mouth and yawning images. Deep learning algorithms have been developed in [30] for mouth, face and nose area extraction. Nose is tracked using a combination of

Kalman filter and TLD tracker (track-learning-detection) which is adaptive to dynamic driving situations. Convolutional neural network (CNN) is trained for yawning analysis and fatigue detection. It uses six input features including four mouth corner values and confidence values of nose tracking. An integrated algorithm based on CNN and LSTM (long short-term memory) networks is proposed in [31] to analyze yawning. The author of [32] has proposed a method containing three phases: facial feature detection using viola jones; eye tracking and yawning analysis using correlation coefficient template matching; binary linear SVM for classification. Appearance based methods are much more complex than feature based methods. Moreover, a huge number of datasets is needed to get accurate results. Various appearance based researches are listed in Table II.

Table I: Feature based yawning detection

Author	Year	Method	Accuracy
M.K.Venkateshab et al. [18]	2016	Skin detection, vertical projection	94%
S.Abtahi et al. [19]	2011	Color based, mouth geometric features	N/A
M.Omidyeganeh et al. [20]	2016	Back projection theory, Viola jones algorithm	75%
N.Kumar et al. [21]	2014	Viola jones algorithm, Contour activation algorithm	88%
T.Azim et al. [23]	2010	Viola jones algorithm, Fuzzy c-means clustering	92%
N.Alioua et al. [24]	2014	Circular Hough transform	98%
Y.Ji et al. [25]	2018	Lip segmentation, contour based extraction	96%

Table II: Appearance based yawning detection

Author	Year	Method	Accuracy
M. Ibrahim et al. [26]	2015	LBP, Neural network	93%
Z. Jie et al. [27]	2018	HOG, LBP, SVM	95%
A. Kumar et al. [28]	2018	SVM, FLDA, Bayesian	92%, 95%, 85%
M. Saradadevi et al. [29]	2008	Viola jones algorithm, SVM	81%
W. Zhang et al. [30]	2015	CNN, Kalman Filter, TLD	92%
W. Zhang et al. [31]	2017	LSTM, CNN	88%
Manu B.N [32]	2016	SVM, Viola jones algorithm	94%
W. Zhu et al. [36]	2017	Fuzzy neural network	79%

3.3 Model based approach

Statistical models such as Active shape model are trained using the labelled images and features of mouth and lips. In [33], [35] Active Shape Models (ASM) algorithm is applied to get the changes on the face, eye closure duration, blink frequency, yawn duration. Active Appearance Model (AAM) is used in [34] to measure the three-dimensional coordinates of the feature points on the face image. K-Nearest-Neighbor method is applied to classify six levels of drowsiness. Table III lists a few model-based methods of yawning detection.

Table III: Model based yawning detection

Author	Year	Method	Accuracy
S. Anumas et al. [33]	2011	Active shape model	N/A
E. Vural et al. [34]	2007	Active appearance model	90%
H. García et al. [35]	2010	Active shape model	100%

IV DATABASE

Yawdd database [37] is widely used for yawning detection and is publicly database used for yawning detection. It consists of videos of drivers simulating drowsiness. There are two sets of videos in this dataset "Mirror" and "Dash" which represents two locations from where the videos of the drivers were taken. Each video contains different mouth conditions such as normal, talking/singing, and yawning. The videos are in 640x480 24-bit true color (RGB) 30 frames per second AVI format without audio. The total data size is about 5.1 Gigabytes. [18], [20], [27], [30], [31] have used yawdd to evaluate the performance of their algorithms. The authors of [25] used image database namely FERET face database, color face database of the California Institute of Technology (CIT).

V CONCLUSION

There are many methods and techniques available that can be used for the purpose of yawning detection. Feature based methods may detect yawning incorrectly if a person is not yawning such as laughing, singing or smiling. These features can also be inaccurate because of different head orientations, illumination conditions, existence of a beard or mustache, or acute lip movement. Real time systems can be developed on the basis of these techniques but there is still a room for improvement. Appearance based methods are too computational complex. Hence, to deploy these systems in vehicles, computational complexity of these algorithms needs to be reduced. Hybrid systems can be developed that can detect a slight change in facial expressions of the driver and generate a warning if there are any signs of fatigue. Reliable and efficient driver assistant software can be developed to reduce the amount of accidents caused due to drowsiness. Behavioral measures being non-invasive are a good choice for developing these systems. Feature, appearance and model based yawning detection techniques were discussed in this paper. Many researches have obtained accuracy above 90%. But there are limited number of datasets available.

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