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# A Microcontroller Based Bluetooth Pulse Oximeter with Adaptive Algorithm for Non-Invasive COVID-19 Detection

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**Research Article**

## Abstract

*A pulse oximeter is a clip-on device that is used to measure the oxygen saturation of the arterial blood. This measurement of oxygen saturation is very important to the medical practitioners because there are many anomalies that can lead to a drop of oxygen saturation such as suffocation, choking, lung infections (ronchitis, pneumonia and bronchiolitis), COVID-19 and inhalation of poisonous chemicals. With the outbreak of the novel Covid-19 pandemic which has in turn led to a paradigm shift in the way that activities are being carried out in different economies of the world, it has indeed become an imperative to adopt a more pragmatic approach in not only combating the thread of the current pandemic but to also adequately prepare ahead for any other outbreak that may occur in the future. A lot of researchers have adopted the use of traditional pulse oximeter for getting the level of oxygen saturation of the blood via non-invasive means. However, the use of traditional pulse oximeter exposed the medical practitioners to infectious diseases due to proximity problem. Also, discrepancies in the environmental factors, the readings obtained from the device becomes flawed with errors. To solve the aforementioned problem, this work designed a robust wireless pulse oximeter which is a very important device used in the medical field to obtain the level of oxygen saturation and heartbeat of a patient with safe proximity. Performance evaluation of the designed pulse oximeter was carried out using the SpO2 and heart rate as performance metrics. It can be observed that the Root Mean Squire Error (RMSE) values of SpO2 and BPM were found to be 1.549 and 3.233 respectively. The small RMSE values obtained indicates the successful performance of the designed pulse oximeter.*

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**Keywords**

COVID-19, Pulse-oximeter, Bluetooth, SpO2 and Heart rate

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## 1. Introduction

Before the invention of the pulse oximeter in the early 1970s, the medical practitioners used to get the level of oxygen saturation of the blood via invasive means which necessitated the piecing of the subcutaneous tissue of the patient. Because of this, the patient is often subjected to the pain of the process involved in the acquisition of the measurement. Another challenge was the time overhead involved in getting the measurement. But by early 1970s, some researchers started working towards the development of a non-invasive medical device that can be used to measure the level of oxygen saturation easily by overcoming the aforementioned problems. Hence the pulse oximeter did not become commercially available up until the 1980s. In fact, even towards the end of the 1990s, there was still a debate regarding the use of the routine pulse oximeter for patients (Lee et al., 2022). A Pulse Oximeter (PO) is a clip-on device that is used to measure the oxygen saturation of the arterial blood. The traditional PO can give inaccurate measurement due to environmental conditions (Crooks et al., 2022). The readings obtained from the device thus becomes flawed with errors. In this case, there are possibilities that the patient may end up receiving the wrong treatment. Apart from the aforementioned reasons, there is also the need to reduce the risk of exposure of the medical practitioners from a pandemic outbreak like the novel Covid-19 (Dunnwald *et al.*, 2021).

This paper was able to show how the accuracy of the pulse oximeter device was improved. This can be read when a finger is placed on the PO. This was achieved through the introduction of an ambient light and temperature sensor whose parameters can be used to compensate for the deviation from the accurate result obtained from the device due to the variation in ambient light and temperature of the surroundings in which the pulse oximeter is put into use. Figure 1 shows a schematic block diagram of a finger placement on the PO sensor.

Section two of this paper, carried out a review of similar works to check the current state-of-the-act in the area of discussion. Section 3 describes the methods carried out in designing a pulse oximeter. Section 4 presents the results obtained and the corresponding discussion. Finally, section five is the conclusion of the paper.

