Wireless Sensor Embedded Steering Wheel For Real Time Monitoring Of Driver Fatigue Detection

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***Abstract*—Accidents due to drowsy driving have shown a steep increase in the past decade. An efficient safety measure is required to mitigate the impact of accidents. This paper details the system architecture for real-time, non-obstructive, automatic detection and alarming for driver drowsiness. Data/sensor fusion technology incorporated with the system monitors the driver drowsiness including fatigue and cardiac problems. Alertness of the driver is monitored by analyzing the heart rate by a non-invasive method. The system reads the pulse rate of the driver through multimodal physiological sensor unit embedded on steering wheel. Formulated data processing algorithm incorporated with the system measures the heart rate of the individual and invokes an emergency alarm, if it falls below a specified threshold value. A second level of alarm is issued to the concerned authorities and rescue forces, if the heart rate variation is found to be consistent. The second level of warning incorporates alert messages constituting vehicle identification number and GPS coordinates. One of the novel ideas incorporated is the development of multiple sensors embedded in the steering wheel and unique heart rate calculation algorithm. The system is capable of measuring the heart rate and dynamically alerts the driver or the rescue team about the driver drowsiness, to avert accidents. At the end of this paper, an analysis on the various methods for failure analysis and prevention is also provided.**

***Keywords*—wireless sensor network, wireless ad-hoc network, drowsiness detection, heart rate variation, photo reflective sensor, real-time monitoring, real-time data analysis, alert dissemination, failure analysis.**

I. Introduction

Today it is well recognized that driver fatigue is a contributing factor in a large number of road accidents. Thus, developing intelligent systems for assessing driver's vigilance level is becoming a central issue in the field of active safety research. A crucial point is therefore the way those changes are revealed that is the methods employed to detect driver's fatigue must be reliable, as well as non-intrusive.

The approaches for assessing driver fatigue or drowsiness can be classified into two major classes according to the source of data used. On the one hand, there are methods based on signals from the driver. These include physiological parameters like electroencephalogram, electrocardiogram, electromyogram and skin conductivity, whose measure usually requires electrodes to be applied to the driver. Other driver-related signals are eye movement, head position and facial expression, which can be acquired using cameras and computer vision. On the other hand the vehicle's behavior including its speed, lateral position and distance from the vehicle in front is monitored.

Different methods have been developed to detect the driver alertness level based on image processing technique, vehicle driving pattern and physiological parameter changes. Camera based image processing technique captures the driver facial behavior like eye gaze, eye blink, head movement and yawning. Face detection method using image processing is a difficult process because of the variability in the nature of face appearance and behavior. Environmental condition and background light effect will adversely affect the detection method and since this method is a universal approach it is applicable for all condition. Also the camera based system will affect the privacy of the driver. Vehicle behavior like lane departure, vehicle speed and steering wheel force has taken to study the drowsiness detection. But all these factors depend on the vehicle type, driving conditions and driving pattern, hence, this is not an efficient method.

Most of the studies revealed that physiological parameters change as the driver falls to sleep and this is a reliable method to assess the driver alertness level. Detection of EEG indicates if the driver is asleep or in the verge of sleep. Other methods adopted to check the driver drowsiness are ECG, EOG and EMG. But the above mentioned methods and systems are inefficient while driving because all these system need to be in contact with the body and the wire connections annoy the driver.

Developing a practical and effective non-invasive method for driver drowsiness detection that can provide significant physiological parameter extraction is the objective of this paper. Based on the fact that physiological parameter heart rate will change while the driver falls asleep, an intelligent heart rate monitoring system is modeled. This paper details a practical, real-time, non obstructive system for driver drowsiness detection. The system comprise of multiple sensors embedded in the steering wheel which is capable of measuring the heart rate. If the driver is found to be drowsy, a first level warning is issued to the driver. A second level warning will be issued to the police, traffic control rooms, or rescue forces at remote centers if the driver remains in the drowsy state after the first level warning. Each individual has a unique heart rate variability pattern and it is difficult to develop a universal system to detect drowsiness using heart rate. Taking this into account, a new unique heart rate variability algorithm that is suitable for the any individual is developed.

