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Hybrid Drowsiness Detection System to Prevent Accident using Non-Intrusive Physiological Measures

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Abstract - In recent years, driver drowsiness has been one of the major causes of road accidents and can lead to severe physical injuries, deaths and significant economic losses. Since car accidents may be caused by the driver's tiredness, there are some assistance systems designed for bringing the attention of a driver. In this paper, we review different measures and discuss its advantages and limitations and we are also discussing different indicators of sleepiness in this paper. We conclude that by designing a hybrid drowsiness detection system that combines the non-intrusive physiological measures with other measures one would accurately determine the drowsiness level of a driver.

Keywords **-** *Drowsiness detection, Driver sleepiness, indicators, Hybrid measures, Drowsiness system*

1. Introduction

Drowsiness is an important factor in the motoring of vehicle accidents [1, 2, 3, 4]. It was demonstrated that driving performance deteriorates with increased drowsiness with resulting crashes constituting more than 20% of all vehicle accidents [6].Many traffic accidents are caused by drivers falling asleep at the wheel [5]. It would thus be beneficial to find a way to detect drowsiness before it occurs and to be able to warn the driver in time. Driving with drowsiness is one of the main causes of traffic accidents. Driver fatigue is a significant factor in a large number of vehicle accidents. The development of technologies for detecting or preventing drowsiness at the wheel is a major challenge in the field of accident avoidance systems. Due to the hazard that drowsiness presents on the road, methods need to be developed for counteracting its affects.

There are many technologies for drowsiness detection and can be divided into three main categories: biological indicators, vehicle behavior, and face analysis. The first type measures biological indicators such as brain waves, heart rate and pulse rate. These techniques have the best detection accuracy but they require physical contact with the driver. They are intrusive. Thus, they are not practical.

The second type measures vehicle behaviors such as speed, lateral position and turning angle. These techniques may be implemented non-intrusively, but they have several limitations such as the vehicle type, driver experience and driving conditions. Furthermore, it requires special equipment and can be expensive.

The third type is face analysis. Since the human face is dynamic and has a high degree of variability, face detection is considered to be a difficult problem in computer vision research. As one of the salient features of the human face, human eyes play an important role in face recognition and facial expression analysis. In fact, the eyes can be considered salient and relatively stable feature on the face in comparison with other facial features. Therefore, when we detect facial features, it is advantageous to detect eyes before the detection of other facial features. The position of other facial features can be estimated using the eye position. In addition, the size, the location and the image-plane rotation of face in the image can be normalized by only the position of both eyes.

2. Drowsiness and Driving

Drowsiness is the state where a person is almost asleep or very lightly asleep. It refers to an inability to keep awake or a drive to sleep [7]. Another concept commonly used is fatigue, which is an extreme tiredness that results from physical or mental activity. Drowsiness can also be described by the grade of wakefulness or vigilance. Wakefulness is the same as alertness or a state of sleep inability, whereas vigilance can be described as watchfulness or a state where one is prepared for something to happen [7][8].

According to [9][10] several factors have been found to affect the grade of wakefulness. The time spent to carry out a task (time on task) and the amount of sleep during night are the most obvious factors. Other factors contributing are the amount of light, sound, temperature and oxygen content. Motivation and monotony of the task will also have an effect on the grade of wakefulness

2.1 Accidents Caused by Drowsy Drivers

The official number of traffic incidents on highways related to drowsiness is 1-3%, according to statistic analyses made by the American National Highway Traffic Safety Administration

(NHTSA) [10]. According to Åkerstedt and Kecklund (2000) the number should be as much as 10-20 %. One reason can be that people that report traffic accidents lack the practice in judging the role of drowsiness as a contributing factor. It is difficult to give an exact measure of drowsiness in the way that is possible with for example alcohol. Furthermore, drowsiness is a transient state, which also makes the detection difficult.

3. Methods used for Drowsiness Detection

Drowsiness can be measured through physiological measures, performance measures, self report or expert ratings [11][12][13]. The different methodologies are described below.

3.1 Physiological Measures

Physiological measures have frequently been used for drowsiness detection as they can provide a direct and objective measure. Possible measures are EEG, eyelid closure, eye movements, heart rate, pupil size, skin conductance and production of the hormones adrenaline, nor adrenaline and cortisol [11][12][13].

