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Fully automated real time fatigue detection of drivers through Fuzzy Expert Systems

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ABSTRACT

This paper presents a non-intrusive fatigue detection system based on the video analysis of drivers. The system relies on multiple visual cues to characterize the level of alertness of the driver. The parameters used for detecting fatigue are: eye closure duration measured through eye state information and yawning analyzed through mouth state information. Initially, the face is located through Viola–Jones face detection method to ensure the presence of driver in video frame. Then, a mouth window is extracted from the face region, in which lips are searched through spatial fuzzy c-means (s-FCM) clustering. Simultaneously, the pupils are also detected in the upper part of the face window on the basis of radii, inter-pupil distance and angle. The monitored information of eyes and mouth are further passed to Fuzzy Expert System (FES) that classifies the true state of the driver. The system has been tested using real data, with different sequences recorded in day and night driving conditions, and with users belonging to different race and gender. The system yielded an average accuracy of 100% on all the videos on which it was tested.

1. Introduction

Recent development in the computer hardware and software industry has bestowed a number of value added services to the society. One of such blessings is the idea of intelligent vehicles and driver support systems, which have the potential to greatly enhance the safety of drivers and passengers by alerting the drivers of dangerous situations. The intelligent vehicles not only recognize the situation, but also the driver's intended actions. Statistics reveal that from 10% to 20% of all the traffic accidents are due to drivers with a diminished vigilance level [1]. This problem has increased the need of developing active safety systems that can prevent road accidents by warning the drivers of their poor driving condition. Drivers with diminished vigilance level and fatigue suffer from a marked decline in their abilities of perception, recognition, and vehicle control, and, therefore pose serious danger to their own life and to the lives of others. In case of fatigue, the driver is so mentally or physically exhausted that he/she either feels drowsy or cannot respond appropriately to the driving situation. Similarly, a crash is also imminent if the driver is inattentive rather than being fatigued. The prevention of such accidents is a major focus of effort in the field of active safety research.

Most of the previous research has focused on the collection of ocular parameters to detect the fatigue level of driver [1–3]. In most of them, the system initializes with the detection of eyes to gather the ocular parameters like blinking frequency, PERCLOS, eye state etc. These systems may fail to predict the driver's true state if the eyes are not detected due to varying light conditions or vibrations experienced in real driving situations. Hence, it cannot be denied that an approach depending on multiple visual cues will work more effectively than the one depending on just one facial feature. For this reason, our proposed system incorporates multiple visual cues such as yawning and eye state analysis to determine the fatigue level of the driver. The selection of the parameters is a tradeoff between accuracy and speed as more accuracy can be achieved by observing more features of the driver but this might affect the response of a real time system in terms of speed. Thus it is important to carefully choose these parameters such that the speed of the system is not compromised for the sake of accuracy. There were a number of other code optimization steps that were taken to enhance the computational speed of the system [4].

To the best of our knowledge, no one has ever investigated the best face and mouth detection algorithm for fatigue detection applications. A careful research was carried out on a number of algorithms that could best segment out the face and mouth of the driver.

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The expert system once tuned during the initialization phase, gives an accuracy of 100% on all the tested videos.

The paper is arranged as follows: In Section 2, a review of the previous studies is presented along with some background knowledge. Section 3 describes the overall system architecture, explaining its main modules. The experimental results are shown in Section 4 and finally we present the conclusion and future studies in Section 5.

2. Background and related work

This section describes the background knowledge that is required to understand the working of fatigue detection and vigilance monitoring systems. Along with that, a literature review of some of the existing fatigue detection techniques is also presented.

