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Drowsy Driver Detection and Alert System using Pulse Sensor

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ABSTRACT

Drowsiness ranks among the highest causes of road accidents in countries all over the world. Hence, it has become imperative for the issue of drowsy driving to be tackled in order to reduce the heavy toll on human life and property exacted by drowsiness-related road fatalities. Various scientific research, have shown that drowsiness is not instantaneous, but, rather, is a gradual process preceded by various changes in the individual's body system, such as the circulatory system. Hence, a system with a capability to sense and measure these changes in a driver's body system is the key to the reduction of drowsiness-related road fatalities. Various methods have been used to build such systems, however many of them are too expensive and complex for the use of the average car owner. Because of this, a simple cost-effective drowsy driver detection and alert system which uses a pulse sensor to measure the heart rate of a driver while he is driving has been designed in this project. The pulse sensor transmits this pulse signal to an Arduino Uno microcontroller which processes the signal and calculates the heart rate in beats per minute (BPM). The system monitors the driver's pulse in real time, and on sensing drowsiness, alerts the driver via an alert module (consisting of an audio system and a vibration motor) attached to the steering wheel, before an accident occurs. The system thus designed is simple, cheap and can be easily integrated into the steering wheel of most vehicles, making it a practicable choice for the average car owner.

Keywords *– Pulse Sensor, Reflectance Photoplethysmography, Heart Rate, Arduino*

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I. INTRODUCTION

Feeling drowsy is a natural response of the human body to the need for sleep. It is a means by which the body signals an individual that it needs sleep, as drowsiness is the precursor of sleep. An individual may feel drowsy at virtually any time of the day. However, the context in which this happens will determine whether or not it will constitute a threat. If, for instance, the individual is involved in some kind of activity that requires maximum concentration and vigilance, it then becomes a problem. Driving is one such activity in which drowsiness will not only constitute a nuisance, but will equally put at risk, the life of the driver, other drivers, as well as pedestrians. Driving is a very dynamic activity, and hence it requires the full attention and alertness of the driver. Nodding off for just three seconds or less can prove fatal. It therefore becomes a serious issue if the driver's alertness or attention is impaired due to feelings of drowsiness. This is because a drowsy driver pays less attention to the road, makes poor decisions (due to impaired information processing), and has a slow reaction time to sudden events that will require his immediate action [1]. Studies have shown that about 30% of road traffic fatalities are related to drowsiness [2]. Even this figure, however, is likely to be an underestimate due to some of the following reasons. Statistics of drowsiness-related road fatalities are usually based on Police Accident Reports (PAR). However, some Police Accident Report formats do not include drowsiness as a cause. In such a case, it is most likely to not appear in the report even though it may have played a significant role in the occurrence of the road fatality. Also, many drowsiness-related crashes are single-vehicle crashes and are likely to go unreported, especially in cases where no serious injury was sustained. Furthermore, it is a fact that many crash-involved drivers may not even be aware of the role that drowsiness played in their crashes and thus may not report it to the police when interviewed, and in like manner, police officers may not be aware of the role of drowsiness in the crash, or may regard available evidence as circumstantial and not verifiable. Even in cases where drivers are aware, they might be reluctant to acknowledge this at the time of accident [3, 4]. And since, unlike alcohol, it is difficult to test for drowsiness, it becomes more elusive as a cause of road fatalities [5]. Drowsiness has been attributed to several factors such as; reduced sleep quality, reduced opportunity for sleep, untreated or unrecognized sleep disorders, job-related sleep restriction, alcohol consumption, use of certain medications, and naturally occurring circadian factors. A comparative test to determine the relative effects on performance of sleep deprivation and alcohol [6] clearly points out the serious dangers imposed by drowsiness. Results from the test showed that a sleep deprivation of more than 24 hours resulted in a performance equivalent to a BAC (blood alcohol concentration) of 0.1%. In simple terms, this means that for every 1000 millilitres of blood in the individual's body, 1 millilitre of alcohol is present. The equivalent alcohol intake of 0.1% BAC is about 3 shots of 80-proof liquor, or 3 glasses of table wine, or 3 cans of beer [7, 8]. In such a drowsy state, a driver shows decreased alertness and impaired psychomotor skills. [14] One of the criteria when selecting a fingerprint authentication system for border control is the speed of acquisition of the Person's fingerprints. So fingerprint scanner helps law enforcement agencies in terms of border control for efficient security against criminal activities. This is achieved by having the ten fingerprints of every individual in case of any problem thus with this data acquisition of any driver will be at ease when accident occur. The authors in [15] shows that Any industry which requires aerial video to be fed back in real-time can benefit hugely from 5G networks – meaning that 5G has implementations in everything from construction to traffic flow analysis and reporting a same with a high speed to the accident management bodies for quick interventions when an accident eventually occur .The work of [16] details Automotive and smart traffic management system.. Sensors in roadways, communications between infrastructure and cars, and communications between cars, will make driving safer and more efficient, and will also support autonomous cars

II. METHODOLOGY

The drowsy driver detection and alert system designed in this project is a simple system that employs reflectance photoplethysmography for sensing the driver's pulse. The sensor sends its output to a processor which is programmed to actuate an alerting device if the driver is sensed to be drowsy.

