VigilEye: System for Prevention of Accidents Caused by Changes in State of Alertness while Driving

Sebastian Ayala-Haro[1[0009-0007-9068-2365]], Andrea Arellano-Garcia[1[0009-0008-2709-9473]], Katia D. Ulloa[1[0009-0008-3225-3068]], Alma Y. Alanis[1[0000-0001-9600-779X]], Maria Cristina Padilla-Becerra[1[0009-0000-1530-0450]], Pedro M. Gomez[1[0009-0006-3396-6292]] and Emilio Barajas-Gonzalez[1[0000-0002-0468-6244]*]

[1] University Center of Exact Sciences and Engineering, University of Guadalajara, Guadalajara 44430, Mexico

sebastian.ayala0067@alumnos.udg.mx
andrea.arellano7545@alumnos.udg.mx
katia.ulloa4415@alumnos.udg.mx
alma.alanis@academicos.udg.mx
maria.padilla5065@alumnos.udg.mx
misraim.gomez@academicos.udg.mx
emilio.barajas0176@alumnos.udg.mx

Abstract. This project presents the development of VigilEye, a prototype system for continuous monitoring of alertness in drivers on long journeys. This monitoring is performed by means of a camera through the analysis of eye movement patterns, with purpose of preventing automobile accidents. Implementation includes a gradual response protocol that includes sound alerts, visual signals and, in critical cases, controlled intervention of vehicle systems. VigilEye proposes a prototype of a two-stage system to respond to detection of decreased alertness in long-distance drivers. This system uses a detailed analysis of eye movements to detect signs of fatigue. In first stage, upon identifying that driver is showing signs of decreased alertness, system emits an acoustic signal to alert driver and stimulate an immediate reaction. If driver does not respond to this warning, system activates second stage of response in which vehicle turns on flashing lights to warn other drivers and simultaneously reduces speed progressively, in order to minimize risk of accidents and ensure safety on the road.

Keywords: Alertness detection, Accident prevention, Eye monitoring, Road safety, Warning systems.

1 Introduction

Previous research demonstrates existence of fatigue detection systems, however, they may present significant limitations that compromise their effectiveness, as some of methods using electroencephalograms (EEG) require connection of electrodes, which is invasive, impractical and costly to implement in real driving environments [1].

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In context of technological advances in automotive industry, systems implemented in current vehicles are capable of detecting if a person is asleep at wheel and system will also alert driver in order to avoid a greater harm. Among these systems developed in recent years are:

1.1 Driver Alert Control (*Volvo*®)

Volvo ® developed Driver Alert system, designed to reduce accidents caused by fatigue and distraction. It uses a camera and sensors to analyze vehicle behavior, issuing alerts if it detects erratic driving patterns. Although it does not intervene in the control of car, it helps drivers to react in time and improve their performance on the road [2].

1.2 Attention Assist (*Mercedes-Benz*®)

Attention Assist is a system that monitors steering wheel and analyzes 70 parameters to detect signs of fatigue in drivers traveling between 50 and 112 mph. If erratic movements are identified, system issues alerts and suggests taking a break [3].

1.3 Driver Monitoring System (*Toyota*®)

Toyota® has improved its Pre-Crash Safety System by including technology that analyzes whether the driver's eyes are open and attentive. Using a camera and an image processor, system issues warnings in case of distraction or drowsiness, contributing to the reduction of accidents [4].

1.4 Detection of eye fatigue through machine learning based on single-channel electrooculography

This method focuses on excessive use of electronic devices, which has increased eye fatigue, making its objective and scientific measurement urgent. It proposes an innovative system based on single-channel electrooculography (EOG) signal, which is convenient, inexpensive and compatible with mobile devices. Research explores link between EOG and eye fatigue, optimizing detection and facilitating its practical application [5].

Together, these technologies can be very useful in accident prevention; however, they do not offer a comprehensive solution to significantly reduce risk of road accidents.

Faced with these limitations, our proposal presents an innovative approach based on two levels of progressive intervention. First level, of a preventive nature, activates audible and/or visual alerts to warn driver of a decrease in his state of alertness. Second level, critical intervention, implements activation of emergency lights and initiates a gradual reduction in speed. This approach not only alerts driver, but also takes proactive measures to ensure safety on the road.

2 Methodology

VigilEye system is developed using a processing that ensures an efficient and organized flow of data from initial capture to alert generation. This work structure allows each stage of process to be optimized independently, ensuring optimal performance and seamless integration of components (see Fig.1).

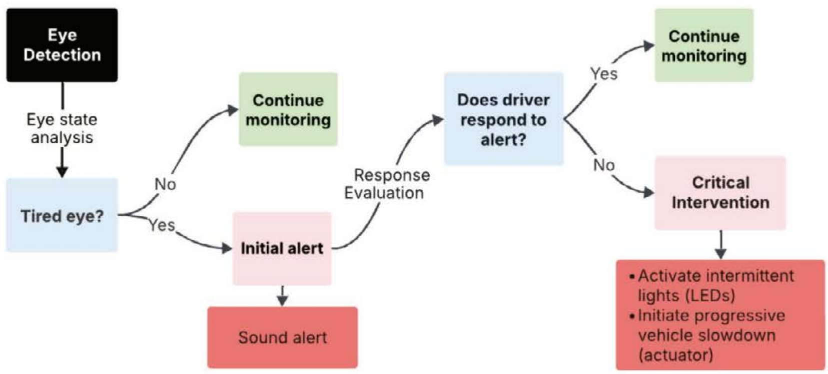

Fig. 1. Decision Flow of the VigilEye Detection and Response System.