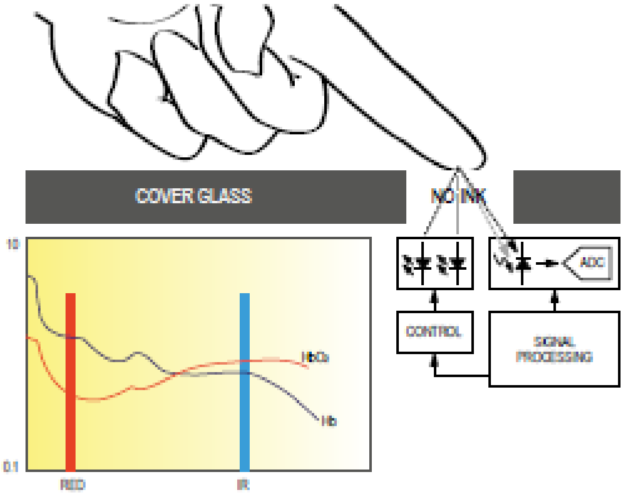

Figure 1: Schematic Block Diagram of a Finger Placement on the Pulse Oximeter Sensor (Luks and Swenson, 2020)

## 2. Review of Related Literature

In order to achieve better performance of pulse oximeter in carrying out an accurate and more precise measurement amidst varying factors like the ambient light and temperature of the environment where the device is used. There are numerous research works carried in this area.

For instance, (Ali et al., 2017) presented a technique which uses a contactless pulse oximetry measurement by photoplethysmography imaging (PPGI). Kalman's filter were employed to reduce the lower harmonics of the PPGI signals. By using a low computational algorithm, the measurement of the pulse oximetry of a patient through a color camera was estimated. The approach he adopted analyzes the plethysmography signals obtained through a standard color camera to calculate the pulse oximetry. The average of each even and odd frame was used to create two signals which were then used for synchronization to an illuminating source of a specified wavelength (primarily 640 and 950nm respectively). A fair estimate of the pulse oximetry was obtained from a sample size of ten persons. Finally, Altman analysis was used to show that a strong correlation between a standard system and the PPGI measurement exists. However, no attempt was made to test for what result will be obtained if the ambient light and temperature of the surrounding was varied to a large extent. Another, major challenge which may to a large extent affect the quality of result obtained through this approach could be the skin color of the patient whose pulse oximetry is to be estimated by their model of the pulse oximeter device. In similar studies, (De et al., 2018) employed the use of a keyed sensor system with a corresponding locked sensor port for the provision of restricted access to the monitor. The keyed sensor had a memory reader associated with the sensor port. Thus, in this underlining system, the monitor was configured to function only when the key was set into active communication with the locked sensor port. Through this approach, the memory reader is able to retrieve a set of predetermined data from the memory element. In this model of pulse oximeter, the monitor can only be accessed setting the key to be different from the keyed sensor. Hence, the key that was used in their model was integrated into an adapter cable and was used to serve as the link between the sensor port and the unkeyed sensor in order to enable the monitor to seamlessly function with the unkeyed sensor. Through their work, they were able to succinctly describe how a restriction can be placed on the peripheral device attached to the pulse oximeter in order to enforce strict adherence to some sort of predefined measurement sensor standard. To further explore the wireless advantages of the pulse oximeter, (Greenhalgh et al., 2021) carried out a group capstone embedded system design project on wireless Bluetooth Pulse Oximeter. In the work, a solution was proffered to the restriction of movement often associated with the wired pulse oximeter. This design approach thus, allows for freedom of monitored ambulation which in turn greatly increased the chances of the patients' quick recovery. In the design, the use of MAX30100 was adopted as the pulse oximeter sensor, an Arduino microcontroller as the processor and an HC-05 Bluetooth module as the wireless transceiver. The pulse oximeter device was connected to a laptop via a Bluetooth, which was then used to get the raw sensor data as well as the oxygen saturation and heart rate data samples. These data having been successfully collected via the Bluetooth link, was used to plot the heart rate photoplethysmography waveform using the Arduino Serial Plotter. Finally, the developed model was tested against existing devices for accuracy and reliability. However, the analytical formula adopted for the implementation of their work, has some limitations in terms of the accuracy and reliability of the result that it can provide. This is primarily due to the fact that it does not take into consideration the errors that may be introduced due to variation in the ambient conditions of the environment where it is put into use. This therefore, necessitates the need to employ a means through which these ambient conditions can be monitored and used properly calibrate the device so as to compensate for the discrepancies that may ensue due to their variation.