2.1 Pseudocode of the System

The operation of the system is described by the following pseudocode:

```
•   WHILE ignition is ON
    ○   System is ON (Sensor is ON, microcontroller is ON and program is running)
    ○   Driver places palm on Steering wheel; sensor starts reading pulse
    ○   First pulse initiates control method in microcontroller program
    ○   Calculate heart rate in BPM
    ○   IF heart rate is greater than THRESHOLD, do nothing
    ○   ELSE send HIGH signal to the audio system pin, and send HIGH signal to the vibration motor pin.
    ○   Transmit audio message, cause motor to vibrate.
```

2.2 System Flowchart

The flowchart of the system is shown in Figure 1. The system comes on when the ignition is turned on, and stays onuntil the ignition is turned off. This avoids wastage of energy and ensures that the system is not monitoring when the driver is not in the vehicle (for instance, when the car is parked).

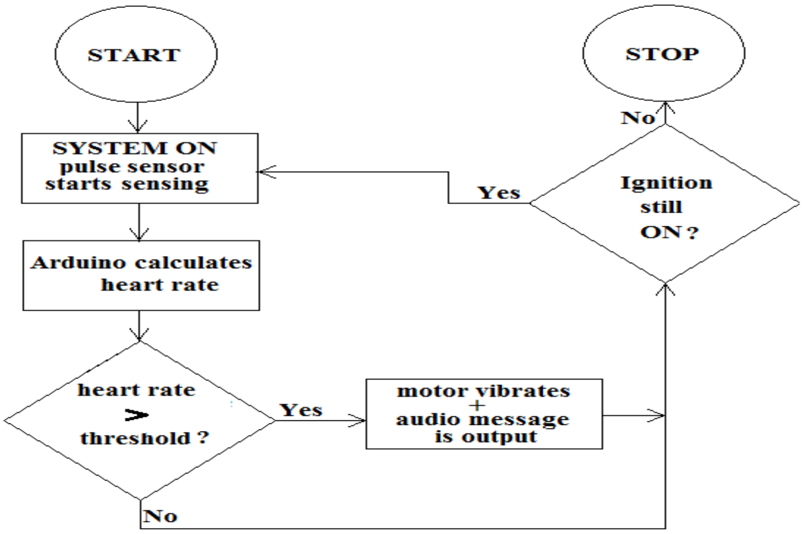

Figure 1: Flowchart of the system

2.3 System Modules

The system consists of three main modules;

- The sensor module
- The processing unit
- The alert module

2.4 Block Diagram of the System

A high level abstraction block diagram of the system showing the three main modules, their input and output signals is shown in Figure 2.

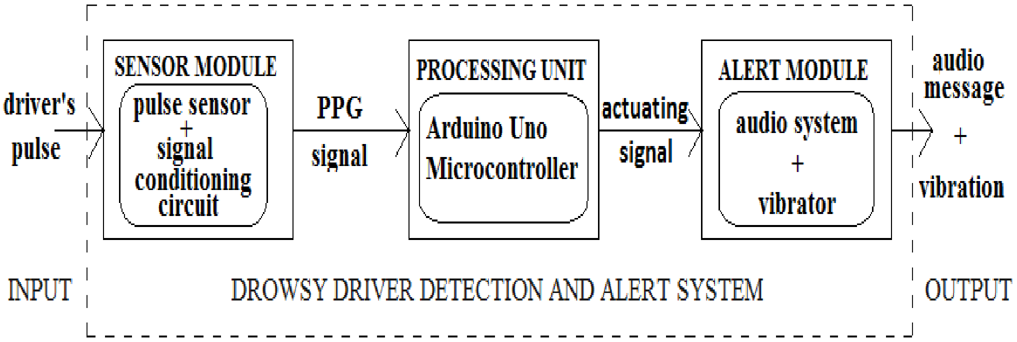

Figure 2: Block diagram of the system

2.5 The Sensor Module

This is the first module that interacts with the driver. It measures the driver's pulse, which is the primary input to the system. The sensor module consists of two parts; the pulse sensor, and the signal conditioning circuit to amplify the raw PPG signal from the sensor as well as remove any accompanying noise. This signal conditioning takes place in two distinct stages.

