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Designing Non contact based ECG System for Driver Drowsiness Detection

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Abstract: Driver drowsiness has been a significant hazard resulting in various traffic accidents, severe injuries, or even fatalities. Therefore, monitoring this condition is crucial not only in alerting drivers but also in avoiding fatal accidents. Therefore, this paper proposes a hardware design for drowsiness detection; in addition, the outputs used to justify this paper were simulated in the LT Spice. Through a thorough observation, it is apparent that a driver's drowsiness is associated with an immediate change in his heart rate, and due to the fact that Electrocardiogram (ECG) is used to detect an accurate heart rate, we used it as a parameter in the proposed design where it consists of a non contact ECG sensor as an input source and a circuit with a two-stage amplifier to improve the ECG signal's strength and filters to minimize noise. An approximate maximum peak ECG output voltage of 2.8V was obtained in LT Spice, and the resulting ECG output is sufficient enough to detect a driver's drowsiness while preventing major accidents.

Keywords: Electrocardiogram (ECG), Drowsiness, LT Spice.

1. INTRODUCTION

Recently, the rate of traffic accidents has increased in conjunction with the increase in vehicle numbers. Among the array of diverse automobile accident scenarios, driver drowsiness is one of the most dangerous situations; similar to alcohol or drugs, driver drowsiness, which can be caused by fatigue, sleep deprivation, extensive driving, a low circadian rhythm, or medication use, can be detrimental to the human brain. According to World Health Organization (WHO), over 1.5 million people die per year and over 40 million people have severe injuries resulting from driver drowsiness related accidents [1]. Due to this, there is a high need for developing a system that detects drowsiness and alerts drivers against hazards.

A driver's drowsiness is detected through various approaches such as analyzing a driver's physical behavior, vehicle response, brain waves, pulse rate, and respiration, but currently, detection using heart waves (e.g. Electrocardiogram (ECG) signals) is one of the most interesting topics of driver drowsiness detection [2]. Since drowsiness is associated with sleep, these physiological measurements provide accurate results that are based on the correlation between physiological signals and sleep. Because the driver's body automatically generates physiological signals and he/she has no control to alter them, the physiological signal detection methods have certain advantages over body movement pattern detection techniques such as eyelid movement. [3] Among the array of physiological signal analysis methods used for detecting driver drowsiness, the ECG analysis method proves more proficient due to its reliance on Heart Rate (HR), and because of this, it has been used in the proposed design.

The system's design begins with a model and simulation in order to validate the results before implementing them in real-time. Electronic circuit simulators such as LabVIEW, PSPICE, MULTISIM, and LT Spice are the various tools utilized to implement the circuit designs, but due to its feasibility and ease of design, LT Spice is the main tool used for simulation. In addition, the ECG signal comprises a human system's physiological information and is used as an input for this paper's LT Spice simulation. In conclusion, the simulation results that were obtained are adequate enough to successfully implement the proposed drowsiness detection design in real-time.

The remaining portion of this paper is methodized as follows: Section 2 reviews related work, Section 3 provides background information on the electrical heart

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signal and its analysis, Section 4 explains the methodology used in our research and the circuit simulation, and this paper concludes by discussing the overall main points in Section 5.

2. Related Work

Due to various driving hazards including driver drowsiness, driver safety has been one of the leading challenges faced by the automobile industry. However, due to the prevalence of driver drowsiness related incidents, several methods have been proposed for drowsiness detection throughout the years. Sahayadhas [4] suggested a hybrid driver drowsiness detection system that utilizes multiple sensors (i.e. a strain gauge sensor and ECG sensors). In his research, he proposed two methods to determine a driver's drowsiness Firstly, it is detected using a verbal questionnaire; in addition, drowsiness levels are evaluated using the driver's response and several tools have been used to convert this rating to measure a driver's drowsiness. Secondly, by utilizing sensors, the change in the data is analyzed to measure drowsiness. The limitation of this system is verbal questionnaire cannot be implemented during driving [5]. Swapnil [6] suggested a driver's fatigue detection technique using a strain gauge sensor; this system consists of a sensor, a signal processing module, and an alarm-producing device. The sensor is positioned in front of the driver and monitors eye and jaw movements micro-sleeps and obtains input data. As soon as the driver feels drowsy, fatigue is detected, and the system produces an alarm to alert the driver, but while this technique is innocuous, the design is costly and requires complex processing techniques. Ghosh [7] presented a computer vision system that uses eye tracking to monitor driver drowsiness in real-time; the system consists of a camera that captures images of the face, a data acquisition block that implements algorithms for face, eye, and pupil detection, and a processor that analyzes drowsiness from eye movements. However, the main drawback of this method is a change in the eye's sensitivity, which produces false positives in the results. Assari [8] proposed a system consisting of a camera and an infrared LED, and by using infrared LEDs, it was able to overcome the issue of intensity variation that resulted from external car lights. Nevertheless, the main shortcoming of this technique is that it yields fault results; for instance, the system will determine a person is drowsy from his appearance, when, in fact, he may not be.

