DRIVER'S FATIGUE DETECTION SYSTEM BASED ON FACIAL FEATURES

IJAZ KHAN

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Universiti Tun Hussein Onn Malaysia

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ABSTRACT

With increasing number of vehicles on roads the risk of getting involved in an accident is increasing as well. In Malaysia alone, the number of traffic accidents in 2007 almost doubled as compared to the number of traffic accidents that occurred in 1997. This high accident rate has led to road accidents being the 5th leading cause of death in Malaysia and caused 9.3 billion ringgit of losses to the country in the year 2003. According to NHTSA (National Highway Traffic System Administration) reports one of the major reasons of road side accidents is fatigue while driving. Therefore, to prevent road side accidents that occurs due to fatigued drivers, it is essential to have an assistive system inside vehicle that monitors the vigilance level of driver and alert the driver in case of fatigue detection. This thesis presents a fatigue detection system based on yawning and eyes status that continuously analyse the face and facial features of the driver. Vision based approach is adopted to detect fatigue because other developed approaches are either intrusive (physical approach) that makes the driver uncomfortable or less sensitive (vehicle based approach). This system has improved the accuracy of fatigue detection by contributing in 3 steps of fatigue detection process. First step is face detection for which combination of Viola Jones and skin color pixels detection is used. Second is accurate detection of eyes and mouth in detected face area. The system uses knowledge based division and Viola Jones technique for second step. The third step is the introduction of dynamic threshold value, to check weather driver is in yawning or sleeping state. The accuracy of the system to detect fatigue level of driver is 98 % and average processing time per frame is 0.0948 seconds. The simulation results show that this system is able to detect fatigue even if driver is wearing spectacles or having beard. The algorithm is developed in MATLAB software.

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LIST OF SYMBOLS AND ABBREVIATIONS

p	-	Polarity
f	-	Applied feature
x	-	Sub window
θ	-	Threshold
η	-	Constant
h	-	Height of mouth
w	-	Width of mouth
Cb	-	Blue chrominance component in YCBCr color space
CCD	-	Charged coupled device
CLOSNO	-	Eye closure rate
Cr	-	Red chrominance component in YCBCr color space
$DOOm$	-	Degree of mouth openness
DWT	-	Discrete wavelet transform
ECG	-	Electrocardiography
EEG	-	Electroencephalography
EMG	-	Electromyography
EOG	-	Electrooculography
ELDC	-	Eyelid distance changes
FCM	-	Fuzzy c-means
HF	-	High frequency
HP_{LO}	-	Horizontal projection of open eyes
HP_i	-	Horizontal projection of frame i
HRV	-	Heart rate variability
KSS	-	Karolinska Sleepiness Scale
LF	-	Low frequency
MTO	-	Minister of transportation

NHTSA	-	National Highway Traffic Safety Administration
NTSB	-	National Safety Traffics Board
NREM	-	Non-rapid eye movement sleeps
PERCLOS	-	Percentage of eyelid closure over the pupil over time
REM	-	Rapid eye movement sleeps
RFID	-	Radio-frequency identification
SDLP	-	Standard Deviation of Lane Position
SSIM	-	Structural Similarity Measure
SVM	-	Support vector machine
SWM	-	Steering wheel movement
VGA	-	Video Graphics Array/Adaptor
VLP	-	Variation of lane position

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LIST OF PUBLICATIONS

Journals:

(i) Ijaz Khan, Hadi Abdullah, Mohd Shamian Bin Zainal (2013) “Efficient fatigue detection system as road safety feature for vehicle Research Journal of Applied Sciences, Engineering and Technology . © Maxwell Scientific Organization.

(ii) Ijaz Khan, Hadi Abdullah, Mohd Shamian Bin Zainal (2013) “Efficient eyes and mouth detection algorithm using combination of Viola Jones and skin color pixel detection.” International Journal of Engineering and Applied Sciences, EAAS, Vol 3, No. 3, (2013).

(iii) Ijaz Khan, Hadi Abdullah, Mohd Shamian Bin Zainal (2013) “A Robust Hybrid Design for Driver Fatigue Detection”, Journal of Information and Communication Technologies, Vol. 3, No. 4, April (2013).

Proceedings:

(i) Ijaz Khan, Hadi Abdullah, Mohd Shamian Bin Zainal “Efficient fatigue detection system as road safety feature for vehicle” Malaysian Technical Universities Conference on Engineering & Technology (MUCET 2013), 2-4 December 2013, Kuantan, Malaysia.

(ii) Ijaz Khan, Hadi Abdullah, Mohd Shamian Bin Zainal “Non intrusive alerting system for drowsy drivers”, Prosiding Seminar Kebangsaan Aplikasi Sains dan Matematik 2013 (SKASM2013) Batu Pahat, Johor, 29 – 30 October 2013.

(iii) Ijaz khan, Hadi Abdullah , Mohd Shamian Bin Zainal “Vision based composite approach for lethargy detection” Signal Processing & its Applications (CSPA), 2014 IEEE 10th International Colloquium on 7-9 March (2014).

CHAPTER 1

INTRODUCTION

1.1 Overview

Driving in fatigue has long been acknowledged to be one of the main hazards in safe driving. Fatigue has a negative impact on driver's abilities of driving and impairs driver's judgment and quick response time.National Highway Traffic Safety Administration (NHTSA) analysis data indicates that driving while drowsy is a contributing factor to 22 to 24% of car crashes, and that driving while drowsy results in a four to six times higher crash risk relative to alert driver (Lee, 2008). According to the National Sleep Foundation's 2005 sleep in America poll, 60% of adult drivers – about 168 million people – say they have driven a vehicle while feeling drowsy in the past year, and more than one-third, (37% or 103 million people), have actually fallen asleep at the wheel. In fact, of those who have nodded off, 13% say they have done so at least once a month. Four percent – approximately eleven million drivers – admit they have had an accident or near accident because they dozed off or were too tired to drive (Facts, 2005).

Drowsy driving denotes a situation when the driver is in a state of mental and physical fatigue, which includes decreasing mental alertness and a sensation of weariness and reduction in eye scanning behaviours (Klauer *et al.*, 2006). A severely drowsy driver will exhibit extended incompetence to safely perform a driving manoeuvre, be unaware of the vehicle's turning radius, perform driving manoeuvres under the incorrect assumption that it is safe, experience eye lid closures and have difficulties keeping his/her head in a lifted position, minimal body/eye movement and repeated yawning(Lee, 2008). When the driver is impaired by fatigue, his/her ability levels, driving behaviours, proficiencies and decisions are adversely affected and in these situations, the high accident rate is due to the fact that sleepy drivers fail to take correct actions prior to a collision (Tun *et al.*, 2010) .