A. The Pulse Sensor: The pulse sensor is achieved using reflectance photoplethysmography which is an optical method of measuring pulse by measuring the relative amount of light absorbed by the arteries during the systolic and diastolic phases of a cardiac cycle. The sensor consists of an infrared emitter and an infrared detector arranged side by side. The circuit diagram is shown in Figure 2.3. The body surface on which measurement is to be made (in this case, the driver's finger) is placed on top of the sensor. The infrareddiode emits infrared rays which get reflected by the arterial tissue, bones and veins to fall on the infrared detector. The detector then outputs a varying voltage which corresponds to these variations in the absorbed infrared rays.

Sensor Stage Calculations

Infrared transmitter parameter calculations: The input voltage is 5V, while the infrared diode has maximum current of 20mA, and forward voltage of 1.5V. Hence, the value of the current limiting resistor (R_a) in series with the infrared diode is calculated using the Equation (1).

$$R_a = \frac{(V_s - V_f)}{I} \qquad (1)$$

Where,V_s is the source input voltage (5V, in this case), $V_f$is the forward voltage of the infrared diode (1.5V), and I is the maximum allowable current of the infrared diode.

Therefore the resistor value is given as;

$$R_a = \frac{(5 - 1.5)}{(20 \times 10^{-3})} = 175\Omega$$

Therefore, any resistance value above and within the range of this value can be used. The actual value used in the circuit is 220Ω.

Photodiode parameters calculation: A biasing resistor (R_b) value of 10kΩ was chosen for the photodiode connection. The choice of this biasing resistor value was made based on the circuit found in [9].

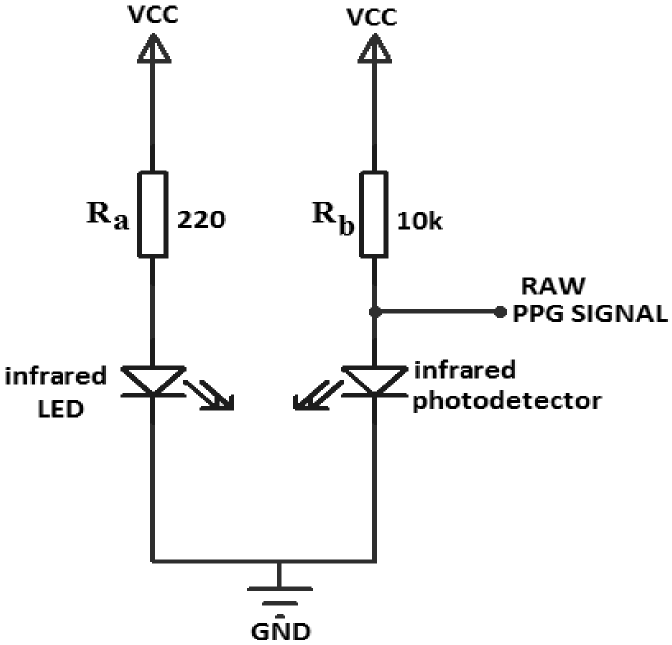

Figure3: Circuit diagram ofthe pulse sensor

B. First Stage Signal Conditioning Circuit: The signal conditioning circuit consists of two similar stages. This arrangement is used to achieve high filtering and amplification of the signal for processing by the microcontroller. The raw PPG signal is fed into the first signal conditioning circuit for amplification and filtering. As can be seen in Figure 2.4, the raw PPG signal from the sensor is first passed through an RC high-pass filter (HPF), consisting of the 4.7µF capacitor and the 47KΩ resistor, to attenuate the low frequency DC component. The capacitor and the resistor values were chosen to give the required cut-off frequency.
The cut-off frequency(f_{cH}) of the HPF is calculated as shown in Equation (2).

$$f_{cH} = \frac{1}{2\pi R_0 C_0} \qquad (2)$$

$$f_{cH} = \frac{1}{2\pi \times 47 \times 10^3 \times 4.7 \times 10^{-6}}$$

$$f_{cH} = 0.7 \text{ Hz}$$

The signal is then passed into the next stage which is an active low-pass filter (LPF) to amplify the pulsatile component. LM324 Op-Amp IC is used in this circuit because its input voltage requirement of 5V matches the voltage output of the power supply unit used in this project.
Equation (3) is used to derive thevoltage gain of this first signal conditioning stage (A_{v1})using the resistor values R_1(680K) and R_2 (6.8K)of the low-pass filter.