From the reviewed literatures, it has become clear that although the wireless pulse oximeter is convenient and easy to use for measuring the pulse rate and oxygen saturation of the arterial blood, there are tendencies that the measurements obtained from the device may be flawed by errors introduced into the system as a result of variations in ambient conditions of the surroundings in which the device is put into use. And in the event of a pandemic like the novel Covid-19 or an outbreak of an infectious disease especially those leading to the depletion in the level of oxygen in the blood hemoglobin, wherein the measurement obtained from the pulse oximeter becomes crucial in the determination of the proper treatment needed to safe the patient's life, the need to mitigate any form of error that may be introduced into the system becomes an imperative that cannot be over emphasized. This research therefore seeks to combat some of these problems especially those relating to variation in the ambient conditions such as the ambient light and temperature of the surrounding. It is also hoped that through the realization of the success of this research, the risk factor of exposure of the medical practitioners in Nigeria, especially to pandemics or outbreak of infectious diseases will be drastically reduced as physical contact with the infected patient will be minimized.

## 3. Proposed System

The processes needed for the completion of this work is presented. The working principles of PO is also presented for better understanding of the designed PO.

### 3.1 Working Principles of the Pulse Oximeter

The basic working principle of the pulse oximeter is called Photoplethysmography (PPG) which is basically an optical technique that is used to obtain the volumetric changes in the arterial blood circulation. It is essentially a low-cost non-invasive approach that is used to sample the measurement from the surface of the skin (Luks *et al.*, 2022). The pulse oximeter uses a pair of red and infra-red LEDs facing a photodiode with a space in between where a patient's translucent body part such as a fingertip or the earlobe, can be placed. The red wavelength is about 660nm while the infra-red wavelength is 940nm. However, the absorption of the light at these wavelengths differs significantly between oxygenated and deoxygenated blood such that absorption of infra-red-light wavelength is more with oxygenated hemoglobin and less for red light wavelength. Reverse is the case for the red-light wavelength (Greenhalgh *et al.*, 2021).

Figure 2 gives the schematic block diagram of the pulse oximeter sensor chiefly the max30100. While plate 1 is a plate showing the developed pulse oximeter. All the outlined subcomponents have been integrated into the sensor module. As seen from the schematic diagram, the module provides an interface where digital data relating to the pulse oximetry can be sampled through the use of inter-integrated circuit (I2C) protocol. Figure 3 shows the circuit diagram of the developed pulse oximeter.

