IR based pulse sensing unit for vital sign monitoring

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***Abstract*—The heart rate can be monitored in two ways: manually checking the pulse at the wrists or neck or using a Heartbeat Sensor. The proposed project measures the heart rate of a person using optical sensors. The optical sensor detects the variation of blood volume at the fingertip. In this project's scope, the sensor will be an infrared light-emitting diode which will be on the same side of the finger (Reflective type PPG). The underlying principle is that the volume of blood inside the fingertip increases when the heart expands and decreases when the heart contracts. The resulting pulsing of blood volume inside the fingertip is directly proportional to the heart rate, and if you could count the number of pulses in one minute, you'd know the heart rate in beats per minute (bpm). An IR transmitter/receiver pair placed in close contact with the fingertip is used for this. When the heartbeats, the volume of blood cells under the sensor increases, reflecting more IR waves to the sensor; when the heart does not beat, the intensity of the reflected beam decreases. Then the sensor converts the pulsating reflection into a suitable current or voltage pulse.[2]**

The lighting condition in the environment is very important to avoid distortion in the signal so we will take necessary actions such as designing a special enclosure to cover the optical sensor and using a band filter to remove unnecessary wavelengths in future implementations for better measurements.

I. Introduction

Heart rate is the number of times one's heartbeats per minute. For an average person, this value lies between 60-100 bpm. The heart rate gradually rises during exercises and gradually returns to the rest value after exercise. The rate at which the pulse returns to normal is an indicator of a person's fitness. As a result, a heart rate monitor is an essential device nowadays for keeping track of your body, not only for people suffering from heart disease but also for people who want to stay fit.

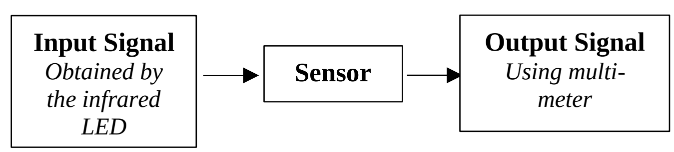
In this project, reflective photoplethysmography (PPG) is used to monitor heart rate. These sensors use light-based technology to sense the rate of blood flow as controlled by the heart's pumping action. This method is less sensitive to motion artifacts and thus more user-friendly.

II. Initial Specifications

- Power supply : 5V
- Working current : <5 mA
- IR driving current : 0-50 mA
- Operating temperature : -40 to 50 ℃
- Heart rate range : 30 to 250 bpm
- Wearable on wrist
- Plug and play type

III. Methods

We have planned to measure the pulse rate by photoelectric pulse wave method which is classified into 2 types depending on the measurement method: transmission and reflection. Our project is based on the reflection of IR waves towards the body and measuring the amount of light reflected using a photodiode or phototransistor.



Methodology

A. Principle of operation

The reflection method was the method used in this project where the light emitted from the Infrared LED is reflected by the blood vessel and the volume change is therefore detected as reflected light by the 5mm Infrared photodiode. (Fig. 1)

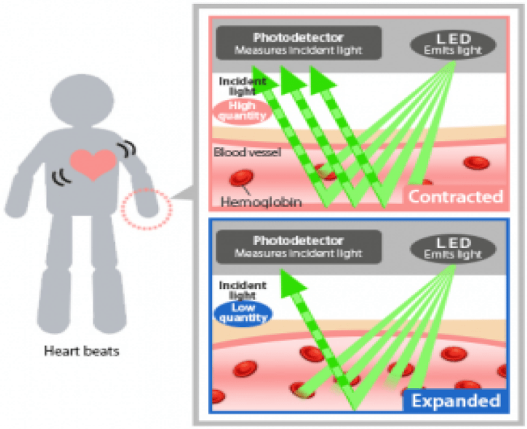


Fig. 1. How IR LED light is reflected from the blood vessels[5]

Our skin has a semi-transparent appearance. Most of the light is absorbed or reflected by our organs and tissues (skin, bone, muscle, blood), but some light can pass through if our tissues are thin enough. When blood is pumped through your body, Oxygenated hemoglobin present in the blood of the arteries has the characteristic of absorbing incident light, the light that is not absorbed but reflected is captured by a Photodetector. Photodetector produces an electrical signal when light strikes it. so, by sensing the blood flow rate (change in blood vessel volume) that changes following heart contractions over time we can measure the pulse wave signal.[1][3]

B. *Circuit diagram*

The circuit model in Proteus Software (Fig. 2) and the prototype circuit (Fig. 3) are given below.