Kumar [9] suggested a drowsiness detection system using electroencephalogram (EEG) signals; it consists of an EEG detection circuit, which comprises an EEG sensor that detects and amplifies the tiny electrical voltages generated by brain cells, a micro-control unit that produces a control signal for processing detected EEG signals, and an EEG signal processing circuit that then processes the EEG signals to identify the driver's drowsiness. The EEG sensors used in this design are wired; hence, it is not suggestible that they be used while driving because it impairs driver's concentration. Deepa [10] proposed a system for drowsiness detection using EEG signals. It contains an EEG sensor that detects EEG signals from the brain, an EEG signal acquisition unit, which amplifies and filters the signal for drowsiness analysis, and a mobile unit that alerts the driver if drowsiness related information is observed in the measured EEG signals. Though, it is necessary to note that the wired EEG sensors used in this proposed system are not safe to implement as it affects the driver's concentration.

Sang-Joong Jung [11] presented a new ECG sensor with conductive fabric electrodes, which can be positioned on a car's steering wheel in order to identify a driver's drowsiness, and the measured ECG signal from the driver's palm has a sampling rate of 100HZ. Yet, the sensors utilized in this design are complicated to employ because the skin-electrode impedance may result in poor quality of the ECG signal. Xun Yu [12] suggested a driver's drowsiness system using two non-intrusive conductive fabric ECG sensors placed on the steering wheel and the back of the driver's seat. The design consists of signal conditioning circuitry such as a notch filter, a bandpass filter, an amplifier and a driven right-hand circuit for improving the strength of the ECG signal obtained from two different sensors. In his proposal, he implemented an adaptive filter algorithm in the software to reduce the baseline noise. Though, it is necessary to note that sensors used in this method will fail to sense the ECG data if a person is wearing any gloves or if the driver uses only one hand. Sangeetha [13] presented an embedded driver drowsiness detection system that not only monitored and controlled the drowsiness state but also provided feedback to stop the automobile once drowsiness was identified. The input obtained from an ECG sensor is amplified and processed to determine the driver's state, and if the driver is drowsy, the processor notifies the driver by emitting an alarm and activating the driver circuit. However, because the design has electrodes fixed to thumb, this leads to impaired driving and therefore, not recommended.

Based on the above-related work, this paper proposes a design that is explained as follows:

- The drowsiness detection system is designed using non contact sensors.
- A low pass filter with a cutoff frequency of 33 HZ is used at each sensor to remove artifact and electrode contact noises.
- Two amplifier stages are utilized, strengthening the ECG signal, and minimizing common mode interference.
- A twin T notch filter with a cutoff frequency 60 HZ is used to remove the powerline noise.

- Simulation is performed in LT Spice with ECG signals as the input source.

3. Background

A. *Electrocardiogram (ECG)*

ECG is a graphical depiction of electrical activity produced by the human heart via the utilization of electrodes placed on skin; these electrodes identify the small electrical variations on the skin that generate from the heart muscle's depolarization and repolarization patterns during each beat.

The typical ECG is made up of PQRST and occasionally U wave. Each PQRST waveform symbolizes a single heartbeat. One cycle of an ECG wave is shown in the Fig 1.