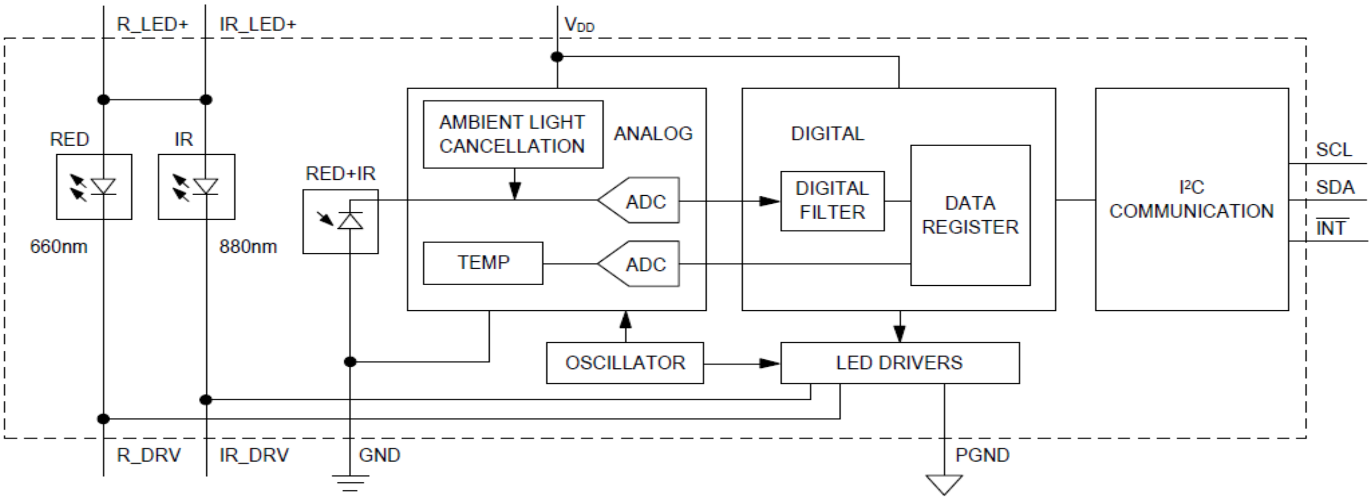

Figure 2: Functional Block Diagram of Max30100

### 3.2 Step-by-Step Process for the Design of Improved Pulse Oximeter

The methodology that will be adopted in this research work will be as follows:

1. Replication of the work of (De- *et al*., 2019)
    a. Evaluation of the ratio of the red and infra-red wavelength based on the equation:
    $R = (AC\ RMS\ RED / DC\ RED) / (AC\ RMS\ IR / DC\ IR)$ *or*
    $R = (\log (I\ AC) * \lambda1) / (\log (I\ AC) * \lambda2)$
    *Where;*
    *R is the ratio of the red to infra-red wavelength*
    *AC RMS RED is the alternating root mean square value of the red wavelength*
    *DC RED is the scaling factor of the red wavelength obtained from the DC filter*
    *AC RMS IR is the alternating root mean square value of the infra-red wavelength*
    *DC IR is the scaling factor of the infra-red wavelength obtained from the DC filter*
    *I AC is the alternating diode current*
    *$\lambda1$ is the red wavelength*
    *$\lambda2$ is the infra-red wavelength*
    b. Evaluation of the Saturated peripheral Oxygen level ($SpO_2$) based on the equation:
    $SpO2 = 110 - 25 * R$
    *Where;*
    *SpO2 is the Saturated peripheral Oxygen level and*
    *R is the ratio of the red to infra-red wavelength*
2. *Development of an improved pulse oximetry measurement algorithm*
    a. *Repetition of steps1a-1b*
    b. *Computation of ambient compensation factor*
    $\mu=\alpha+\beta$
    *Where;*
    *$\mu$ is the ambient compensation factor*

*$\alpha$ is the ambient light compensation factor and ß is the ambient temperature compensation factor*

c. *Recalculation of the wavelength ratio $R_\mu$ Where;*

*$R_\mu$ = ((AC RMS RED – $\mu$) / DC RED) / ((AC RMS IR – $\mu$) / DC IR) or*
*R = (log (I AC - $\mu$) * $\lambda$1) / (log (I AC - $\mu$) * $\lambda$2)*

3. *Implementation of steps 1 and 2 using MATLAB R2017a version*
4. *Comparison of the improved algorithm*