$$A_{v1} = [1 + \frac{R_1}{R_2}] \qquad (3)$$

$$A_{v1} = [1 + \frac{680}{6.8}]$$

$$A_{v1} = 101$$

The cut-off frequency of the LPF (f_{cL}) is calculated by substituting R_1 and C_1in place ofR_0 and C_0 in Equation (3).

$$f_{cL} = \frac{1}{2\pi \times 680 \times 10^3 \times 100 \times 10^{-9}}$$

$$f_{cL} = 2.34 \text{ Hz}$$

Thus the cascaded HPF/LPF pair attenuates the unwanted DC component of the PPG signal as well as the high frequency noise including 50Hz AC supply mains interference. It equally amplifies the low amplitude pulse signal by a gain of 101.

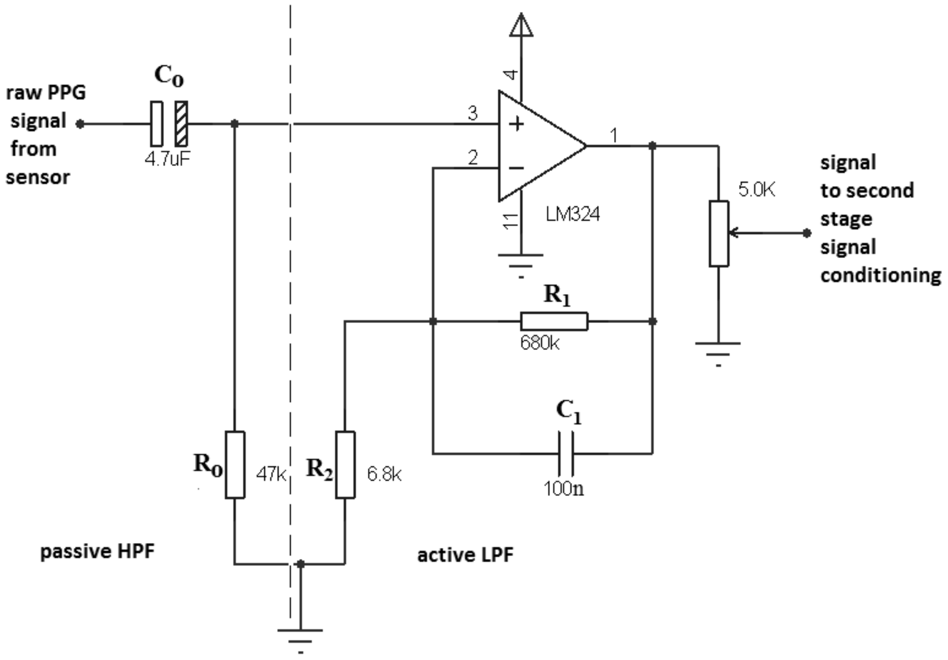

Figure 4: First signal conditioning stage

C. Second Stage Signal Conditioning Circuit: The output signal from the first signal conditioning stage is fed into a similar HPF/LPF cascaded pair for further filtering and amplification. The circuit is clearly shown in Figure 5. The voltage gain of this second stage (A_{v2}) is also equal to 101.

The total voltage gain (A_{vT}) achieved by the two cascaded stages isgiven by the product of the gain of the first stage (A_{v1}) and the gain of the second stage (A_{v2}), as shown in Equation (4).

$$A_{vT} = A_{v1} \times A_{v2} \qquad (4)$$

$$= 101 \times 101$$

$$= 10201$$

A 5KΩ potentiometer is placed at the output of the first signal conditioning stage to vary the gain in the event that the total gain of the two stages is required to be less than 10201. An LED with a 1KΩ current limitingseries resistor is connected to the output of the second signal conditioning stage, and will blink when a heartbeat is detected. Hence, the two signal conditioning stages convert the input raw PPG signals to pulses that are synchronous with the driver’s heartbeat.