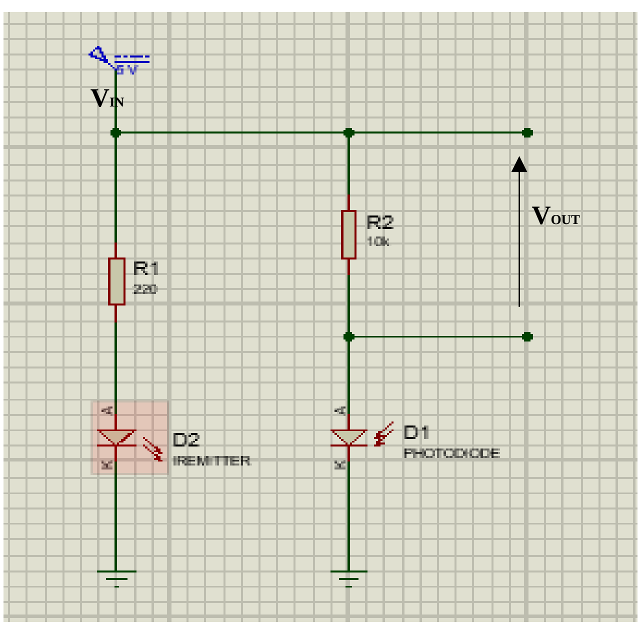


Fig. 2. Basic Circuit diagram

C. *Testing Setup*

The minimum resistance value required for R_1 is 190Ω according to the IR-led specifications [9]. Since it is not available, a 220Ω resistor is used. And it was found that the resistance value of R_2 is $10\,k\Omega$ made a reasonable voltage change with the help of IR receive specification data [8]. The Arduino UNO board was used to connect to the ground (GND) and V_{in} (5V) voltage.

The testing setup (Fig. 3) was made on a breadboard to ensure the circuit works fine and also to ensure whether the circuit is sensible for pulse variations. Initially, the IR is reflected randomly by covering the emitter and receiver with a paper; in-order to allow maximum current (~worked as a closed circuit) through the receiver for ensuring the circuit was connected properly. Then the voltage across each component was observed for a while and the perfect connection was ensured by confirming the absence of noises due to connections to minimize the final output noises. To measure the voltage, the voltmeter was set to maximum and then minimized step by step to 200 mV. As the result, stable voltage outputs across each element could be observed. Therefore, all the elements were soldered and the final device (Fig. 4) was obtained.