An important irony in driver’s fatigue is that the drivers may be too tired to realize their own level of vigilance. This serious problem is often ignored by the driver. Driving in fatigue not only affects those who are driving while drowsy, but it puts all other road users in danger as well. Therefore, it is important to use new technologies to design systems, which are able to monitor driver’s level of vigilance through the whole driving process. Fortunately, people in fatigue exhibit many visual clues that can be detected on human face e.g.

(i) Yawning
(ii) Eye blinking frequency
(iii) Eye gaze moments
(iv) Head movements
(v) Facial expressions

Taking advantage of these visual characteristics, computer vision is the viable and felicitous technology to deal with this problem. This research presents a fatigue detection system that detects fatigue by analyzing the status of driver’s eyes and yawning. The aim of this project is to develop algorithm and simulation for fatigue detection. The focus will be placed on designing such algorithm and simulation that will accurately monitor eyes and yawning status of driver and will alert (written warning in case of simulation) the driver in case of fatigue detection.

1.2 Motivation

Driving is a common activity in people’s everyday life therefore; improving driving to reduce car crashes is an important issue. Even though a lot of studies and work has been done on road and vehicle designs to improve driver’s safety yet the total number of car crashes is increasing day by day. Reducing the number of car crashes would save millions of lives around the world every year. Most of crashes occur due to impairment of the driver’s attention. Four major causes of attention impairments that affect driver’s response time and alertness are alcohol, aging, distraction and fatigue. Alcohol and age factor results in slower response to hazards. Easy access of internet on cell phones and navigation systems increase driver's distraction .Out of the four major causes of driver's attention impairments, fatigue is often cited in accidents since drivers tend to adopt risky strategies to drive while drowsy(Lee, 2008). The National Highway Traffic Safety Administration has reported that driving in fatigue is one of the major reasons behind road accidents, and it exposes the driver to a much higher crash risk compared to alert drivers(Klauer *et al.*, 2006). According to MTO Driver's Handbook, driver's abilities are affected by fatigue long before they notice that they are getting tired(MTO, 2013). Therefore the need of designing and implementing an assistive monitoring system to detect driver's fatigue and to alert the driver after fatigue detection is realised that can give better performance than existing systems.

1.3 Problem statement

Researchers have been developing many methods for driver's fatigue detection using computer vision techniques. In these researches fatigue was detected by analyzing head movements, eyelid blinking and yawning. Limitation of these algorithms is that, they are dependent on one factor only (yawning or eye blink or head movement). Although some researchers used combination of two factors to improve the accuracy, however with the increasing rate of cars and car's accidents in every day's life, it is important to adjust, develop and validate the existing work for fatigue detection. This research provides an algorithm and simulation that combine two factors (yawning and eyes status detection) for fatigue detection. Combination of Viola Jones and Skin color pixel detection is used for face detection to increase the accuracy of face detection. Furthermore, combination of knowledge based division and Viola Jones method are used to increase the accuracy of facial features.

1.4 Objectives of the study

The objectives of this project are

(i) Developing algorithm and simulation for face and facial feature detection.

(ii) Developing algorithm and simulation for yawning and closed eyes status detection.

(iii) Developing algorithm and simulation for fatigue detection using information and results obtained in objective (ii).

1.5 Scope of the study

The scopes that need to be proposed in this project are:

(i) The image can be processed accurately in day light only.

(ii) Since fatigue level will be detected from facial expressions, hence user must face towards the camera.

(iii) The project will detect the fatigue level of user on software bases only.

(iv) Even if one factor (eye) is covered by spectacles, the system will be able to detect fatigue from the other uncover factor (mouth).

(v) Facial features (eyes and mouth) must not be covered simultaneously.

(vi) The project might give different results if the driver is suffering from illness.

1.6 Significance of the study

Fatigue or drowsiness often affects a person's ability of driving and increase the risk of road side accidents. The national Safety Traffics Board (NTSB) concluded that 52 % of 107 single-vehicle accidents were fatigue related; in nearly 18% of the cases, the driver admitted to falling asleep(Esre, 2009). With increasing number of vehicles on roads the risk of getting involved in an accident is increasing as well. In Malaysia alone, the number of traffic accidents in 2007 almost doubled as compared to the number of traffic accidents that occurred in 1997. This high accident rate has led to road accidents being the 5th leading cause of death in Malaysia and caused 9.3 billion ringgit of losses to the country in the year 2003(Statistics., 2008),(Mani *et al.*, 2003). Figure 1.1 shows the rate of occurrence of accidents between 2001 and 2010 and Figure 1.2 shows the increasing number of road side accidents from 1974 to 2004.

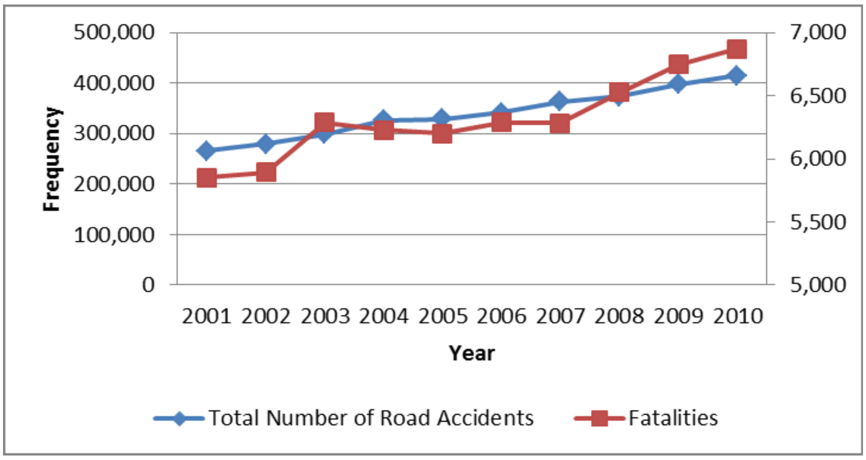

Figure 1.1: Accident Records in Malaysia from 2001 to 2010.

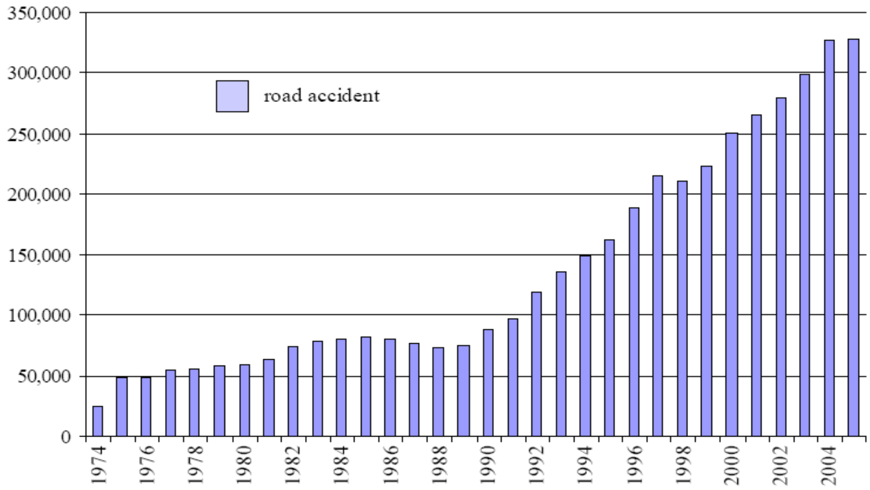

Figure 1.2: Statistics road accidents in Malaysia (2005)

The number of hours spent driving has a strong correlation to the number of hours driven and the percent of crashes related to driver fatigue related accidents.(Esre, 2009).Details of this relationship is described in Figure 1.3.