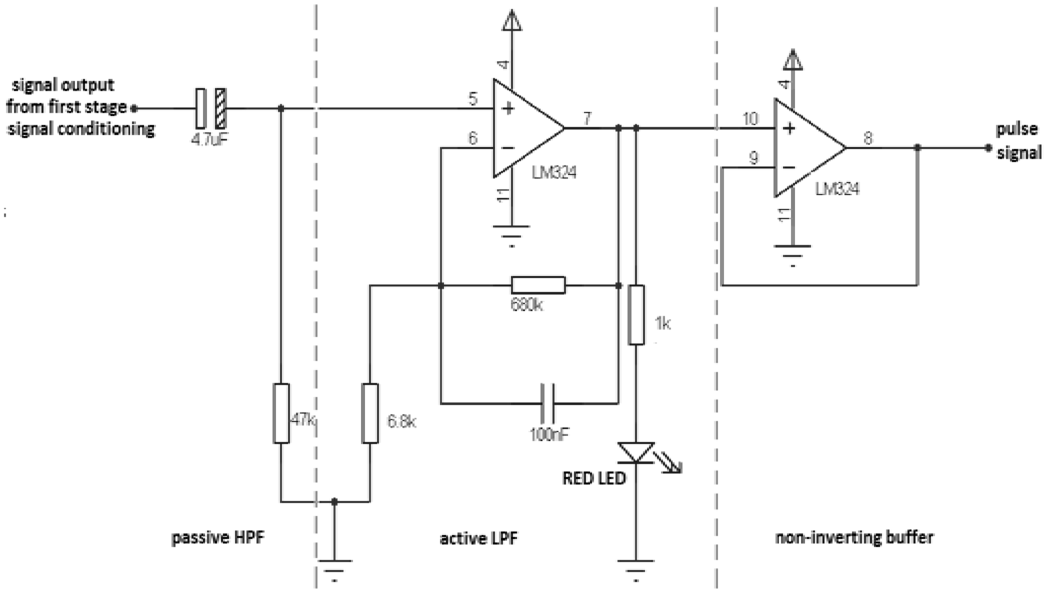

Figure 5: Second signal conditioning stage

The heart rate in beats per minute can be derived from the frequency (f) of the pulses using the mathematical expression given in Equation (5).

$$\text{Heart rate in beats per minute (BPM)} = 60 \times f \qquad (5)$$

Finally the output pulse signal from the second signal conditioning stage is fed into a simple non-inverting buffer to lower the output impedance. This is important because the amplified PPG signal is fed into an ADC channel of the Arduino Uno microcontroller.

2.6 The Processing Unit

To implement an intelligent decision-making system, a processing unit is required to process the pulse signal output from the sensor module. AnArduino Uno was used in this project. It is a microcontroller board based on the ATmega328P microcontroller IC [10].A picture of the board is shown in Figure 6.

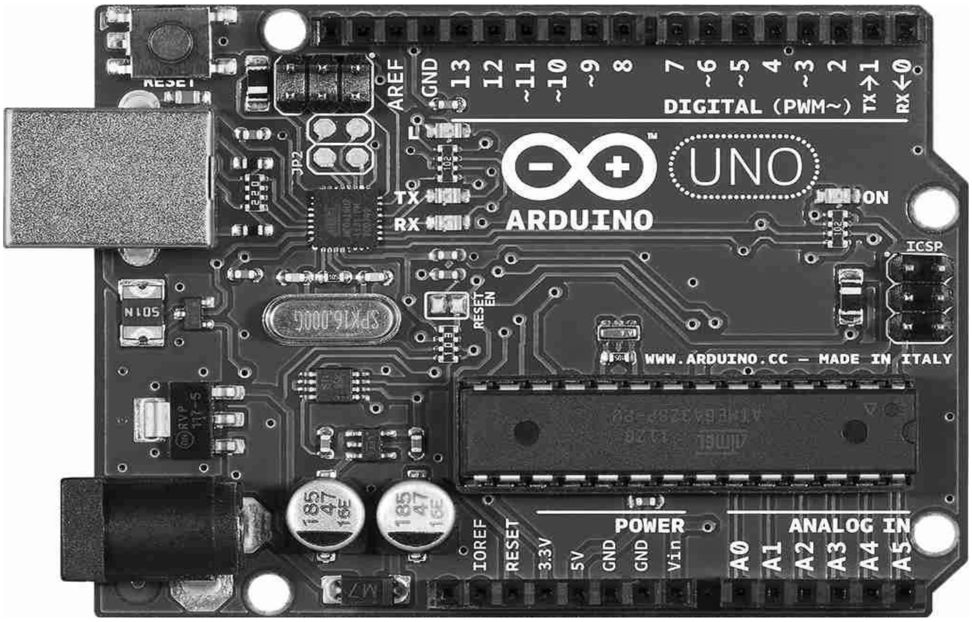

Figure 6: Arduino Uno

2.6 The Alert Module

The alert module consists of two major sub-systems that produce alert signals; the audio system and the vibration motor. The Arduino sends an actuating signal to the alert module whenthe pulse signal from the sensor indicates that the driver is drowsy. The processing is achieved by the control program uploaded into the Arduino Uno. The source code of the control program is given in Appendix A. A warning message is preloaded into the Arduino as part of the program. When the driver is sensed to be drowsy, the Arduino sends an actuating HIGH signal to the output pins to which the alert module is connected. This will cause the vibration motor to send out tactile vibrations, while a warning audio message will be output through the speaker. The purpose of the alert mechanism is to wake the driver in time before an accident occurs.