2.1 Data Acquisition

Data acquisition is the first step in system's *pipeline*. Using a high-definition *webcam*, system captures continuous video of driver's face at 30 frames per second (FPS). Camera is strategically positioned on vehicle dashboard in front of driver to ensure an optimal field of view, allowing accurate capture of eye movements without interfering with driving.

Each frame is processed to extract coordinates of points that define contour of eyes. This accurate facial mapping is essential to determine state of eyes at each moment, providing basis for blink pattern analysis (see Fig. 2). This accurate facial mapping is essential to determine state of eyes at every moment, providing basis for blink pattern analysis. Image quality and capture stability are critical, so preprocessing techniques are implemented to enhance contrast and reduce noise, ensuring that data are consistent and accurate.

Fig. 2. Facial landmarks generated by MediaPipe Face Mesh [6].

2.2 Implementation of Detection System

Detection system is based on a continuous processing *pipeline* using *MediaPipe Face Mesh* for accurate detection of facial markers. Calculation of Eye Aspect Ratio (EAR) (see Fig. 3) is performed by ratio between vertical and horizontal distances of points defining eye contour. This value provides an accurate measure of eye opening state, allowing reliable detection of blinks and their temporal features.

Fig.3. Mathematical principle of the Eye Aspect Ratio (EAR) applied to flicker detection using facial landmarks [7].

Processing of data obtained implements a real-time classification system that determines driver's state of alertness. Algorithm analyzes three fundamental parameters:

blink frequency, duration of each blink and PERCLOS (percentage of eye closure). These data are processed through a 60-second sliding window, allowing detection of temporal patterns indicative of decreased alertness. Implementation of detection system is optimized to minimize latency, ensuring that alerts are generated in a timely and accurate manner.

2.3 Response System

Based on the analysis of detected states, system implements two response levels proposing number 1, as value of closed eye, and value 0 as value of open eye designed to intervene effectively upon detection of reduced alert states:

Stage 1 response. Upon detection of prolonged state 1 sequences (>400ms), the system activates a 2000Hz audible alert via a buzzer, seeking to regain the driver's attention in an immediate and non-intrusive manner. This alert is designed to be loud enough to capture attention without causing additional distraction.

Stage 2 response. When a maintained state 1 (>500ms) is detected, the system activates a series of more intense responses, including:

Emergency Lights. LEDs that simulate emergency flashing lights, alerting both driver and other road users. This visual signal is crucial to warn other drivers of a potential problem.
Braking Actuator. Activation of an actuator that simulates the ability to stop vehicle safely, demonstrating potential for direct intervention in vehicle control. This actuator is designed to integrate with vehicle's braking systems, providing controlled deceleration.
Audible Alert. Maintenance of audible alert to ensure that driver receives warning. Combination of audible and visual signals maximizes likelihood that driver will respond appropriately.

3 Discussion, Application, Trends and Opportunities

3.1 Innovation

This work aims to introduce an innovative solution in automotive industry, focusing on road safety and driver well- being. Through processing of biomedical signals, it seeks to revolutionize the way in which vehicles monitor driver's health and condition, allowing these systems to predict and react to risk situations.

As part of this innovation, aim is to encourage more effective human-vehicle interaction, thus improving driving conditions and promoting healthy habits, as well as importance of adequate rest. In addition, company plans to collaborate with automotive industry to take speed reduction prototype beyond its initial phase, with aim of implementing it in a wide range of vehicles. This initiative not only aims to improve road safety, but also to contribute to general well-being of drivers.

3.2 Social Impact

Road Safety. Our main objective is to reduce accidents and fatalities by implementing systems that monitor drivers' health to prevent road incidents. This not only increases confidence in public transportation, but also ensures the safety of passengers when driving with health monitoring. By monitoring drivers, public transport users will feel safer, which will encourage their use.

The decrease in social costs associated with accidents will be notable, as preventing accidents reduces medical and rehabilitation costs and lost productivity, generating economic benefits and improving the healthcare system.

Public Health. Implementation of our system will help reduce work- related stress for drivers, who often face high levels of tension. Monitoring their health indicators allows us to identify when they need rest, thus improving their physical and mental health. In addition, better rest habits will be encouraged: monitoring sleep helps avoid fatigue, which improves concentration and reduces the risk of accidents. Promoting adequate rest increases road safety.

3.3 Development or Marker Potential

Project of detecting driver fatigue by analyzing eye movement patterns and using biometric technologies presents considerable development and market potential due to significant number of car accidents, growing public and government awareness about road safety has generated a growing demand for solutions that help prevent these incidents.

This creates a receptive market for technologies that address this critical problem. Project also benefits from growing awareness of health and wellness, especially in context of mental health and fatigue. By aligning with these broader trends, system can promote healthy habits and highlight importance of adequate rest. Going forward, and with the possibility of collaborating with automakers to integrate this system into new vehicles represents a significant opportunity: creation of mobile apps or platforms that complement fatigue detection system, providing information on sleep habits, personalized recommendations and alertness tracking, can increase value of product and appeal to a wider audience.

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