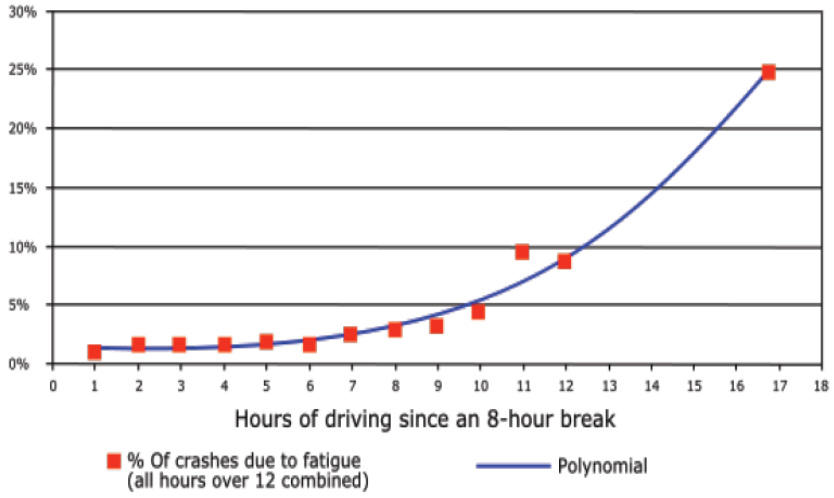

Figure 1.3: Relationship between number of hours driven and the percent of crashes related to driver fatigue

In fact, NTHSA has concluded that drowsy driving is just as dangerous as drunk driver. Therefore, it is an important issue to develop and improve the automatic fatigue detection systems that can help in saving lives and can contribute to the well being of the society.

There has been an increasing interest in computer vision approaches to prevent road side accidents as it is a prominent and non invasive approach to detect vigilance level of driver.

This project has the goal of using computer vision to detect fatigue level of driver in accurate and fast way. Many researchers have used one factor for fatigue detection but this project analyses and combines two different methods for face detection to increase the accuracy level of the system, and use two facial factors (eyes and mouth) for fatigue detection. The thesis contributes to understand how to build a robust fatigue detector based on vision without disturbance the driver's skills.

1.7 Contribution

This research has contribution in three section of driving behavior fatigue detection system which improves the accuracy of the system to 98% and reduces the average processing time per frame to 0.09488 seconds.

(i) In first section face detection is improved by using combination of skin colour pixel detection and Viola Jones technique.

(ii) In second section facial features (eyes and mouth) detection is improved using combination of knowledge based division and Viola Jones technique.

(iii) In third section a dynamic threshold value is introduced which improves yawing detection and closed eyes status detection.

1.8 Project schedule

The project schedule is given in Appendix A.

1.9 Outline of the thesis

This thesis presents the design and evaluation of the driver monitoring system to detect vigilance level of driver. It reviews existing fatigue detection approaches, propose a robust method for fatigue detection and finally presents a set of results and associated evaluations. The structure of the thesis is as following

CHAPTER 2 LITERATURE REVIEW:

Discus the existing approaches and methods of driver monitoring systems with detail.

CHAPTER 3 RESEARCH METHODOLOGY:

Describe the detail about proposed method of fatigue detection in MATLAB and its implementation.

CHAPTER 4 SIMULATION RESULTS AND ANALYSIS:

Presents the evolution results of simulation of proposed system and analyse its performance.

CHATPTER 5 CONCLUSION AND FUTURE WORK:

Summarizes and concludes the thesis and give an outline for future work.

CHAPTER 2

LITERATURE REVIEW

This chapter presents the relevant background information and theory on fatigue detection systems. Detection of fatigue is the main focus of this research, so a general concept of fatigue and its factors are discussed in Sections 2.1, 2.2 and 2.3. A review of existing fatigue detection approaches is presented in Section 2.5.Different methods and their results on the relevant topic, that have been conducted in daylight illumination and infrared illumination are presented in Section 2.6. Finally, face detection techniques, which is the first step of fatigue detection system in vision based approaches, are included in Section 2.7.

2.1 Fatigue definition

Fatigue, also referred to as tiredness, exhaustion, lethargy, and listlessness is a weariness caused by exertion. It describes a range of afflictions, varying from a general state of lethargy to a specific work-induced burning sensation within one’s muscles. It can be both physical and mental(Gandevia, 1992; Hagberg, 1981; Hawley J. &Reilly., 1997). Although physical and mental fatigue is different, the two often exist together – if a person is physically exhausted for long enough, they will also be mentally tired. During physical fatigue, it is hard for human bodies to continue functioning at their normal levels of physical ability. However, mental fatigue is more inclined towards feeling sleepy, and as a result reduces the vigilance level which in turns makes a person unable to focus or concentrate properly(Publich-health-article, 2012).

Fatigue has two forms, one manifests as a local, muscle-specific incapacity to do work, and the other manifests as an overall, bodily or systemic, sense of energy deprivation. Due to these two different aspects of fatigue symptoms, it has been suggested to look at the roots of fatigue from “central” and “peripheral” perspectives. Fatigue can cause formidable situations when doing tasks that need constant concentration, such as driving a vehicle. When a person is fatigued, he/she may experience loss of concentration or micro sleeps (Enoka, 1992).

2.2 Fatigue factors

Several factors have been addressed as main reasons of driver’s fatigue. Some are related to the cab environment and road conditions, others to the driver’s condition. These conditions are discussed in this section. This section also presents the factors of fatigue that have been addressed as major issues by different researchers.

Fatigue or sleepiness increases with the length of time a person has been awake. People who get insufficient sleep, either as a result of their life routine (e.g. late night socializing, shift work) or as a result of sleep disorder (e.g. sleep apnea syndrome, insomnia), may experience chronic sleepiness. Lack of sleep decreases the vigilance level and increase the risk of crash involvement. According to some researchers, being awake for more than 20 hours acutely increases the risk of crashes(Pack *et al.*, 1995). The most important factor, which is 58% of the fatigue related car crashes, are the length of the driver’s last sleep, total time of sleep in the last 24 hours and splinters sleeping patterns. Analysis of police reports in Europe and USA describes that accidents due to drowsy drivers occurs during night time and mid-afternoon (Dinges, 1995).