A. The Audio System: The audio system consists of an audio amplifier and an 8Ω magnetic speaker connected to the output of the amplifier. The schematic diagram is shown in Figure 2.7. LM386 op-Amp IC is used. The amplifier serves a dual purpose in the audio system. Apart from its primary function of amplifying the audio output from the Arduino Uno, it equally serves as a protection circuit for the Arduino.

The maximum current that should be drawn from the output pins of the Arduino is 40mA. The actual value of the current ($I_{speaker}$) that will be drawn by the 8Ω speaker running on 5V from the source when connected directly to the Arduino is calculated using Equation (6).

$$I_{speaker} = \frac{\text{source votage } (V_S)}{\text{speaker resistance } (R)} \qquad (6)$$

$$= \frac{5}{8}$$

$$= 625\text{mA}$$

This value which is much higher than 40mA will damage the output pin, and may even damage theArduino itself.

Parameters used: The component values used with the LM386 IC were derived based on information from its data sheet [11].

- The 10µF capacitor at the input filters-off any DC noise accompanying the audio signal.
- The 10KΩ potentiometer provides a voltage divider network, acting as a volume control by determining the amount of current input to the IC.
- The function of the 10µF connected between pins 1 and 8 is to increase the gain to the maximum of 200.
- The 220µF, 0.1µF and 10Ω resistor at the output pin 5 of the IC form a HPF to attenuate DC noise.

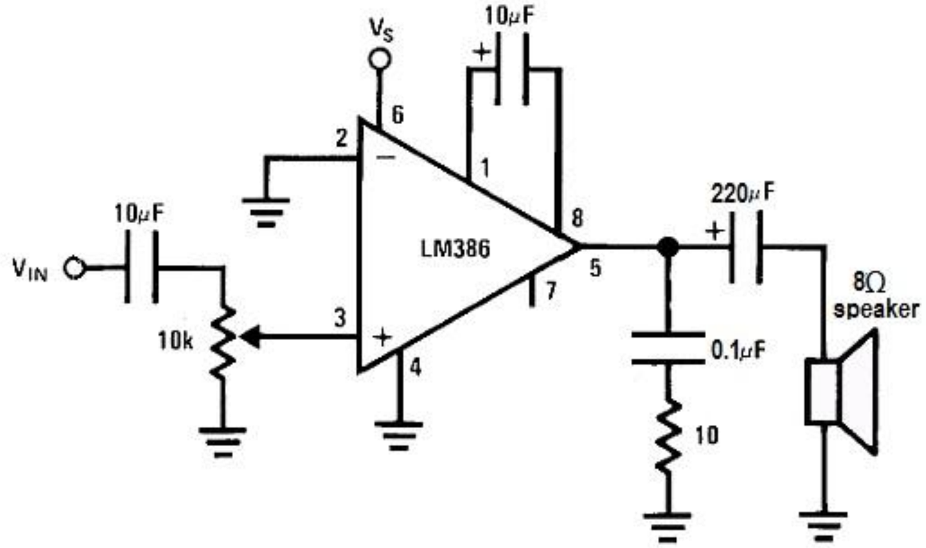

Figure 7: Schematic diagram of the audio system

The Audio Message: The audio message is a mono 16-bit PCM 8KHz WAV (Waveform Audio File Format) file. The speech content “you are advised to please take a break,” was converted from text to WAV format using the web-based application Text2speech. It was then converted to a 16-bit 8KHz mono-channel WAV file using the Audacity software. Finally, the WAV file was encoded into numeric form using the software EncodeAudio. This string of numbers is then used to initialize the array variable of the audio message in the sketch. The array

is declared using the keyword PROGMEM, which causes the data to be stored in the Arduino's program memory (Flash) instead of its RAM (which is much smaller).
Also, only approximately 4 seconds of audio can be stored in this memory [12].

The audio playback works using two of the Arduino board's timers, and the hardware functionality of the ATmega328 microcontroller that is normally used to generate PWM output with the analogWrite() function. One timer is used to generate a high-frequency square wave whose duty cycle corresponds to a particular amplitude in the audio sample. Another timer is used to update this duty cycle at 8 KHz, the sample rate of the audio.