EEG has shown to be a reliable indicator of drowsiness. The amount of activity in different frequency bands can be measured to detect the stage of drowsiness or sleep. Several studies [11][14][13] also reveal that eye parameters such as blink duration, blink frequency, delay in lid reopening and the occurrence of slow eye movements (SEM) are good indicators of drowsiness. These parameters can be measured by EOG. In a paper by Renner and Mehring (1997) it has been suggested that drowsiness should be defined based on a combination of brain and eye measures. EEG could be used to detect deficiencies in information processing, which can occur even though the eyes are wide open, and the slow eye closures would detect insufficient perceptual capabilities. The problems with both EOG and EEG are the requirement of obtrusive electrodes which make them unsuitable to use in cars, as cabling of the drivers would not achieve any acceptance. Hence, they are not feasible to be used in a real-time drowsiness detection system. A decrease in heart rate and an increase in heart rate variability have shown to be indicators of drowsiness, as well as decrease in pupil size, spontaneous papillary movements and decrease in skin conductance. A decreased production of adrenaline, nor adrenaline and cortisol are other possible indicators of drowsiness [11[12][13].

3.2 Driving Performance Measures

Driving performance measures include steering wheel movements, lateral position, speed variability and reaction time. Studies indicate that the steering wheel variability increases with the amount of drowsiness. The steering movements also become larger and occur less often, and the lateral position variability increases as the driver gets drowsier. Also, the speed variability increases and the minimum distance to any lead vehicle decreases. The reaction time to any unexpected events also gets longer with increased drowsiness. One problem concerning using driving performance measures as indicators of drowsiness is inter- and intra individual differences in driving performance, which could be solved by a combination of different measures. It has been suggested that the combination of performance measures with physiological measures would give a sufficient reliable detection method [11][12][13].

3.3 Self-Report

Self-report refers to the subjective rating made by the driver and can be obtained through various rating scales. It is important that the scales are displayed in such a way that they are unobtrusive and don't alert the driver, since that would affect the drivers state. Various rating scales have been constructed, for example the Stanford Sleepiness Scale (SSS) and the Karolinska Sleepiness Scale (KSS) [15].

KSS is a nine graded absolute rating scale that has been validated against EEG and EOG indicators of sleepiness [15][16]. Step 1, 3, 5, 7 and 9 contain a verbal description of drowsiness. The original KSS has been modified by Reyner and Horne (1995) who have added descriptions to the intermediate steps as well. The reason for this is that people seemed to report the steps with verbal descriptions more often than the intermediate steps. The modified KSS will be used in this thesis and is described in Table.

Table 1. Karolinska sleepiness scale (KSS).

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

3.4 Expert Ratings

Expert ratings refers to the rating made by an observer and are made on a similar scale as the self-report. Results from earlier studies indicate that these ratings are reliable and consistent [17]. The observer looks for behavioral indicators of drowsiness, for example eyelid closures, yaws, a vacant stare, body movements or the head falling backward or forward [18].

4. Driver Sleepiness

Driver fatigue and sleepiness (or drowsiness) are often used interchangeably [19]. Fatigue refers to an inability or disinclination to continue an activity, generally because the activity has, in some way, been going on for "too long" [20]. Fatigue is often considered to be a generic term, and sleepiness is one of the major subcomponents. Most often they should be considered separate, even though they are related to the same concept.

Fatigue is defined as a global reduction in physical or mental arousal that results in a performance deficit and a reduced capacity of performing a task [21]. Sleepiness on the other hand is defined as the physiological drive to sleep [22]. The reason for sleepiness is more or less related to time being awake, time of the day and hours slept last 24 hours. The reasons for fatigue could be several, from physical, perceptual, boredom to apathy [23]. A person can be fatigued without being sleepy, but a person cannot be sleepy without being fatigued. The countermeasure for sleepiness is only sleep. The countermeasure for fatigue could be other. This is why they need to be separated.

There are lots of studies focusing on selection of the most promising indicators and algorithms to detect or predict driver sleepiness. Most of them are based on data from driving simulators, but recently also data from driving under real conditions are used. There are also several approaches used in order to classify indicators or fuse indicators in order to have a high degree of both sensitivity and specificity.

4.1 Indicators

Several different measures and indicators of sleepiness are described in the literature. Physiological measures such as EEG and EOG are often used in research, but they are not feasible for commercial use because they are too obtrusive or impractical. Camera based systems can provide several measures of sleepiness, for example blink behavior and nodding, and they are frequently reported in literature. Camera-based detection systems are suitable for driving and there are a number of commercially available devices [24].

Another type of indicators is driving behavior measures, including e.g. lateral position, steering wheel movements and speed. Context information, such as time of the day and trip duration, has also been suggested as indicators of sleepiness [25].