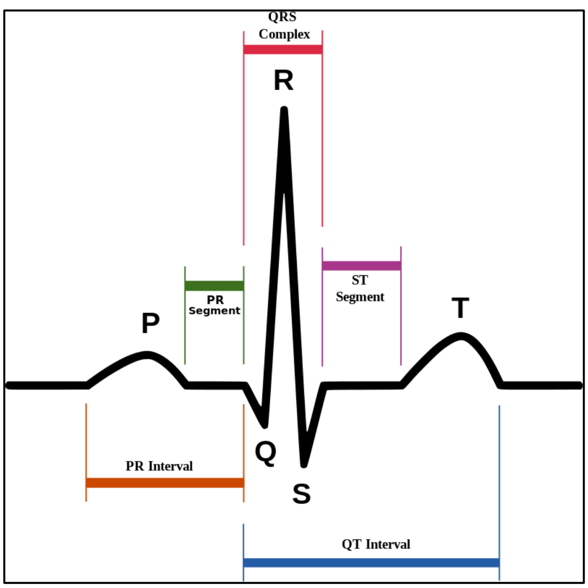

Figure 1. ECG of a heart in normal mode.

B. *Heart Rate Variation (HRV)*

The ECG Waveform varies according to a person's physical activities and is associated with heart rates. In driver drowsiness scenarios, the heart rate continuously alternates between sleep and awake states [14]; yet, by using ECG Waveform, the change in heart rate will be detected accurately. The heart rate variability is calculated by the variation in the time interval between consecutive R peaks of the QRS complex, and this variation is utilized to detect the driver's drowsiness. Heart Rate Variation (HRV) is shown in Figure 2.

C. *HRV Analysis*

Previous research confirms that the ratio of LF to HF is correlated to driver drowsiness. HRV analysis can be divided into two categories: time domain and frequency domain [15]. The time-domain approach is the most facile to perform considering that it is used on a series of consecutive RR intervals in order to obtain variables (e.g. the standard deviation of NN intervals (SDNN), the root mean square of consecutive differences (RMSSD), etc).

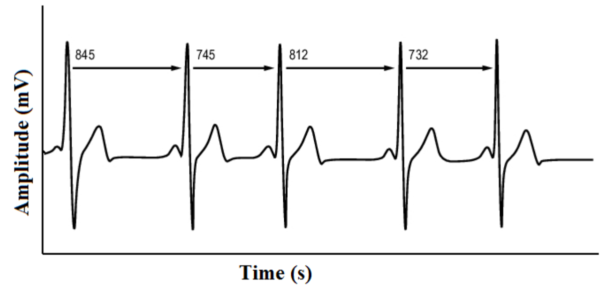

Figure 2. Heart Rate Variation.

In the frequency-domain approach [16], the RR interim series is transformed to an equally sampled series, and then, a Power Spectral Density (PSD) using Fast-Fourier Transform (FFT) is calculated. To further clarify, the PSD is split into 3 frequency bands: high frequency (HF) from 0.15 to 0.4 HZ, low frequency (LF) ranging 0.04 to 0.15 HZ, and the very low frequency (VLF) from 0.0033 to 0.04 HZ. For each frequency region, actual and relative powers are calculated and the ratio of low frequency (LF) to high frequency (HF) power is crucial for measuring parasympathetic activities.

D. *Noises in ECG signal*

Heart rate variation is highly prone to artifacts, and the smallest errors in 2% of the data generate undesirable biases in heart rate variation measurements; therefore, accurate measurements are made by reducing baseline, artifacts, electrode contact, and powerline noises before the heart rate variation analysis. Largely, these noises are either removed using the software or hardware filters.

1) Electrode Contact Noise and Muscle Artifacts: The Electrode contact noise is generated either due to the loss of contact between the electrode and the skin or the electrode's movement away from the contact area on the skin; contrarily, the artifact noise results from the electrical activity of the driver's muscle contractions. In truth, these noises result in abrupt changes in the ECG signal's amplitude thus producing errors. Nonetheless, these noises are approximately 30 HZ and are removed using a low pass filter realized in hardware with a specified cutoff frequency of 33HZ.