2.1. Techniques of monitoring vigilance and fatigue

The techniques of monitoring vigilance and fatigue of the drivers can be divided into following four categories:

- Physiological measures
- Indirect vehicle behavior
- Directly observable visual behavior
- Hybrid approaches

2.1.1. Physiological behaviors

This is the most accurate technique of fatigue detection as it is based on physiological measures like brain waves, heart rate, pulse rate, respiration etc. These parameters are collected with the help of various sensors placed either on the body of the driver or are embedded in a car. The main disadvantage of this technique is that it is intrusive because it requires electrodes to be attached to the drivers, causing annoyance to them. A representative project in this line is the MIT Smart Car [5], where several sensors (electrocardiogram, electromyogram, respiration, and skin conductance) are embedded in a car and visual information for sensor confirmation are used. In the advanced safety vehicle (ASV) project conducted by Toyota [6], the driver must wear a wristband in order to measure his heart rate. Other techniques monitor eyes and gaze movements using a helmet or special contact lenses [7]. These techniques, in spite of their accuracy, are still not acceptable in practice due to their intrusiveness.

2.1.2. Indirect vehicle behavior

This technique involves the use of indirect vehicle behaviors like lateral position, steering wheel movements and time-to-line crossings to detect the driver's vigilance and fatigue level. Although these techniques are not intrusive, they are subject to several limitations such as vehicle type, driver experience, geometric characteristics, condition of the road, etc. These procedures also require a considerable amount of time to analyze user behaviors and therefore, they do not work with the so called micro-sleeps—when a drowsy driver falls asleep for a few seconds on a very straight road section, without changing the lateral position of the vehicle [8]. In this line, we can find different experimental prototypes by Toyota, Mitsubishi and other individuals but none of them has been commercialized.

2.1.3. Directly observable visual behaviors

People experiencing fatigue show some easily observable visual behaviors from the changes in their facial features like the eyes, head, and face. Typical visual characteristics observable from the images of a person, with a reduced alertness level include a longer blink duration, slow eyelid movement, smaller degree of eye opening (or even closed), frequent nodding, yawning, gaze (narrowness in the line of sight), sluggish facial expression, and drooping posture. Computer vision can be a natural and non-intrusive technique for extracting visual characteristics that typically characterize a driver's vigilance from the images taken by a camera placed in front of the user. An example of such a system is FaceLAB developed by Seeing machines [5].

2.1.4. Hybrid techniques

Hybrid techniques believe that driver's state and performance can improve the sensibility and reliability in fatigue detection. These methods make use of visual behaviors to notice the driver's state and then further combine this information with the indirect vehicle behavior information to predict the state of the driver. Doering et al. [8] used a range of measures like eye-closure, lane tracking and changes in physiological state to predict fatigue-related crashes. Recently, the European Union has completed an ambitious project called AWAKE (System for Effective Assessment of Driver Vigilance and Warning According to Traffic Risk Estimation) [9] whose aim was to demonstrate the technological feasibility of driver vigilance monitoring systems and to look at the non-technical issues that can influence the use of such systems. The project estimates driver state through eyelid movement, changes in steering grip and driver behavior including lane tracking, use of accelerator and brake and steering position. These measures are then combined and evaluated against an assessment of current traffic risk obtained from digital navigation maps, anti-collision devices, driver gaze sensors and odometer readings. Despite of the increased accuracy provided by such systems, they take more response time due to the increased computations involved in gathering hybrid parameters and deducing fatigue.

2.2. Challenges posed by real time active safety systems

The challenges that are commonly faced by active safety systems are:

- Lighting
- Changing background
- Vibration

Problems are encountered in fatigue detection due to the variations in above parameters. The lighting conditions may vary due to different weather conditions (sunny, stormy, cloudy, etc.) and day timings (night time, day time). Similarly, the background of the driver is also subjected to changes because the car is constantly moving on the road with different scenes side-by, in reality. The vibration of the car can also be a hindrance in the visual data collection process.

2.3. Critical requirements of active safety systems

2.3.1. Accurate and early detection of drowsiness

The critical issue that a drowsiness system must address is the question of how to accurately detect drowsiness at an early stage. This is required because if the warning occurs early enough in the development of fatigue, such devices can enhance driver alertness sufficient to avoid a collision [2].

2.3.2. Identifying right combination of parameters

A single measure is not sufficiently reliable and sensitive enough to quantify driver fatigue. One may encounter difficulty when the required feature cannot be acquired accurately. For example, drivers with glasses could pose serious problems to those techniques based on detecting eye-characteristics. Hence, there is a