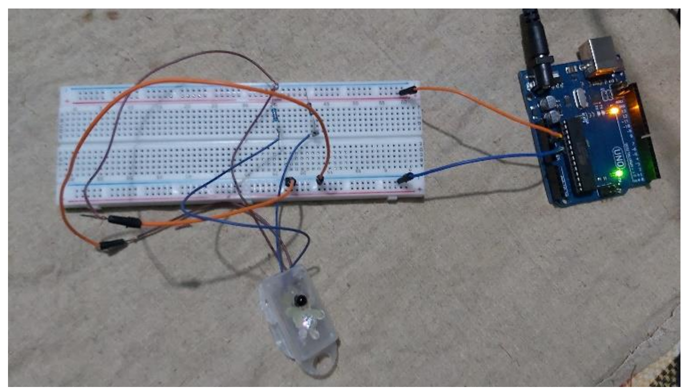


Fig. 4. Testing setup

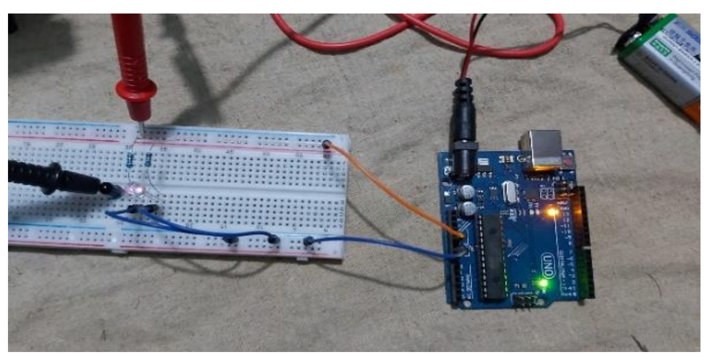


Fig. 3. Hardware circuit

TABLE I. CALIBRATION AND STATISTICAL ANALYSIS

Time(s)	**Voltage across R (mV)**				**Average**	**R.M.S. value**	**Standard deviation**	**Skewness**	**Kurtosis**
	Attempt 1	***Attempt 2***	***Attempt 3***	***Attempt 4***					
0	0	0	0	0	0	0	0	0	0
10	31.9	29.4	29.7	28.7	29.925	29.95	1.38	1.421	2.441
20	31.8	29.2	30.3	29.4	30.175	30.19	1.18	1.190	0.558
30	32.1	29.5	29.5	29.3	30.100	30.12	1.34	1.97	3.906
40	31.9	29.0	29.8	28.2	29.875	29.90	1.42	1.036	1.058
50	32.1	29.0	29.7	29.1	29.975	30.00	1.45	1.724	2.884
60	31.9	29.1	29.8	29.0	29.950	29.97	1.35	1.617	2.454
Heart Rate (BPM)	44	19	14	23					

D. Calibration Setup

The Sensor was attached to the wrist firmly without relative movements between the sensor and the hand. Then the voltmeter was connected between the resistor R_2 . According to the researches, it was found that the blood volume change is proportional to the IR intensity [7]. The blood volume change and the IR intensity cannot be measured. Thus, the reading was recorded with time (1 min for each attempt). Then the readings were plotted with time to get waveform.

E. Verification Method

To verify the result, the same procedure was repeated many times same day and another day on the same person. Then the output pulse rates and the voltage readings corresponding to the time were examined through statistical analysis. Through the analysis result, the performance of the sensor was verified.

F. Validation Method

To check the validity, the input-output characteristics should be compared with the existing technologies. The outputs through the existing sensor and our designed sensor should be recorded with time under the same conditions (the same person on the same sit and at the same place of the wrist). By comparing the output waveforms and input-output characteristics, the validation of the device can be tested.

G. Statistical analysis

The standard deviations are very small values. Thus, the values are closely distributed around the mean. And the kurtosis is strongly positive and denotes that the distribution is highly peaked. Therefore, our system outputs highly accurate and precise readings. But, the pulse rate readings get collapsed due to noises. Thus, the standard deviation is high and the skewness, kurtosis values displays the low accuracy and precision of the readings.

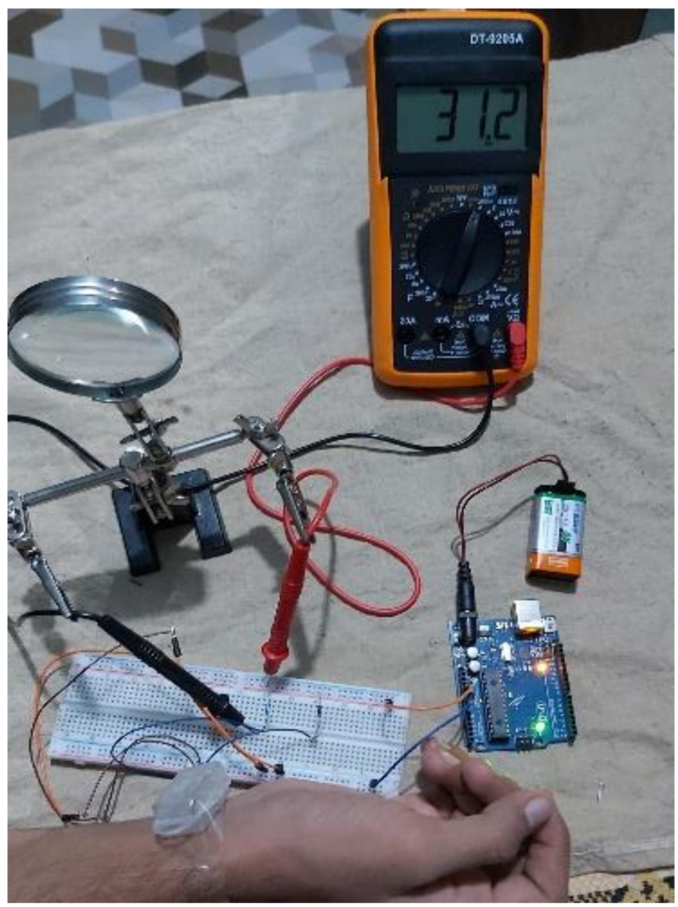


Fig. 5. Calibration setup

IV. Results

A. Observations

When we placed our wrist in the IR sensing area, the voltage reading from the multimeter started to fluctuate from the steady-state voltage (2.0-2.3 mV).