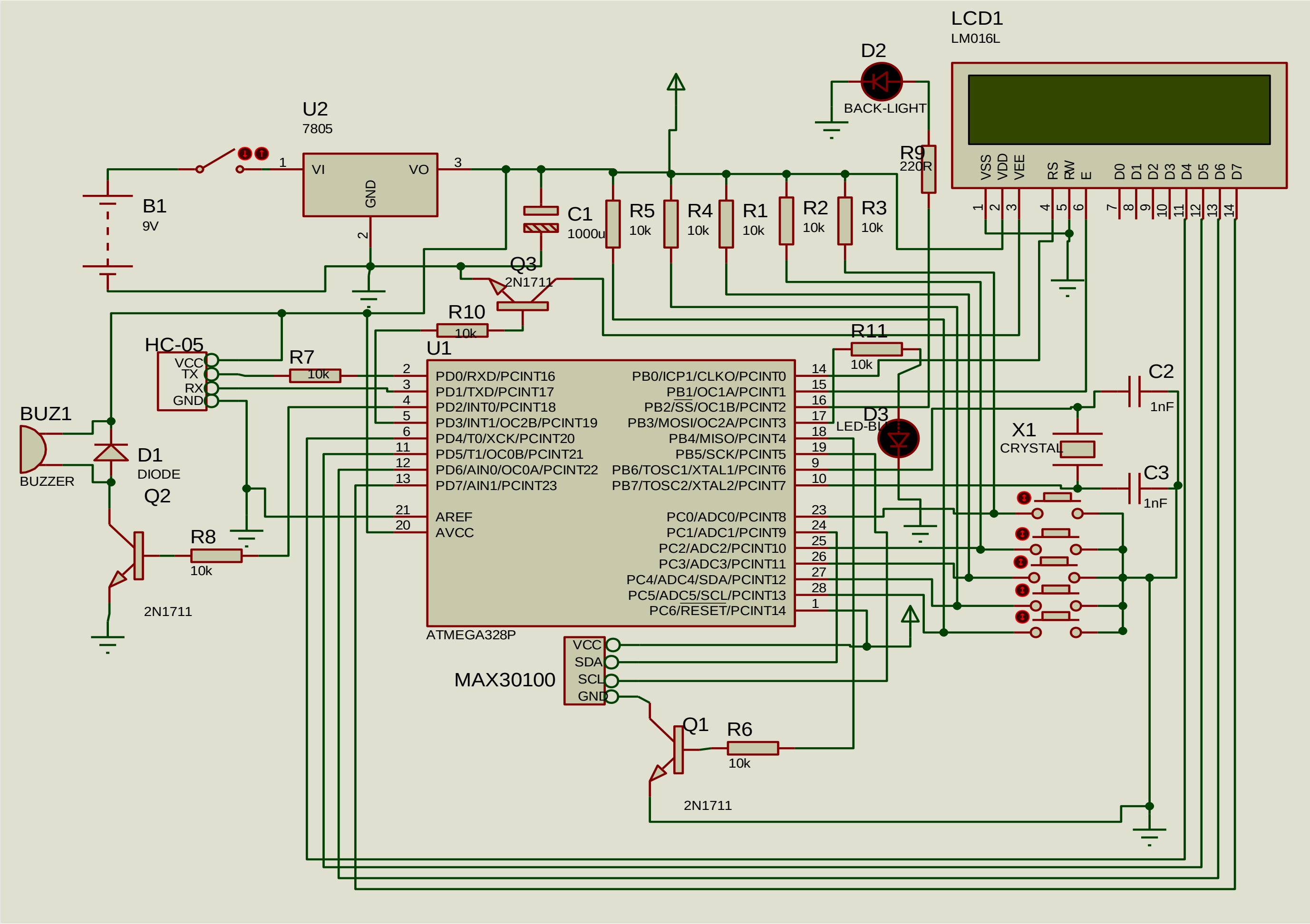

Figure 3: Schematic Circuit Diagram for the Proposed Bluetooth Wireless PO

### *3.2.1 Designed System Model of PO*

In this research, the improvement of the performance of the pulse oximeter through the use of the adaptive algorithm technique was achieved as follows:

a. Computation of the compensation factor μ, given by (1)

$$\mu = \gamma + \theta \qquad (1)$$

Where: $\mu$ is the compensation factor, $\gamma$ is the ambient light compensation factor and $\theta$ is the ambient temperature compensation factor.