2) Power line noise: The noise generated from the power system is the major cause of noise in the process of monitoring ECG signals (also known as power line interference) [17]. It is 60HZ in the USA and 50HZ in other countries; furthermore, this noise is caused by the device's electromagnetic field, stray effects of ac current fields, electromagnetic interference of power line, and improper grounding of the ECG device or the subject. Thus, if this noise is not removed, it will corrupt ECG data.

4. Design And Implementation

A. Design of the system

A detailed explanation of the proposed architecture is shown in Figure 3.

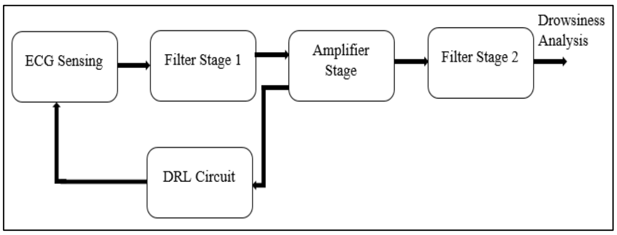

Figure 3. Drowsiness detection system architecture.

1) ECG Sensing: Traditionally, ECG devices have had electrodes, which are placed on the patient's skin in order to determine the heart's electrical activity, and recently, the use of ECG signals has extended into the technological field. Initially, analysis of ECG waveforms for driver drowsiness detection were performed using wet electrodes attached to the driver; however, in utilizing these electrodes for driver drowsiness detection, it has made it difficult to drive effectively. Therefore, it is crucial to eliminate the wires so that these drivers can drive unimpeded. Further research on the ECG compatible components required for drowsiness detection led to the development of dry or non contact sensors, which combats the complications that wet electrodes pose. In this paper, a PS25255 non contact sensor was used to capture the ECG required for drowsiness detection. These sensors are incorporated on to the seat back and seat belt with appropriate conductive fabric.

2) Filter Stage 1 : Filter stage 1 is employed at the input terminal after the ECG sensing stage in order to remove 30HZ of electrode contact noise and muscle artifacts. Due to the presence of these noises, the ECG signal is corrupted; hence, in order to remove the noise, a low pass filter with a cutoff frequency of 33HZ was used.

3) Amplifier Stage: In order to improve the strength of the ECG signal for accurate drowsiness detection results, we used the amplifier stage. In this paper, the amplifier stage was implemented in two stages. In the first stage of amplification, the input ECG signals are weak; therefore, it was observed that they should be strengthened in order to facilitate the analysis. In the second stage (also called the differential stage), the first stage's output is amplified by minimizing the sensor's common potential. Moreover, the process of diminishing the interference depends on the type of differential amplifier employed in the ECG detecting hardware's input stage. In this paper, we used the unity gain stable OPA 2277 for amplifier stage 1 because of its high common-mode rejection, output free from phase inversion, ease of use and high performance. OPA 177 for amplifier stage 2 because it is unity gain stable and has high performance.

4) Filter Stage 2: Filter stage 2 is employed after the amplifier stage to remove 60HZ of powerline noise, which results in false positives during the analysis. Thus, a twin-T notch filter with a 60HZ cut off frequency was used to eliminate the powerline noise; additionally, a variable quality factor is achieved with a potentiometer that not only enhances the efficiency of the filter but also reduces errors. Broadly, this adjustment will give flexibility to the board, and in our design, all the resistors contain 0.05% tolerance to avoid frequency drift from 60HZ. Here, we used OPA 2277 for filter stage 2 because it is unity gain, operates up to 36-V supply rails, ultralow offset voltage,offset voltage drift, and 1-MHz bandwidth.

5) Driven Right Leg (DRL) circuit: A Driven Right Leg Circuit (DRL) is added to the bio-amplifiers to decrease the common-mode interference. To clarify, Bio-amplifiers measure very low frequency signals produced by the body, and due to the electromagnetic interference, the body operates as an antenna and picks up the 60HZ power line noise. Furthermore, the DRL circuit has an ECG sensor that detects the ECG signals and eliminates interference.

B. Hardware Simulation

A drowsiness detection system is viewed as a fundamental system with inputs and outputs; thus, in order to run this system in a simulation environment, the environment itself must support inputs and outputs that are typically analogous to those of the real-time signals. Consequently, the motive is to simulate the complete hardware in a SPICE simulator of electronic circuits. In our research, we used LTSpice, a freeware computer software, which implemented a SPICE simulator. The step-by-step procedure for the simulation is shown in Figure 4.