Given below are the graphs plotted corresponding to the voltage output using MATLAB. (Fig. 6-9)

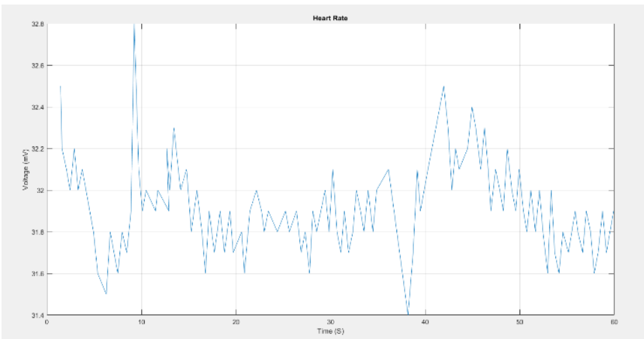


Fig. 6. Output Analog waveform of the sensor for attempt 1.

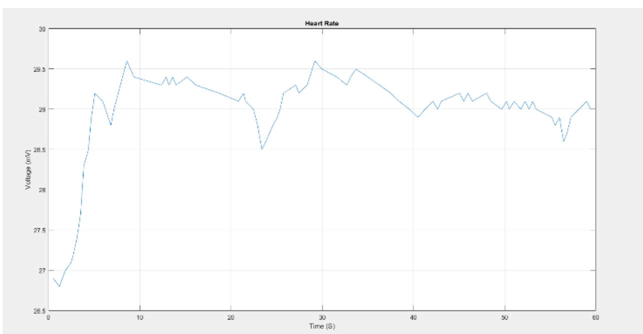


Fig. 7. Output Analog waveform of the sensor for attempt 2.

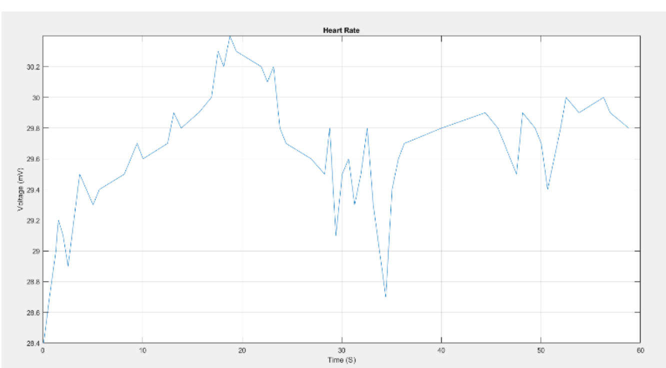


Fig. 8. Output Analog waveform of the sensor for attempt 3.

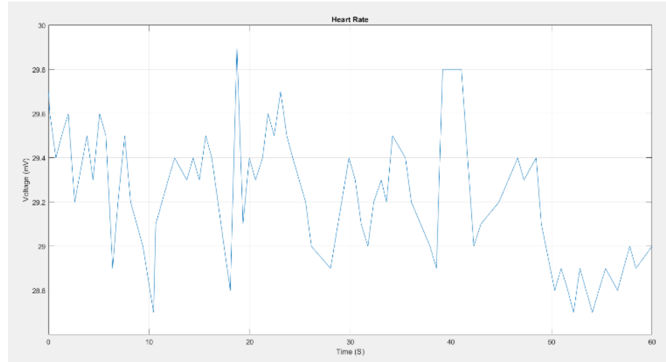


Fig. 9. Output Analog waveform of the sensor for attempt 4.