The Vibration Motor: The connection circuit for the vibration motor is a simple circuit described in the schematic diagram shown in Figure 8.
The parameters used in the circuit are given below:

- The 1N004 Zenerdiode connected in reverse bias functions to protect the Arduino from any voltage spikes that may be produced by the vibration motor. These voltage spikes when they occur will be absorbed by the 0.1μF capacitor connected in parallel with the diode. This is value falls within the range of acceptable values for snubbing capacitors.
- The 2N3904 NPN bipolar junction transistor amplifies the current output from the Arduino from the maximum 40mA to the value required by the vibration motor (which is about 75mA). The current output from the Arduino is first stepped-down by the 1KΩ resistor connected to the base of the transistor in order to avoid over-amplification by the transistor, thereby damaging the vibration motor. Any high value resistor can be used here. The value chosen here is 1KΩ.

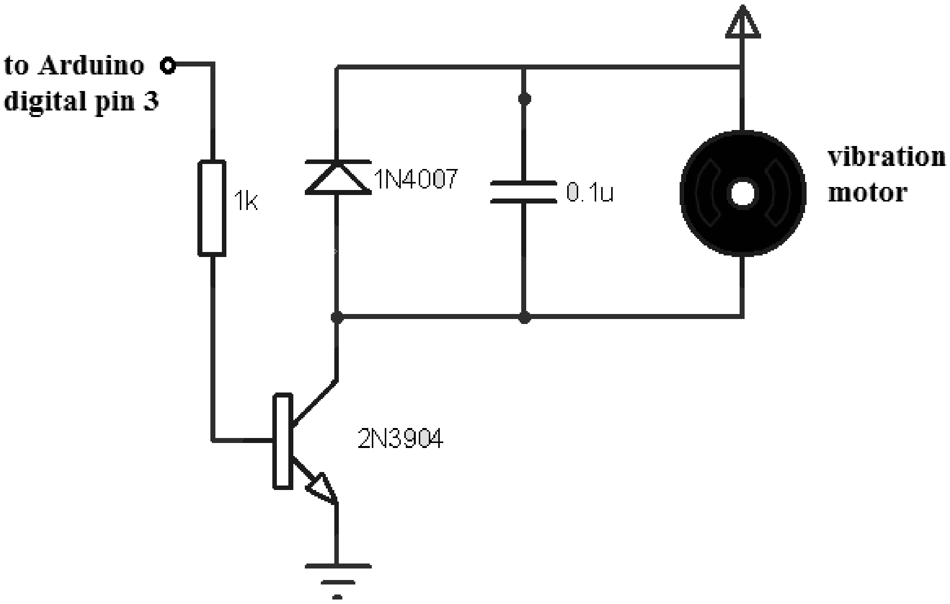

Figure 8: Vibration motor circuit schematics

2.7 The Complete System Description

The schematic diagram of the complete system was designed in the Proteus 7.0 simulation software environment. The three modules are interconnected as shown in the schematic diagram in Figure 9. The pulse sensor and the signal conditioning circuit form the input peripherals to the Arduino Uno microcontroller, while the audio system and the vibration motor circuit constitute the output peripherals.