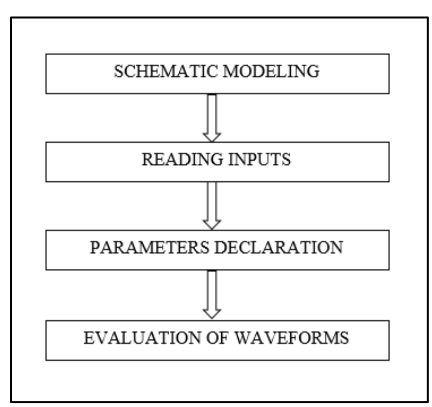

Figure 4. Simulation Steps

In LT Spice, the design model was initiated by a schematic capture. The input ECG samples were collected from different drivers from various driving scenarios, and the values that were obtained were converted into an excel file using MATLAB software. In the subsequent step, this file was converted into a text file and given as the input (it is necessary to note that the transient time and AC analysis are the parameters used for the simulation). The waveforms were generated for each of the design's stages, and they were then further analyzed for drowsiness detection.

1) Input Stage: In this simulation, the ECG signal with a peak amplitude of 150mV was applied differentially to the system's input; this signal comprises muscle noise and powerline noise. Figure 5 represents the input of the ECG signal applied to the circuit.

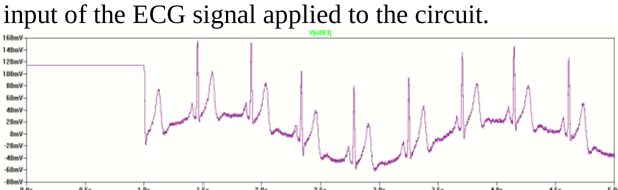

Figure 5. Input signal

2) Filter Stage 1: The applied input passes through two low pass filters with a cutoff frequency of 33HZ, and these filters suppress the interference due to muscle artifacts. In this stage, the peak output voltage of the ECG signal is 150mV. Figure 6 represents waveform at filter stage 1.

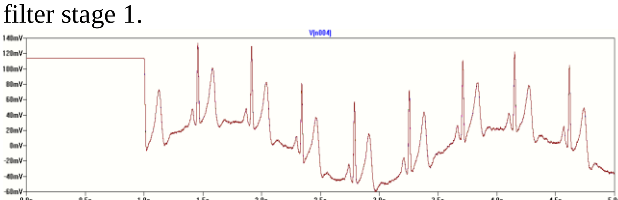

Figure 6. The filtered output from filter stage 1

3) Amplifier Stage 1: After passing through the low pass filter, the input then passes through amplifier stage 1. Principally, these amplifiers improve the strength of the two ECG signals, resulting in a peak output voltage of 1.4V. Figure 7 displays the output at amplifier stage 1.

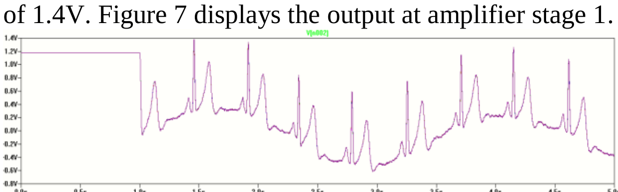

Figure 7. The output obtained from one of the stage 1 amplifiers

4) Amplifier Stage 2: Once the ECG signal passed through amplifier stage 1, the signal passes through a differential amplifier in order to minimize the common voltage between the two sensors. The peak output voltage of this stage is 2.8V. Figure 8 represents the output obtained at amplifier stage 2.

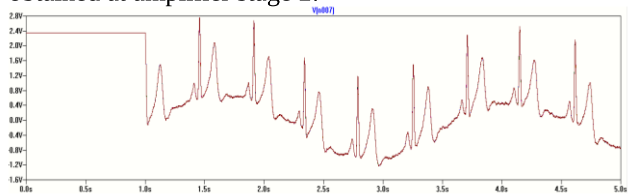

Figure 8. Output after amplifier stage 2.