II. Intelligent Steering Wheel Distributed Sensor Network

The novel idea of this paper is to integrate sensors in the steering wheel without causing any inconvenience to the driver. Intelligent Steering Wheel Distributed Sensor Network (ISDSN) consists of multiple sensors embedded on the steering wheel. The pulse sensors encircled on the steering wheel captures the pulse rate of the driver. The main advantage of this sensor is that the IR emitter and detector are arranged in a small single package and this tiny sensor package is encircled in the steering wheel cover. The arrangement of the sensor network in the steering wheel is depicted in Fig.1. The sensor network makes no inconvenience to the driver since it is closely packed inside the steering wheel cover and only the sensor portion is exposed outside and a direct contact is enough to measure the heart beat using this system.

Figure 1. Sensor Embedded Steering Wheel

When the driver places the palm on the steering wheel, the light from the sensor is obstructed and the reflected light from the palm is registered. The light reflected back is taken for subsequent data analysis and processing to determine the heart rate variability. The light reflected back depends on the blood volume changes through the blood vessels. The ISDSN detection system consists of four modules namely, IR sensor assembly, filtering and amplification module, data conversion module, data aggregation and processing module as shown in Fig.2. A sensors embedded steering wheel model is depicted in the figure and the notations 1, 2, 3...N are the sensor assembly fixed in the steering wheel cover. Each sensor assembly is a tiny set of signal conditioning circuit that can easily been accommodated in the steering wheel cover. The signal conditioning circuitry comprises of a filter and an amplifier. The primary section of the entire assembly is the sensor unit alone.

The reflective IR sensor array used for drowsiness detection comprises of IR emitters and phototransistor detectors. Infrared light is absorbed well in blood and weakly absorbed in tissue. When the palm is placed on the sensor the light passes through the skin and the light that is reflected back on account of blood passage is captured by the detector. The light reflected back has intensity variation that occurs as the blood volume changes in the tissue and these results in voltage variations. This voltage level variation determines the heart rate.

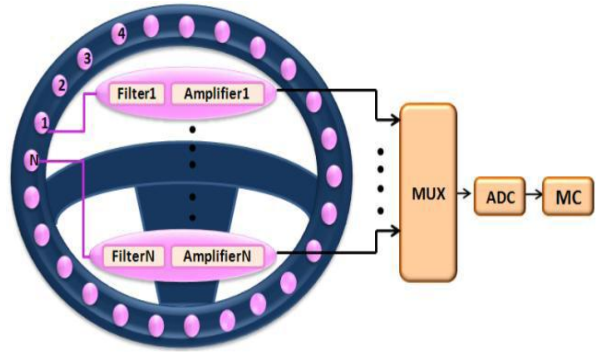

Figure 2. ISDSN Detection System

III. Wireless Sensor Network

The architecture for the proposed wireless sensor network system, to detect driver drowsiness, includes an intelligent steering-wheel distributed sensor network (ISDSN), a sensor data storage (SDS), a data analysis and feedback module (DAFM), and remote reporting centre (RRC). The proposed system design is given in the block diagram below. The wireless sensor system will gather signals from multiple sensors placed on the steering wheel, provides real time monitoring and feedback, data analysis and reporting driver performance to remote centre. Each module has different functionalities to detect driver drowsiness.