Swedish statics (1998) shows that 41% of accidents involve only one vehicle in darkness. However there is no significant proof that darkness as a single factor made drivers fall asleep but rather that the circadian rhythm makes the body want to sleep at night time. Study shows that fatigue induced accidents on Swedish highways occurs at three or four in the morning during week days, independent if it was summer or winter, Hence indicating that darkness was the not the main reason for falling asleep. Most of the accidents occurred later in the morning around eight or nine which indicates that it had more to do with lack of sleep than to lighting conditions(Kritina, 2007).

Cab environment, gender and age of driver are other factors that might add to the risk of falling asleep. Also the amount of noise in cab environment could be a factor to increase the sleepiness of the driver. The level of performance goes down when the continuous average intensity noise goes up(Kritina, 2007).

The stages of sleep can be categorized as awake, non-rapid eye movement sleeps (NREM), and rapid eye movement sleeps (REM). The second stage, NREM, can be subdivided into the following three stages (Brodbeck *et al.*, 2012)

Stage I: transition from awake to asleep (drowsy)

Stage II: light sleep

Stages III: deep sleep

In order to analyse driver fatigue, researchers have mostly studied Stage I, which is the fatigue phase. The crashes that occur due to driver's fatigue have a number of characteristics (Howe, 1998)

(i) Involve a single vehicle running off the road
(ii) Occur on high-speed roadways
(iii) Driver is often alone
(iv) Driver is often a young male, 16 to 25 years old
(v) No skid marks or indication of braking

In relation to these characteristics, the Southwest England and the Midlands Police databases use the following criteria to identify accidents that are caused by fatigue (Liu *et al.*, 2009)

(i) Blood alcohol level below the legal driving limit
(ii) Vehicle ran off the road or onto the back of another vehicle
(iii) No sign of brakes being applied
(iv) Vehicle has no mechanical defect
(v) Good weather conditions and clear visibility
(vi) Elimination of "speeding" or "driving too close to the vehicle in front" as potential causes
(vii) The police officer at the scene suspects sleepiness as the primary cause.

Statistics derived using these criteria cannot account fully for accidents caused by fatigue because of the complexity involved; therefore, accidents that can be attributed to driver's fatigue may be more devastating than the statistics reveal. Hence, in order to avoid these types of accidents, it is necessary to derive effective measures to detect driver's fatigue and alert the driver(Arun *et al.*, 2012).

2.3 Micro sleep

A micro sleep is an episode of sleep which may last for a fraction of a second or up to thirty seconds (American academy of sleep medicine 2005).A micro sleep is defined as a 3-14 sec episode during which 4-7 Hz (theta) activity replaced the waking 8-13 Hz (alpha) background rhythm(Amit &Matthew, 2005). Often, it is the result of sleep deprivation, mental fatigue, depression, sleep apnea, hypoxia, narcolepsy, or idiopathic hypersomnia. For the sleep deprived, micro sleeping can occur at any time, typically without substantial warning. Micro sleeps (or micro sleep episodes) become extremely dangerous when they occur in situations which demand constant alertness, such as driving a motor vehicle or working with heavy machinery. People who experience micro sleeps usually remain unaware of them, instead believing themselves to have been awake the whole time, or to have temporarily lost focus(Laura, 2013). There is little agreement on how best to identify micro sleep episodes. Some experts define micro sleep according to behavioral criteria (head nods, drooping eyelids, etc.) while others rely on EEG markers(Govinda *et al.*, 2012),(Amit &Matthew, 2005).

At times, drowsy drivers may slip into brief micro sleeps. Driving simulator studies of such drivers have indicated that driving performance during these brief periods becomes significantly worse, as illustrated by reduced control over vehicle position in the lane and greater likelihood of leaving the lane on a curve. Drivers are often unaware of slipping into micro sleeps, and thus may be not aware of their worsening attention and vehicle control(Laura, 2013).

2.4 Fatigue detection approaches

The process of falling asleep at the wheel can be characterized by a gradual decline in alertness from a normal state due to monotonous driving conditions or other environmental factors; this diminished alertness leads to a state of fuzzy consciousness followed by the onset of sleep. The critical issue that a fatigue detection system must address is the question of how to accurately and early detect fatigue at the initial stage(Qiong *et al.*, 2006). Possible techniques for detecting fatigue of drivers can be broadly divided into three major categories which are based on sensors and computer vision while one other method in which fatigue is measured either verbally or by questionnaire method.

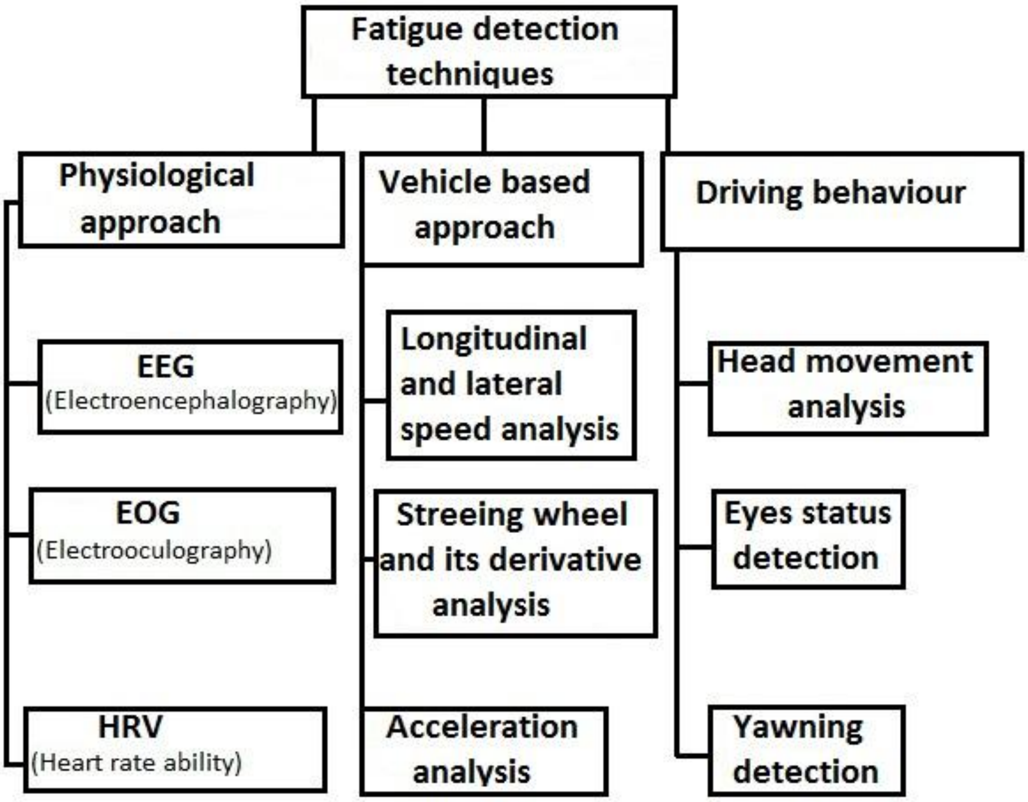

Figure 2.1: Driver fatigue detection approaches

In subjective method several questions are asked directly from user about their vigilance level, performance, effort level, mental alertness and response time. While in other methods sensors and computer vision technologies are used to detect fatigue using different approaches. Some of the major approaches are shown in Figure 2.1 and are described with detail in following section.