Table2: Indicators used for sleepiness detection

Type of indicator	*Measures*
Eye activity (camera)	Blinking frequency, blink duration, PERCLOS, fixation duration, eyelid distance, saccadic peak velocity
Head/face activity	Nodding frequency, face position, yawn frequency, facial actions
Physiology	EEG-based measures, EOG (blink frequency, blink duration, PERCLOS, closing duration, opening duration, fixation duration, blink amplitude, delay of lid

	re-opening, lid closure speed, blink amplitude/peak closing velocity, saccadic peak velocity), heart rate based measures, head motion, force applied to steering wheel
Driving behaviour	Steering wheel angle (reversal rate, std, energy in 0-0.4 Hz band), lateral position (mean, std), speed variability, time to line crossing, lanex
Contextual information	Trip duration, time of the day, hours of sleep/sleep deprivation

What indicators to use depend on the application. Physiological indicators and driving behaviour measures are feasible in controlled studies, while camera-based indicators might be the best choice for commercial systems. In a review on vehicle measures for are stated as the most important (vehicle) measures [26]. A limitation of these measures is that they are also related to vehicle type, driver experience, geometric characteristics, condition of the road etc [27].Sandberg has investigated the use of several different driving behaviour signals (variability indicators based on lateral position, yaw, steering wheel angle and derived measures such as standard deviation of lateral position, time to line crossing etc.) and concluded that these indicators basically contain the same information [28].

Most important measures are fixed gaze, PERCLOS and blink duration [27]. Åkerstedt and colleagues have studied the responsiveness of several sleepiness indicators to sleep loss, time of day and time on task in a simulator study [29]. Clear main effects of time of day and time on task were found. The most sensitive indicators were subjective sleepiness, standard deviation of lateral position and EOG measures of eye closure (duration, speed and amplitude). EEG measures and line crossings were less responsive. The authors have also studied individual differences and found that they exceed the fixed effects of the physiological indicators, but not those of the standard deviation of lateral position and subjective sleepiness. Individual variations in eye activity are discussed by Yang et al., who elucidate the fact that some drivers might look awake, although their driving performance is severely deteriorated [30]. Eye activity may thus be less sensitive as a sleepiness indicator. Individual variations imply the need of combining several indicators.

5. Discussion

Each method used for detecting drowsiness has its own advantages and limitations. Vehicle-based measures are useful in measuring drowsiness when a lack of vigilance affects vehicle control or deviation. However, in some cases, there was no impact on vehicle-based parameters when the driver was drowsy [31], which makes a vehicle-based drowsiness detection system unreliable. Behavioural measures are an efficient way to detect drowsiness and some real-time products have been developed [32].

However, when evaluating the available real-time detection systems, Lawrence *et al.* observed that different illumination conditions affect the reliability and accuracy of the measurements [32]. Physiological measures are reliable and accurate because they provide the true internal state of the driver; however, their intrusive nature has to be resolved. Among all physiological parameters investigated, ECG can be measured in a less intrusive manner. EEG signals require a number of electrodes to be placed on the scalp and the electrodes used for measuring EoG signals are placed near the eye which can hinder driving. Non-obtrusive physiological sensors to estimate the drowsiness of drivers are expected to become feasible in the near future [33, 34]. The advantages of physiological measures and the increasing availability of non-intrusive measurement equipment make it beneficial to combine physiological signals with behavioral and vehicle-based measures. A sample drowsiness detection system developed by combining ECG signals, standard deviation of lane position and facial images is shown in Figure.

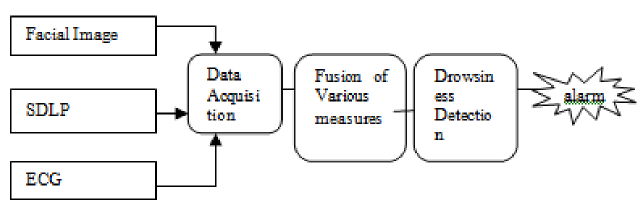

Figure 1: A Sample Hybrid drowsiness system

Few research studies are attempting to detect driver drowsiness by the fusion of different methods [35]. Cheng *et al.* combined behavioral measures and vehicle based measures and concluded that the reliability and accuracy of the hybrid method was significantly higher than those using single sensors [36]. Guosheng *et al.* used a mixture of subjective, behavioral (PERCLOS) and physiological measures (ECG, EEG) to detect drowsiness and found that this combination resulted in a significantly higher success rate than any individual metric.

6. Conclusion

In this paper, we have reviewed the various methods available to determine the drowsiness state of a driver. This paper also discusses the various indicators of sleepiness. These were also discussing the advantages and limitations of each measure. It would be worth fusing physiological measures, such as ECG, with behavioral and vehicle-based measures in the development of an efficient drowsiness detection system.

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