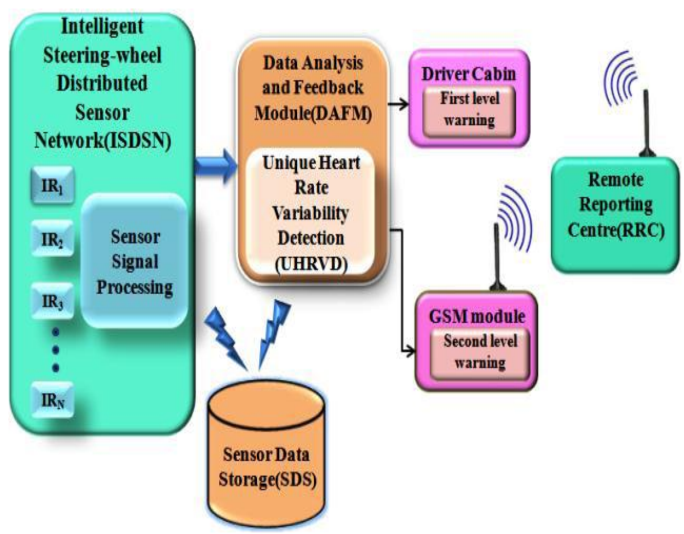

Figure 3. Block Diagram

The flow diagram of the system is shown below in Figure 4.

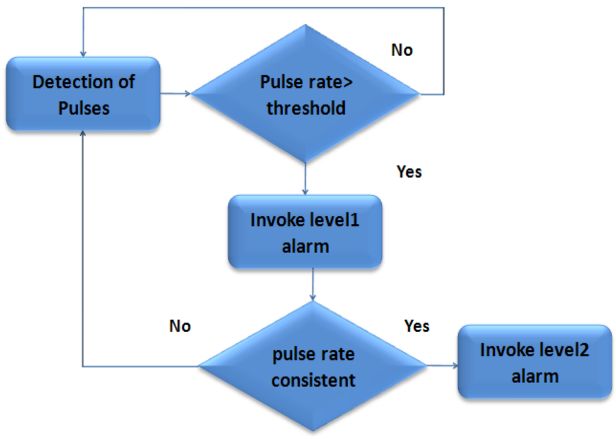

Figure 4. Flow Diagram

IV. DATA ANALYSIS

Consider the steering wheel system model in which n sensors are spatially distributed. The region of interest in the sensor cluster coverage area where the sensor voltage needs to be monitored is denoted as 'Rs' in time 't' and S1, S2, S3,..Sn be the number of sensors in the coverage area. Each sensor will read a scalar random value Xi (t). Using probability distribution the error rate and measurable output voltage from the sensor assembly can be calculated. Since each sensors output voltage are independent of each other and P(S1), P(S2),..P (Sn) >0 the system will take the sensor value only if (Sm ∩ Sn) >Vt, where Vt is the threshold voltage set for the sensors

$$P(Sm \cap Sn) = P(Sm/Sn) * P(Sn) \qquad (1)$$

Let Y(t) denote the output state of Sj sensor in response to the input Xi(t), then

Y(t)= {1, if the sensor output voltage greater than threshold voltage, Vt

0, if the sensor output voltage doesn't reach threshold voltage, Vt

Using probability the expected number of measurable sensors voltage for calculation in time't' can be calculated as

Expected number of sensors voltage greater than Vt at random time can be calculated as follows:

$$E[x] = {}^{1}\sum_{i=0} E\,[x/Y\,(t) = i]\; P[Y(t) = i] \qquad (2)$$

$$E[x] = E\,[x/Y(t) = 0] * P0 + E\,[x/Y(t) = 1] * P1 \qquad (3)$$

Where,

P1 is the probability that sensor output voltage >Vt, and

P0 is the probability that sensor output voltage <Vt.

The sensors S1, S2, S3,…Sn are independently and identically distributed on [0,1] with 'n' total number of samples. The fusion error rate for each of the Ns sensors, where Ns is the number of sensors to be monitored, is calculated using Bayes' theorem of conditional probability.