2.4.1 Physiological approach

Any physical changes that occur within the body during the onset of fatigue are considered to be physiological measures. Physiological measures have frequently been used for fatigue detection as they can provide a direct and objective measure. In general, different physiological measures have been used in attempts to detect tiredness; Possible measures are electroencephalogram (EEG), eyelid closure, eye movements, pupil size, electrocardiogram (ECG), electromyogram (EMG), electrooculogram (EOG), heart rate, pulse rate, breathing, skin conductance and production of the hormones adrenaline, noradrenalin and cortical(Belz, 2000), (Kircher, 2002),(Arun *et al.*, 2012).

Electroencephalography (EEG) is a method for measuring the electrical activity generated by the nerve cells of the brain, mainly the cortical activity(Svensson, 2004). In clinical contexts, EEG refers to the brain’s spontaneous electrical activity as recorded from multiple electrodes placed on the scalp. EEG-signal can be classified on the basis of its amplitude and frequency range. The patterns most reliable in consistence and occurrence are beta waves, alpha waves, theta waves and delta waves(Andreassi, 2000).

Beta waves (13-25 Hz) are common in the alert condition, during physical activity and when performing cognitive tasks. They can also be present in the first stages of sleep. The beta waves are irregular and have a small amplitude (2-20 μV) and relatively high frequency(Andreassi, 2000), (Muzet, 2002), (Stern *et al.*, 2001) . Alpha waves (8-12 Hz) are common in the awake and relaxed condition and can be used as a first measure of fatigue. They are rhythmic and have amplitude of 20-60 μV. When fatigue appears the first sign is a rise in alpha activity. Later in the process the alpha waves diminish and are replaced by theta waves. Up to 10 % of the population does not show alpha activity at all. When alpha activity shows during relaxation, a sudden exposure to a cognitive task will make it disappear and be replaced by beta activity. This state is called alpha blocking(Andreassi, 2000), (Gottlieb *et al.*, 2004).

Theta waves (5-7 Hz) have amplitude of 20-100 μV and will occur in the early stages of sleep. There exist two types of theta activity, one that is associated with performance of cognitive tasks and one associated with the early stages of sleep(Andreassi, 2000),(Stern *et al.*, 2001).

Delta waves (0, 4-5 Hz) occur during the deepest sleep or by brain tumors. Their amplitude is in the range 20-200 μV. Existence of frequencies in the delta range in the awake condition is not normal and probably due to artifacts, but can also be an indicator of a brain tumor(Andreassi, 2000), (Muzet, 2002),(Stern *et al.*, 2001). The major problem with the measurement is the small amplitude, which makes it difficult to separate it from artifacts. Blinking and tension in the face muscles induce artifacts in the EEG. The amplitude of the artifacts varies but can be as high as 50μV .Another problem is the small electromagnetic disturbances induced in the cables. The person should also be as still as possible and a proper electrode preparation is necessary to minimize the impedance between skin and electrode(Andreassi, 2000).

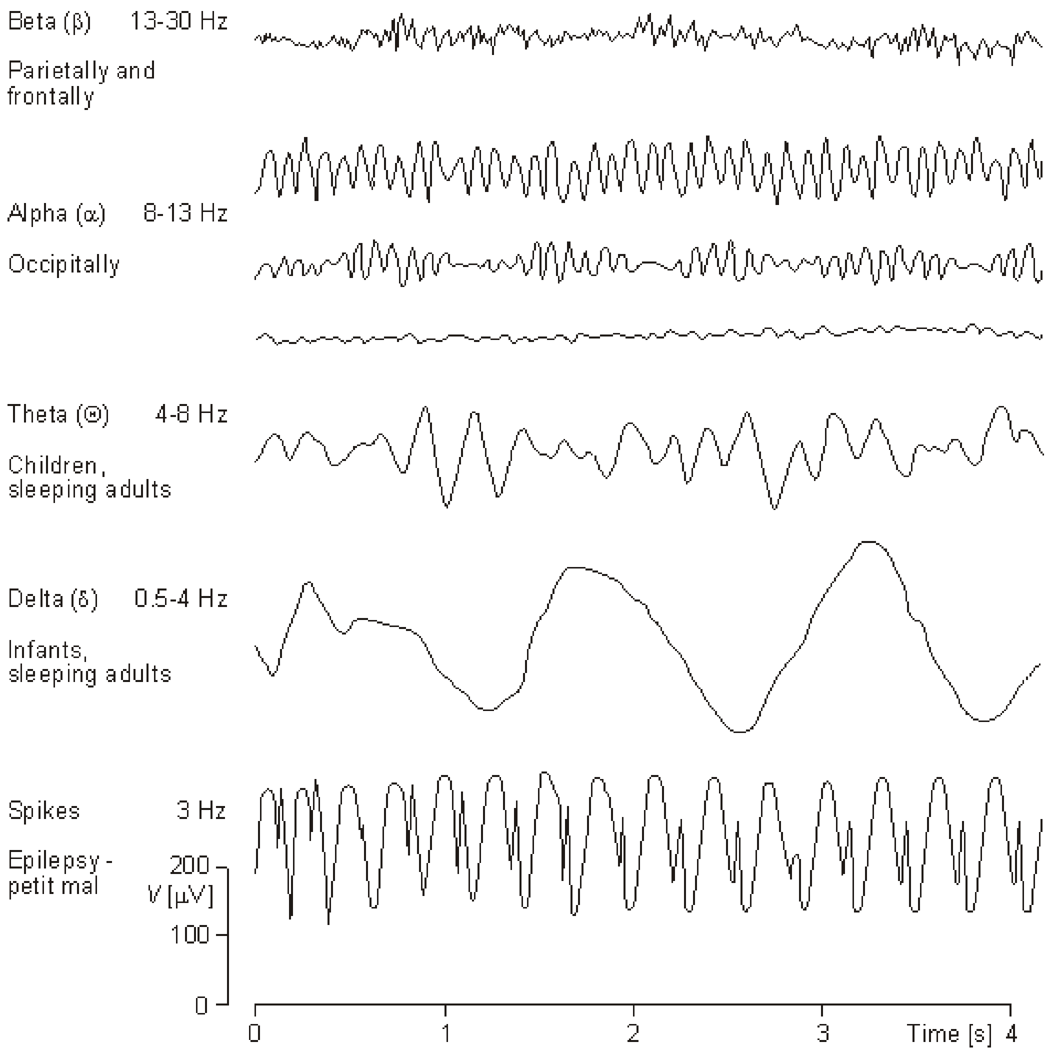

Figure 2.2: EEG waves(Svensson, 2004).