b. Recalculation of the wavelength ratio $R_\mu$, given by (2)

$$R_\mu = \frac{((\text{AC RMS RED}) - \mu)\ /\ (\text{DC RED})}{((\text{AC RMS IR}) - \mu)\ /(\ \text{DC IR})} \qquad (2)$$

c. Recalculation of the SpO$_2$ value using (3)

$$SpO_2(t_\mu) = \frac{\varepsilon_{Hb}(\lambda_1) - \varepsilon_{Hb}(\lambda_2) R_\mu(t_\mu)}{\varepsilon_{Hb}(\lambda_1) - \varepsilon_{HbO_2}(\lambda_1) + [\varepsilon_{HbO_2}(\lambda_2) - \varepsilon_{Hb}(\lambda_2)] R_\mu(t_\mu)} \qquad (3)$$

The flowchart of the improved model that this research work is shown in Figure 4. These improvements are outlined in the orange blocks of the flowchart. Figure 5 is the main circuit diagram of the designed work.

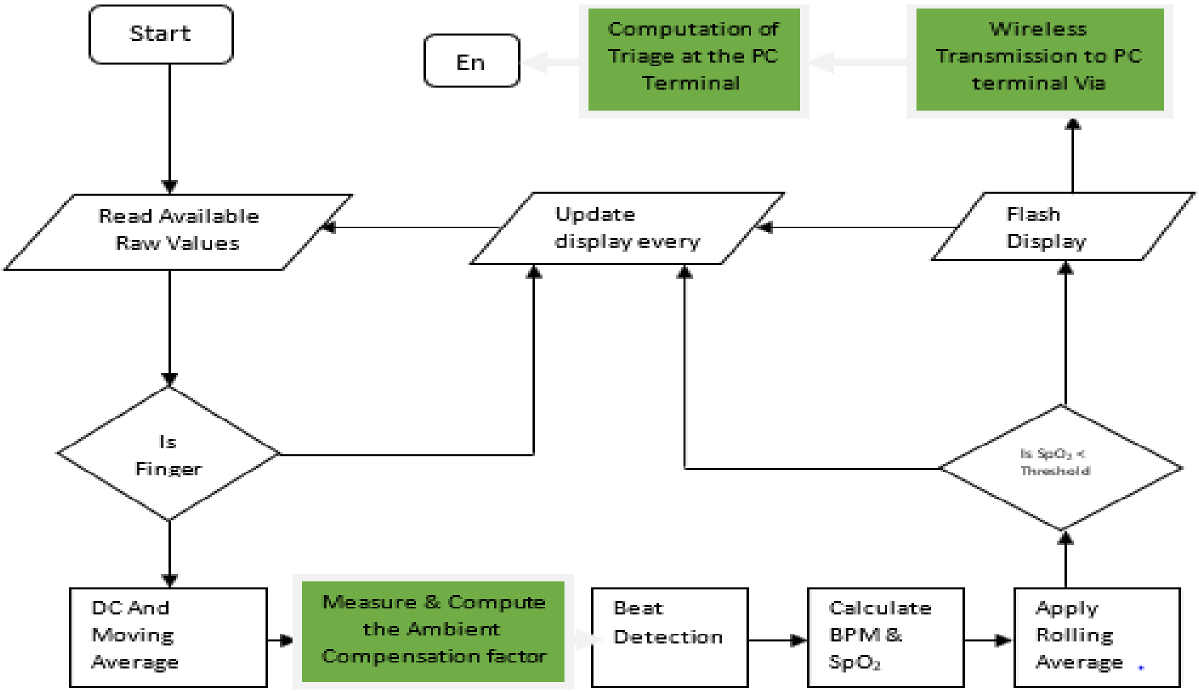

Figure 4: Flowchart of the Proposed Model

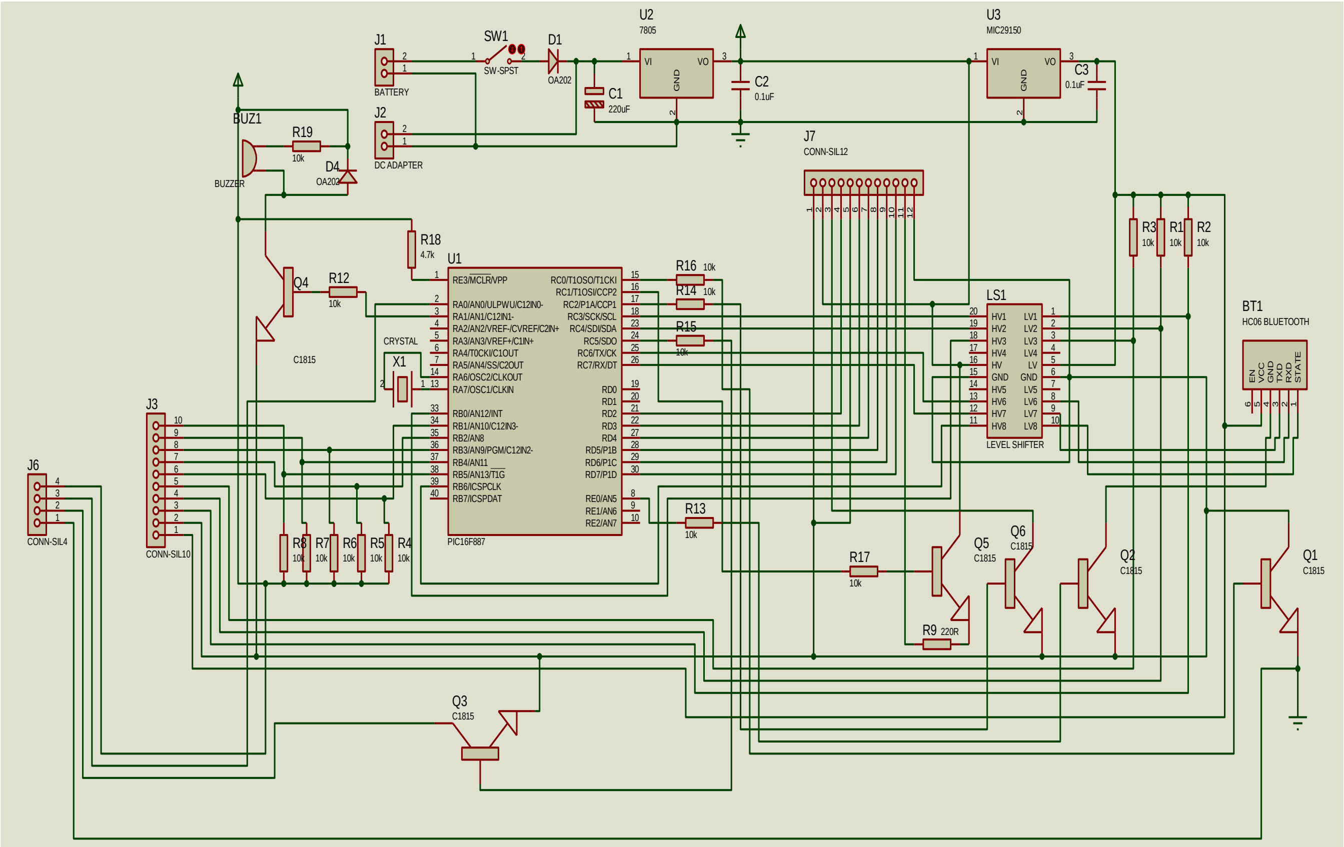

Figure 5: Main Circuit Schematic Diagram for the Implementation of the Research Work

## 4. Results and Discussions

This objective was met through two major paradigms. The first being the hardware implementation and the second being the firmware implementation.

### 4.1 SpO$_2$ Analysis of the Pulse Oximeter

Table 1 shows the comparison of the measurement results for SpO$_2$ obtained from the developed pulse oximeter and that of a clinical model. Measurements were obtained from twenty patient and the results were presented in table 1. The range of acceptable SpO$_2$ values for normanl patient are 95-100%.