Let Ts be the time taken to test the threshold cut off voltage of each sensor in the cluster and P(Ts/Vt+) and P(Ts/Vt-) be the probability of getting the sensor voltages greater than and lesser than Vt respectively. The test rate and expected error rate of the fused sensor can be calculated as follows.

$$P(Vt^{+}/Ts) = P(Vt^{+}) * P(Ts/Vt^{+}) / P(Ts) \qquad (4)$$

Where

$$P(Ts) = P(Vt^{+}) * P(Ts/Vt^{+}) + P(Vt^{-}) * P(Ts/Vt^{-}) \qquad (5)$$

This test result is applicable for the succeeding data being captured. By this manner the number of sensors that meets the estimated voltage levels in the region of interest can be calculated.

V. RESULTS

The prototype of driver drowsiness detection system using IR reflective sensors was developed and tested using Labview software. The simulation result of pulse rate variation is given in the graph below. The pulse signal obtained from the hand by placing the palm on the IR reflective sensors is captured as given below in Figure 5.

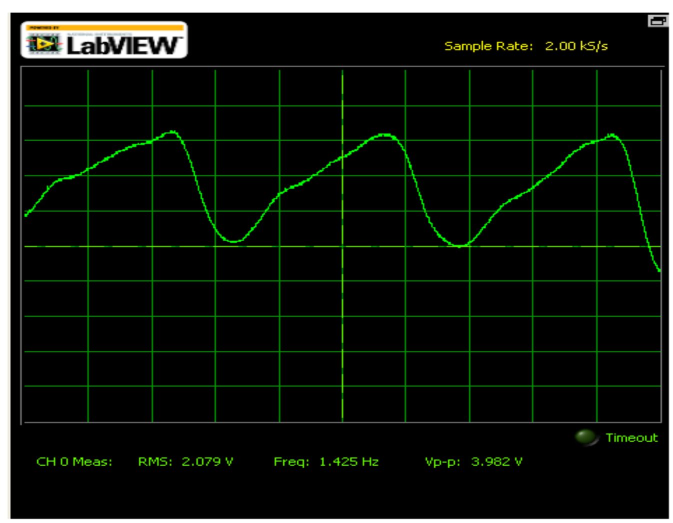

Figure 5. Pulse Rate Variation From ISDSN

Here the feature point is repeated at intervals. Each signal peak in the feature point gives the heart beat pulse received by the detector. The light transmitted from the emitter will be reflected back with little absorption when the heart pumps blood through the blood vessels. When the blood pumping withdraws, the light will be passed through the palm hence no signal is obtained. The high and low peak shown in the graph indicates this level. Consecutive signal peaks were analyzed and checked the variation with actual set threshold value since the peak and interval between the pulses determines the heart rate variability. The software developed takes the pulse value and calculates the amplitude and the interval in each feature point that is repeated at intervals.

VI. Failure Analysis And Prevention

Failure of any one of the components present in the Intelligent Steering-wheel Distributed Sensor Network can lead to accidents and hence this has to be prevented. For this, it is essential to provide crucial failure information about each component. Failure Modes and Effects Analysis (FMEA) includes the various types of analyses including prior engineering knowledge and experience which are commonly used to determine the potential modes of failures a product might encounter during its lifetime. A function-failure method is used to design the product with solutions for functions that eliminate or reduce the potential of a failure mode. In particular, methods to understand and predict the potential failure modes are viewed as essential for fault monitoring and failure prevention. This method explores the relationship between failure modes and functionality of components.

VII. Conclusion and Future Work

The system presented here is characterized by maintaining simplicity, low cost and non-obstructive real time monitoring of drowsiness. The proposed intelligent steering wheel sensor network consisting of multiple embedded IR sensors encircled on the steering wheel. An attempt to correlate the drowsiness and heart rate variability gave way to a non-obstructive and cost-effective method of drowsiness detection. The system incorporated with unique heart rate calculation algorithm is adaptable for the entire individual. When a significant variation in pulse rate is observed the system issues a two level warning system. Failure of the entire system can be prevented by employing failure analysis and prevention method for individual components at the design stage. The efficiency of the system can be further improved by employing the sensors on seat belt for achieving better accuracy. This work is a contribution to the objective of mitigating vehicular accidents and saves thousands of lives.

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