Electrooculography is a method used for measuring the potential difference between the front and back of the eye ball. The EOG can thus be used for detection of eye movements and blinks. The eye is a dipole with the positive cornea in the front and the negative retina in the back and the potential between cornea and retina lies in the range 0.4 – 1.0 mV. When the eyes are fixated straight ahead a steady baseline potential is measured by electrodes placed around the eyes. When moving the eyes a change in potential is detected as the poles come closer or farther away from the electrodes(Andreassi, 2000), (Thorslund, 2003) .Figure 2.3 describes the electrodes couple and its derived signal. The sign of the change depends on the direction of the eye movements.

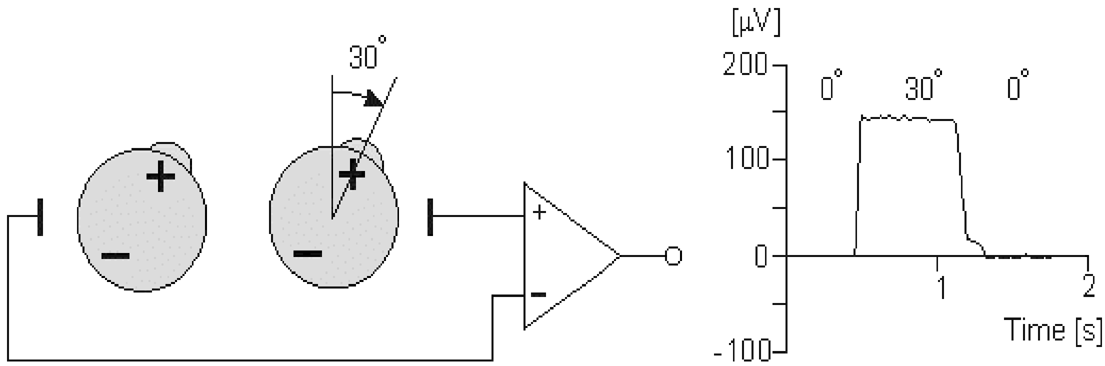

Figure 2.3: Change in EOG potential when looking 30 º to the right (Svensson, 2004).

It is important to be able to separate horizontal eye movements from vertical, and eye movements from eye blinks. By using different kinds of electrode placements the obtained recordings can be either vertical or horizontal(Muzet, 2002). In vertical recording electrodes are placed under and above the eye, and in horizontal recording they are placed at the outer edges of the eyes. Vertical recording is usually monocular, which means that the recording is made across one eye, whereas horizontal recording usually is binocular(Andreassi, 2000), (Stern *et al.*, 2001),(Thorslund, 2003). Figure 2.4 shows the placement of electrodes near the eyes. Eye blinks are detected by using vertical recording

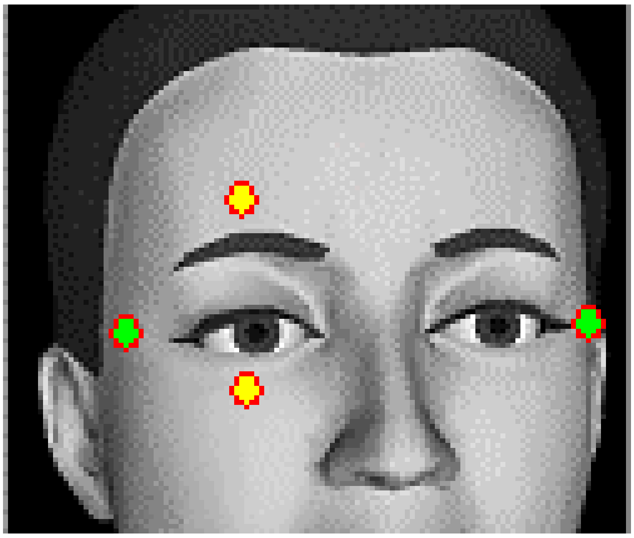

Figure 2.4: Electrode placement (Kircher, 2001)

Problems with EOG measurement are artifacts that arise from muscle potentials and small electromagnetic disturbances that can be induced in the cables. To reduce the impedance between skin and electrode, the skin must be cleaned carefully before measurement and electrode paste should be used (Andreassi, 2000),(Stern *et al.*, 2001). Time series of heart beat pulse signal can be used to calculate the heart rate variability (HRV) – the variations of beat-to-beat intervals in the heart rate (HRV, 1996), and HRV has established differences between waking and sleep stages from previous psycho-physiological studies(Elsenbruch *et al.*, 1999),(Xun, 2009). The frequency domain spectral analysis of HRV shows that typical HRV in human has three main frequency bands: high frequency band (HF) that lies in 0.15 – 0.4 Hz, low frequency band (LF) in 0.04 – 0.15 Hz, and very low frequency (VLF) in 0.0033 – 0.04 Hz(HRV, 1996),(Xun, 2009). A number of psycho-physiological researchers have found that the LF to HF power spectral density ratio (LF/HF ratio) decreases when a person changes from waking into drowsiness/sleep stage, while the HF power increases associated with this status change(Xun, 2009),(Elsenbruch *et al.*, 1999).

Table 2.1: Previous work done based on physiological approach

Reference	**Sensors**	**Feature extraction**	**Pre processing**	**classification**	**Accuracy**
(Khushaba. *et al.*, 2011)	EEG EOG	Fuzzy MI based Wavelet packet algorithm	Optimal and fuzzy wavelet packet	LDA, KNN, SVM	95-97% (31 drivers)
(Fu *et al.*, 2012)	EEG	Fast-Fourier-transform	Independent component analysis decomposition	Self organizing Neural fuzzy Inference network	96.7 % (6 drivers)
(Patel *et al.*, 2011)	ECG	Fast-Fourier-transform	Band pass filter	Neural network	90% (12 driver)
(Muhammed *et al.*, 2009)	EOG	Discreet wavelet transform	Filter and visual inspection	ANN	97-98% (10 tests)
(Jianping *et al.*, 2010)	EEG	Wavelet packet analysis	LMS algorithm, Visual inspection	Hidden Markov Model	84% (50 tests)

Table 2.1 gives a brief review of previous work done on fatigue detection using physiological approach. The accuracy of driver's fatigue detection using physiological approach is high; however, the intrusive nature of physiological approach considers being a problem for driver. Many researchers have developed wireless devices to measure physiological signals in a less intrusive manner, in which electrodes are placed on driver's body and signals are obtained using wireless technologies like zigbee(Hiroyuki, 2013), Bluetooth(Klingeberg, 2012). Many researchers attempted to measure physiological signals in a non intrusive way; by placing electrodes on the steering wheel(Xun, 2009).