5) Filter Stage 2: Due to the power line interference, ECG signals are mixed with a 60HZ power line noise; however, this noise can be removed using an active twin T notch filter with a cutoff frequency of 60HZ. After passing the output of amplifier stage 2 through a notch filter, powerline interferences are removed; hence, the peak output voltage of this stage is 2.8V. Figure 9 portrays the output after the notch filter stage.

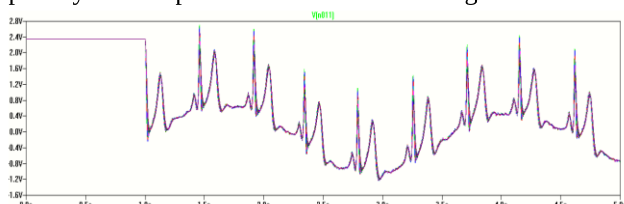

Figure 9. Output after notch filter stage.

6) Output: The output of the proposed circuit was adjusted by using a potentiometer at the output stage. The peak output voltage of this stage is 2.8V for diverse potentiometer values, and Figure 10 shows the potentiometer output.

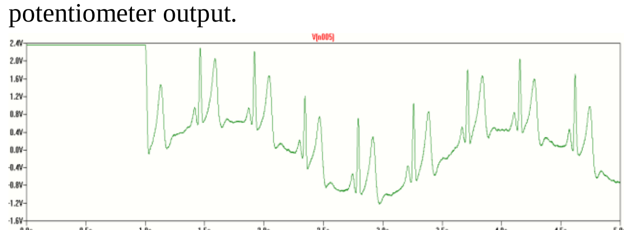

Figure 10. Output for a value of the potentiometer.

From Figure 10, it is evident that the proposed circuit produces an output ECG signal with peak amplitude of 2.8V, which is sufficient for drowsiness analysis.

Table 1 summarizes the output voltages obtained at each stage. From the table we can infer that the input was processed at each stage to obtain an amplified signal without noise. Additionally, the results suggest that the output produced from the proposed two-stage amplifier and filter is sufficient for detecting driver drowsiness.

TABLE I. OUTPUT VOLTAGES OBTAINED AT EACH STAGE

STAGES	OUTPUT VOLTAGE (V)
Input stage	0.150
Low-pass filter stage	0.150
Amplifier stage 1	1.4
Amplifier stage 2	2.8
Notch filter stage	2.8
Output	2.8

For the simulation, we collected data from different drivers for five-hour period including the subject's transition from awake state to asleep state and the data after sampling is then converted to discrete data. An algorithm for detecting HRV from the data and making the decision between the non-drowsy and drowsy states is done using logistic regression. The developed algorithm shows a consistent accuracy over 90% in 20 seconds. This algorithm was developed by our software team. [18]

5. CONCLUSION AND FUTURE WORK

Statistically, driver drowsiness is the leading cause of traffic accidents, and because of this, we need to employ a drowsiness measuring technique to subvert the prevalence of drowsy related driving accidents. In this paper, we detect drowsiness from ECG signals that are captured by non contact ECG sensors, and these collected ECG signals are amplified using two-stage operational amplifiers. The amplified signals are distorted by the presence of muscle artifacts and power line interference; thus, these noises are removed using filter stages 1 and 2 Within this research, a low-pass filter with a cutoff frequency of 33HZ was used to remove muscle artifacts, and a twin-T notch filter with a cutoff frequency of 60HZ was utilized to eliminate power line interference. The simulation was performed using LT Spice, and ECG signal graphs were plotted for the proposed design's multiple stages. The proposed methodology produces a maximum output of 2.8V, which proves adequate for drowsiness analysis. The results conclude that the proposed design is effective in generating the input signals required for drowsiness detection.

As a future work, the proposed design can be remodeled with different simulation tools, amplifiers, filters, and sensors to monitor driver drowsiness; moreover, the design's efficacy can be checked by placing the sensors in various positions. The proposed design can be implemented with a microcontroller along with an alarm and software algorithm in order to be used in real-time. In conclusion, the proposed method in this paper produced the maximum output voltage required for drowsiness detection and can be altered with new components for future developments.

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