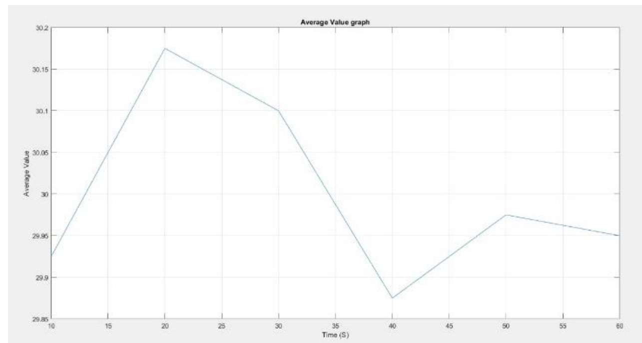


Fig. 10. Variation of Average Voltage with Time.

B. Verification Results

All the voltage fluctuations happened between ~25 to ~35 mV range on the same day and another day on the same person. Thus, it could be verified that there were no errors on the circuit.

According to the statistical analysis done above, it is proved that the accuracy and precision of the input-output relationship are significantly high. Even-though, the pulse rate is much erroneous because of errors. Since, our target is to improve the accuracy, precision, and the sensitivity of input-output relationship, we have left the BPM for future improvement. Therefore, we verify that our aim is satisfied with this device.

C. Calibration Results

Statistical calibration is the only possible way to calibrate our sensor circuit. Therefore, according to the statistical analysis results (TABLE I.), the standard deviation values are small. Therefore, the outputs are more accurate and precise.

TABLE II. Calibration and Statistical Analysis

Time (n^{th} sec)	Average	STD	STD error
10	29.925	1.38	0.69
20	30.175	1.18	0.59
30	30.100	1.34	0.67
40	29.875	1.42	0.71
50	29.975	1.45	0.725
60	29.950	1.35	0.675

D. Final Specification

- Power supply/ Maximum Vin (V_{max}) : 5V
- Maximum allowable current(I_{max}) : 17 mA
- Operating temperature : -40 to 80 °C
- Wavelength : 940 nm
- Heart rate range : 10 to 250 bpm
- Wearable on wrist
- Plug and play type

V. DISCUSSION

Since the voltage variations are very small values (~ in µV range), it was unable to get a measuring device with that much accuracy. Therefore we set the resistor value to get the almost same fluctuations within the available measuring device. And also, this is more sensitive to noises. Thus we had to make sure the stability of the whole system throughout the entire process. This is ensured through fixing all the connections (including hand) stably. Before fixing to the hand the voltmeter displayed 2.0 mV - 2.3mV. It might be caused due to the direct IR radiations, the reflected IR waves on the setup elements, or the IR radiations from other sources. Because the experiment couldn't be done in an isolated place.

It is more convenient for daily usage and portable. As mentioned earlier, this basic sensing circuit is more sensitive to noises like motion artifacts [10]. Therefore it will result in an erroneous pulse waveform. To avoid that, a filter and an amplification circuit can be attached [10][11]. Moreover, skin tone, low perfusion, sensor location on the body, and the crossover problem are some of the weaknesses of our sensing unit.

The resistor values had been modified to get a more reasonable DC voltage variation of the output signal. It had resulted in a more sensitive output. Therefore, it will result in a more accurate detailed pulse wave format. It is an advantageous feature than other existing sensors. Cost is almost equal to other sensors. But the voltage fluctuations could be observed clearly with the same cost. [6][12]

The blood volume change cannot be measured. Therefore, it was unable to plot the input-output characteristics graph. Due to this, the input-output relationship and the accuracy couldn’t be measured. To get the accurate measurement, the procedure can be repeated many times and the average voltage readings in each time or the average pulse rate should be calculated. This has been done on the statistical analysis part. It was unable to check the validation test since we were unable get the existing sensor. Because, all the sensors available on market includes amplifier and filter circuits on PCBs. Thus, the extraction of pure sensing circuit was also not possible.

VI. CONCLUSION

The application of engineering principles to medical platforms is known as the biomedical field. A pulse wave is a change in the volume of a blood vessel that occurs when the heart pumps blood, and a detector that monitors this volume change is called a pulse sensor. We have implemented an IR pulse sensing method. We have used 5 main components to build our prototype. An infrared source, infrared receivers(photodiode), resisters, an Arduino board, and a 5V battery to power up the Arduino board. Our simple sensor can approximately detect human pulses with acceptable accuracy for simple applications. with some level of amplification and filter techniques, we hope to implement the device further in the future.

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