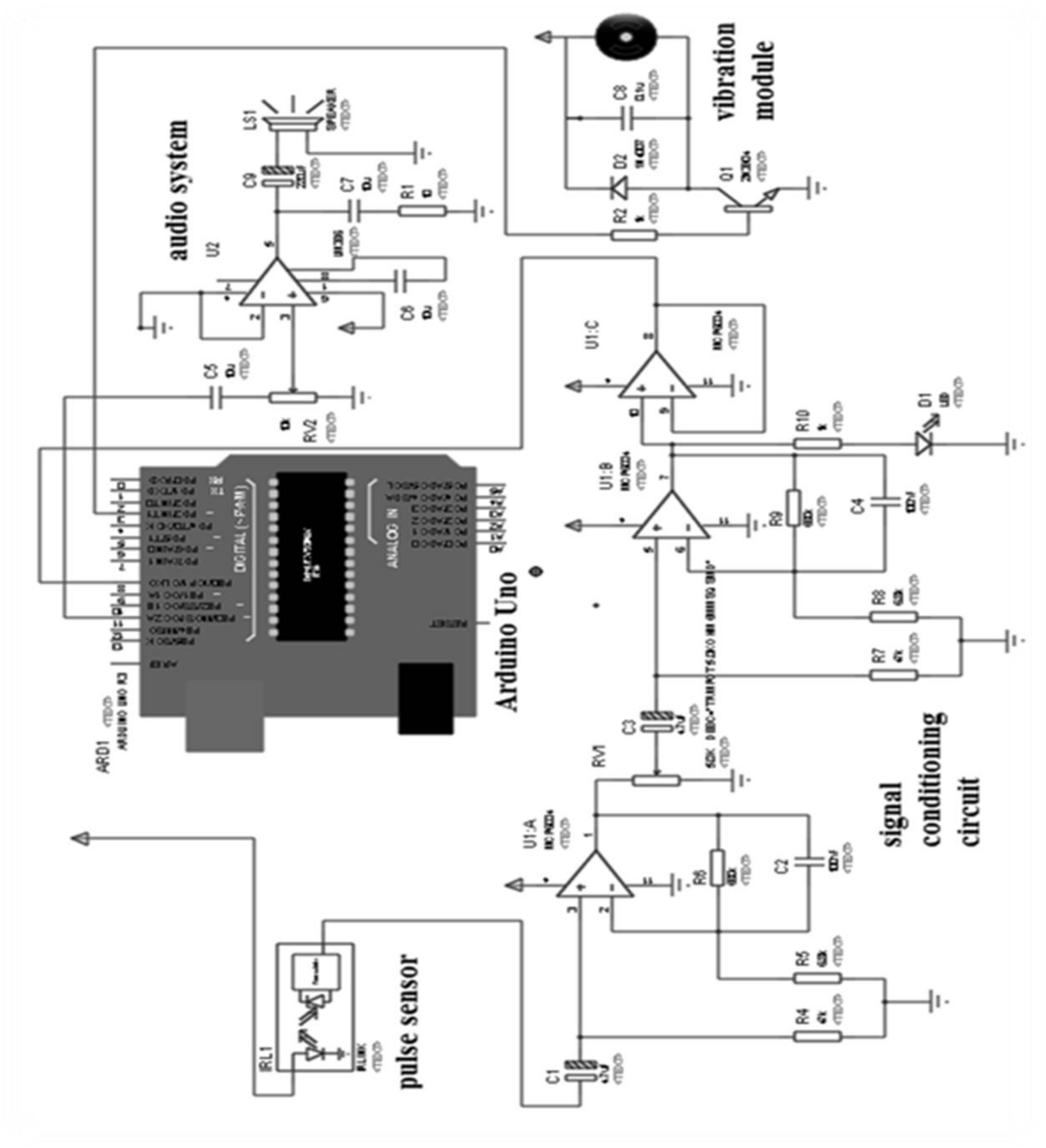

Figure 9: The complete system schematic diagram

2.8 Basic Assumptions and Approximations

In accordance with the scope of the project, some assumptions were made during the design stage of the system with respect to its functioning, as well as its scope of usability. These assumptions are as follows:

- At least one of the driver's palms will be in contact with one of the pulse sensors on the steering wheel at all points in the duration of driving.
- In the event that the driver falls asleep, his palms must still be on the steering wheel. Otherwise, the vibrations would have no effect, and the means of alerting the driver would be solely reliant on the audio message.

III. RESULTS AND DISCUSSION

The pulse sensors on the steering wheel measure the driver's pulse when his left and right palms are placed on them. Two pulse sensors were used to add redundancy to the design. In the event that one of the driver's palms is not in contact with a pulse sensor, the other one would still be reading the driver's pulse. The important parameter for testing the system is the heart rate of the driver in beats per minute (BPM). The timeliness of the system is also considered.

Heart Rate as the Measurement Parameter for Drowsiness

Studies show that the heart rate of a person goes through a gradual decline as sleep sets in. Hence, the heart rate is used as the measurement parameter for drowsiness analysis.The heart rate is the number of heart beats or pulses per unit time. Usually,a minute is chosen as the time unit. The heart rate is related to the frequency of the pulse signals by the mathematical expression given in Equation .5.

The heart rate in beats per minuteundergoes a significant decline when a person is drowsy. Therefore, this variation was made use of in the control program in the Arduino to test for drowsiness. The normal heart rate for average adults is in the range of 60 – 100 BPM [13]. Therefore, a threshold value of 60BPM was used as the test criterion in the control program. Any value below that would indicate that the driver was feeling drowsy, and the Arduino would send the actuating signals to the alert module in order to alert the driver.

The system when tested showed a delay in the normalizing of the heart rate reading. This is because many samples of the input signal had to be taken before the heart rate is computed. However, the test results produced were as expected.

IV. CONCLUSION

The drowsy driver detection and alert system constructed in this project is meant to simplify drowsiness detection by employing a simple method for measuring the physiological state of the driver using a pulse sensor. The simplicity of the system was achieved by making some very useful approximations all of which are outlined in Sectiion 2.8. It may be noted that these approximations did not significantly diminish the functionality of the system in real life applications.

The system is both compact and efficient. The cost may look big as a single project. However, on a large scale of manufacture, the cost will be far less than the stated cost used in this project. This reduction would be achieved through the automated bulk production of components and circuits.

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