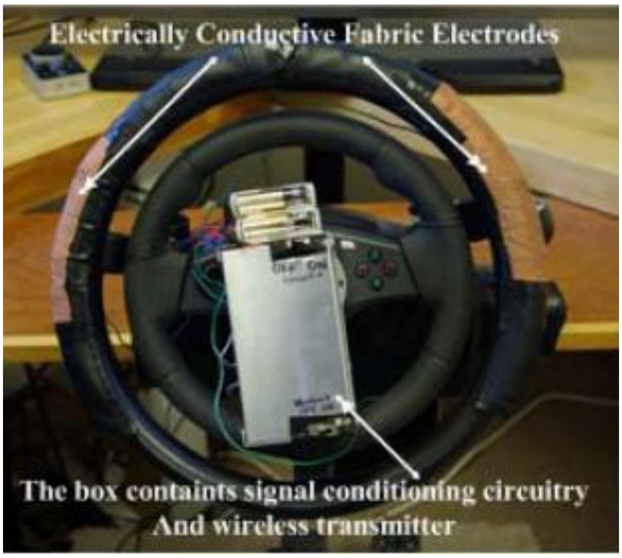

Figure 2.5: Electrodes placed on steering wheel (Xun, 2009)

The obtained signals were processed in android based smart phone devices(Wan-Young, 2012). However the reliability and accuracy of non-intrusive physiological approach systems are relatively less due to errors in measures that occur due to improper electrode contact. Therefore a system based on non intrusive approach that provides high accuracy and reliability is still needed that can increase road side safety by alerting the driver on time.

2.4.2 Vehicle based approach

Vehicle-based measure is another approach to detect driver's level of vigilance. Vehicle-based measures include speed variability, lateral position, steering wheel movements, and reaction time. In this approach, measurements are determined in a simulated environment by placing sensors on various vehicle components like steering wheel and the acceleration pedal; the signals received from the sensors are then analyzed to determine the vigilance level of driver(Takei &Furukawa, 2005).

The two most commonly used vehicle-based measures are standard deviation of lane position and the steering wheel movement. Standard Deviation of Lane Position (SDLP) is a measure through which the vigilance level of driver can be determined(Ingre *et al.*, 2006). The software itself gives the standard deviation of lane position in a simulated environment and in case of field experiments the position of lane is tracked using an external camera. However limitation of SDLP (standard deviation of lane position) is that it is purely dependent on external factors like road marking, climatic and lighting conditions.

Measurement of steering wheel movement (SWM) is a widely used vehicle-based approach for fatigue detection(Sarah *et al.,* 2005),(Portouli *et al.,* 2007). In this method sensors are mounted on steering wheel that senses the movement of the steering wheel. Many researchers used driver steering wheel movements and steering grip as a sign of fatigue. Micro corrections for steering are necessary for environmental factors and the reduction in number of micro-corrections to steering shows an impaired state(Ruijia. *et al.,* 2009). Study shows that sleepy drivers made less steering wheel reversals than normal drivers(Fairclough &Graham, 1999). A comparison graph between the normal and sleepy driver from the study of the (Ruijia. *et al.,* 2009) is shown in figure 2.6.

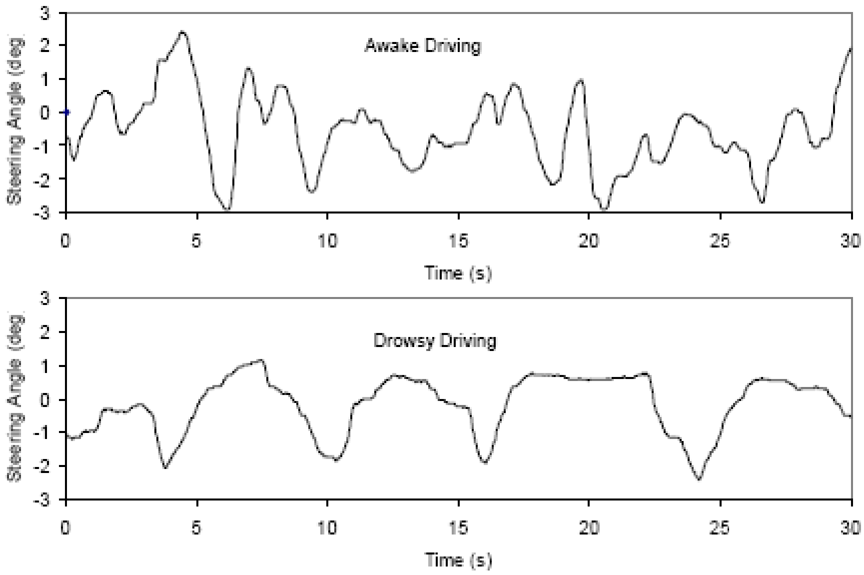

Figure 2.6: Steering wheel angle for awake and drowsy driver (Ruijia. *et al.,* 2009)

The researchers considered only small steering wheel movements (between 0.5° and 5°), which are needed to adjust the lateral position within the lane that helped in eliminating the effect of lane changes(Sarah *et al.,* 2005). Car companies like Renault (Artaud *et al.,* 1994) and Nissan (Keiichiro *et al.,* 1985) adopted this technology however the main problem with steering wheel input is that it works in very limited situations(Lavergne. *et al.,* 1996).

A commercial product, A Alert (AA), is a flexible rubber device that uses motion and reaction time to detect fatigue level. When a driver is tired and takes a break from the wheel, the device vibrates. If a driver, while driving, doesn't move his/her wrist for more than 15 seconds, a vibration is sent to the bracelet. The driver needs to move his/her wrist in order to stop the vibration of the bracelet. The slower the reaction to the vibration, the more likely it is that the driver is tired and should take a break from the wheel. The device communicates with an RFID tag positioned in the car and only starts detecting fatigue when the driver is in the car. Figure 2.7 shows the A Alert device.

Figure 2.7: A Alert device was developed by Dan Ruffle(Esre, 2009).

In summary, several studies have shown that vehicle-based approach is not an effective way to predicate fatigue with high accuracy. Moreover, vehicular-based metrics are not specific to fatigue. SDLP (Standard Deviation of Lane Position) can also be caused by any type of impaired driving, including driving under the influence of alcohol or other drugs, especially depressants(Esre, 2009),(Das *et al.*, 2012).

2.4.3 Driving behaviour

When drivers get drowsy behind the steering wheel, they exhibit some particular characteristics including yawning, rapid eye movements or swinging head(Esra *et al.*, 2007). Computer vision technology is widely used to detect these particular characteristics of humans to determine the vigilance level of drivers. The advantage of computer vision techniques is that they are non intrusive and are easy to use by the general public.

The current technology provides us reasonable tools to develop computer vision systems that can detect fatigue level by observing facial motion, eyelids movements and yawning. Many researchers focused on eyes blinking to determine the fatigue level of driver and proved that it is a reliable measure to detect fatigue (Bergasa *et al.*, 2006), (Luke &Alexander, 2009),(D'Orazioa *et al.*, 2007). Some researchers used other facial features like inner brow rise, outer brow rise, lip stretch, jaw drop, yawning and eye position orientation to detect vigilance level of driver(Xiao *et al.*, 2009a), (Esra *et al.*, 2007), (Lingling &Chen, 2009), (Murphy-Chutorian &Trivedi, 2010),(Xuetao. *et al.*, 2009).

In driving behavior approach mostly simple CCD or web camera is used during day time (Arun *et al.*, 2012) and IR camera during night (MarcoJavier *et al.*, 2010) for image acquisition at around 30 fps. After capturing video the first step towards fatigue detection is the detection of face and facial features which is normally achieved by using different techniques like Viola Jones, skin color detection techniques , Cascade of Classifiers or Hough Transform, Haar Algorithm, Connected Component Analysis or Gabor Filter(Zhang &Zhang, 2010), (Esra *et al.*, 2007), (D'Orazioa *et al.*, 2007),(MarcoJavier *et al.*, 2010). After localization of the face in the image, features such as eye blink, yawning and head position, are analyzed using feature extraction technique, such as Discrete Wavelet Transform, Condensation Algorithm , Wavelet Decomposition or Gabor Wavelets(MarcoJavier *et al.*, 2010), (Esra *et al.*, 2007). The status of the driver's vigilance level is then classified as either normal, slightly drowsy, highly drowsy by using of different classification methods such as support vector machine, fuzzy classifier, neural classifier and linear discriminant analysis(Xiao *et al.*, 2009b), (Esra *et al.*, 2007),(D'Orazioa *et al.*, 2007).

A list of previous works on driver's fatigue detection using behavioral measures and its accuracy is given in Table 2.2. The advantages of this approach over previous mentioned approaches are that driving behavior approach is nonintrusive and more reliable as well as accurate and robust. That's why in this project we used driving behavior approach to detect face and facial features.

Table 2.2: Previous study on driving fatigue using behavioural measures

References	**Image acquisition**	**Fatigue measures**	**Face detection techniques**	**Facial feature detection**	**Classification types**	**Accuracy**
(Xiao *et al.*, 2009b)	CCD camera	Yawning detection	Grey projection and gravity center template	Gabor wavelets	Linear discriminant analysis	91%
(MarcoJavier *et al.*, 2010)	Infrared camera	Eye state	Gabor filter	Condensation algorithm	Support vector machine	93 %
(Esra *et al.*, 2007)	Digital Camera	Facial expressions	Gabor filter	Wavelet decomposition	Support vector machine	96 %
(Xiao *et al.*, 2009a)	Camera	Multi scale Dynamic features	Gabor filter	LBP(local binary pattern)	Adaboost algorithm	98%
(Zhang &Zhang, 2010)	Infra red Illuminator camera	Eyes blinks Per minutes	Haar algorithm	Kalman filters	Support Vector Machine	99%
(D'Orazioa *et al.*, 2007)	Webcam And fire Wire cam	Frequency and duration of eye closure	Hough transform	DWT (Discrete wavelet transform)	Neural classifier	95%
(Danghui *et al.*, 2010)	Simple camera	Eyes blinks	Cascade Classifiers	Color pixel difference	Region mark algorithm	98%

2.4.4 Subjective measures

Although most of researches to detect driver's fatigue are based on Physiological approach, vehicle based approach and driving behavior approach yet many researchers tried to detect fatigue using subjective measures. Subjective measures are based on the driver's personal estimation and many tools have been used to translate this rating to a measure of driver's fatigue. Karolinska Sleepiness Scale (KSS) is a nine-point scale that has verbal anchors for each step, is the most commonly used fatigue detection scale. Table 2.3 shows the nine point scale used for fatigue detection(Sarah *et al.*, 2005).

Table 2.3: Karolinska Sleepiness Scale (KSS)

Rating	**Verbal description**
1	Extremely alert
2	Very alert
3	Alert
4	Fairly alert
5	Neither alert nor sleepy
6	Some signs of sleepiness
7	Sleepy, but no effort to keep alert
8	Sleepy, some effort to keep alert
9	Very sleepy, great effort to keep alert, fighting sleep

Some researchers measured the KSS ratings of drivers every 5 min and used it as a reference to the EOG signal collected(Shuyan &Gangtie, 2009). But some researchers compared the variation of lane position (VLP) measured by vehicle based approach with self-determined KSS, which was recorded every 2 min during the driving task, and concluded that these measures were not in agreement(David *et al.*, 2010).

According to (Ingre *et al.*, 2006) fatigue related physiological signals, the major lane departures and high eye blink duration measures are prevalent for KSS ratings between 5 and 9. However, the subjective rating does not fully match with the measurements of vehicle-based, physiological and driver's behavior approaches. The reason of this variation is that the level of fatigue is measured every 5 min, using subjective measures sudden variations cannot be detected. Another limitation is that subjective measures are only useful in simulated environment because it is very difficult to get fatigue feedback from driver while he/she is driving in real.

A comparative table of all mentioned approaches in this chapter is given in Table 2.4 which describes the advantages, limitations, reliability and accuracy of all discussed approaches.

Table 2.4: Advantages and limitations of discussed approaches

References	**Approach**	**Parameters**	**Advantages**	**Limitations**
(Hyun *et al.*, 2012)	Physiological	EEG, EOG, HRV	Reliable	Intrusive
(Charles *et al.*, 2009)	Vehicle based	Speed, acceleration and angle of steering wheel analysis	Non intrusive	Unreliable and limited to vehicle type
(Abtahi *et al.*, 2011), (Laurence *et al.*, 2000)	Driving behavior	Eye status, yawning and head position analysis	Non intrusive, Ease of use , reliable	Lighting problem
(Ingre *et al.*, 2006)	Subjective measures	Questionnaire	Subjective	Impossible in real time

2.5 Face detection techniques

The first step to detect driver's fatigue using driving behavior approach is face detection; therefore it is an essential goal of this project to develop a robust and accurate face detection algorithm. Over the past decade, many researchers have been working to develop and improve the performance of human face detection and they proposed several approaches like active shape model(Lanitis *et al.*, 1995), shape template(Ian *et al.*, 1992), Eigen face(Matthew &Alex, 1991), neural network (Rowley *et al.*, 1998) Hidden Morkov model (Rajagopalan *et al.*, 1998) and many

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