Table 1: Comparison of the measurement results for SpO$_2$ obtained from the pulse developed pulse oximeter and that of a clinical model.

| **S/No** | **Clinical SpO2 ($X_1$) in %** | **Model SpO2($Y_1$) in %** | **Error ($X_1$-$Y_1$)** | **Square Error ($X_1$-$Y_1$)$^2$** |
|---|---|---|---|---|
| 1 | 99 | 97 | 2 | 4 |
| 2 | 97 | 95 | 2 | 4 |
| 3 | 98 | 97 | 1 | 1 |
| 4 | 96 | 96 | 0 | 0 |
| 5 | 95 | 96 | -1 | 1 |
| 6 | 98 | 96 | 2 | 4 |
| 7 | 96 | 95 | 1 | 1 |
| 8 | 97 | 96 | 1 | 1 |
| 9 | 99 | 97 | 2 | 4 |
| 10 | 98 | 98 | 0 | 0 |
| 11 | 96 | 98 | -2 | 4 |
| 12 | 99 | 96 | 3 | 9 |
| 13 | 97 | 95 | 2 | 4 |
| 14 | 96 | 95 | 1 | 1 |
| 15 | 98 | 96 | 2 | 4 |
| 16 | 95 | 95 | 0 | 0 |
| 17 | 99 | 97 | 2 | 4 |
| 18 | 96 | 97 | -1 | 1 |
| 19 | 97 | 96 | 1 | 1 |
| 20 | 95 | 95 | 0 | 0 |
| TOTAL | | | | 48 |

### 4.2 Root Mean Square Error Analysis

Where the root mean square error is computed using the formula in (4).

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}/X_1-Y_1/^2}{N}} \qquad (4)$$

$$RMSE = \sqrt{\frac{48}{20}} = 1.549$$

It can be observed that the RMSE value of 1.549 obtained indicates the successful performance of the designed pulse oximeter. The simulation graph for the designed pulse oximeter in terms of $S_PO_2$ is shown in Figure 6. From the figure, it can be observed that the $S_PO_2$ measurement using the clinical and the designed PO has similar pattern. This implies that the developed PO and the clinical PO are in agreement. Also, it can be observed that the RMSE between the clinical and the designed PO is within acceptable range.

### 4.2 BPM Analysis of the Pulse Oximeter

Table 2 shows the comparison of the measurement results for Heartrate obtained from the pulse developed pulse oximeter and that of a clinical model.

Measurements were also obtained from twenty patient and the results were presented in Table 2. The range of acceptable BPM value for normanl patient is 60-100BPM.

Table 2: Comparison of the measurement results for Heartrate obtained from the pulse developed pulse oximeter and that of a clinical mode

| **S/No** | **Clinical Heart Rate ($A_1$) in BPM** | **Model H. Rate ($B_1$) in BPM** | **Err ($A_1$-$B_1$)** | **Square Error ($A_1$-$B_1$)$^2$** |
|---|---|---|---|---|
| 1 | 68 | 66 | 2 | 4 |
| 2 | 68 | 65 | 3 | 9 |
| 3 | 68 | 66 | 2 | 4 |
| 4 | 65 | 63 | 2 | 4 |
| 5 | 66 | 68 | -2 | 4 |
| 6 | 66 | 62 | 4 | 16 |
| 7 | 65 | 62 | 3 | 9 |
| 8 | 69 | 66 | 3 | 9 |
| 9 | 68 | 65 | 3 | 9 |
| 10 | 70 | 66 | 4 | 16 |
| 11 | 64 | 66 | -2 | 4 |
| 12 | 69 | 65 | 4 | 16 |
| 13 | 67 | 63 | 4 | 16 |
| 14 | 72 | 67 | 5 | 25 |
| 15 | 71 | 66 | 5 | 25 |
| 16 | 68 | 65 | 3 | 9 |
| 17 | 69 | 66 | 3 | 9 |
| 18 | 66 | 67 | -1 | 1 |
| 19 | 65 | 61 | 4 | 16 |
| 20 | 69 | 67 | 2 | 4 |
| TOTAL | | | | 209 |

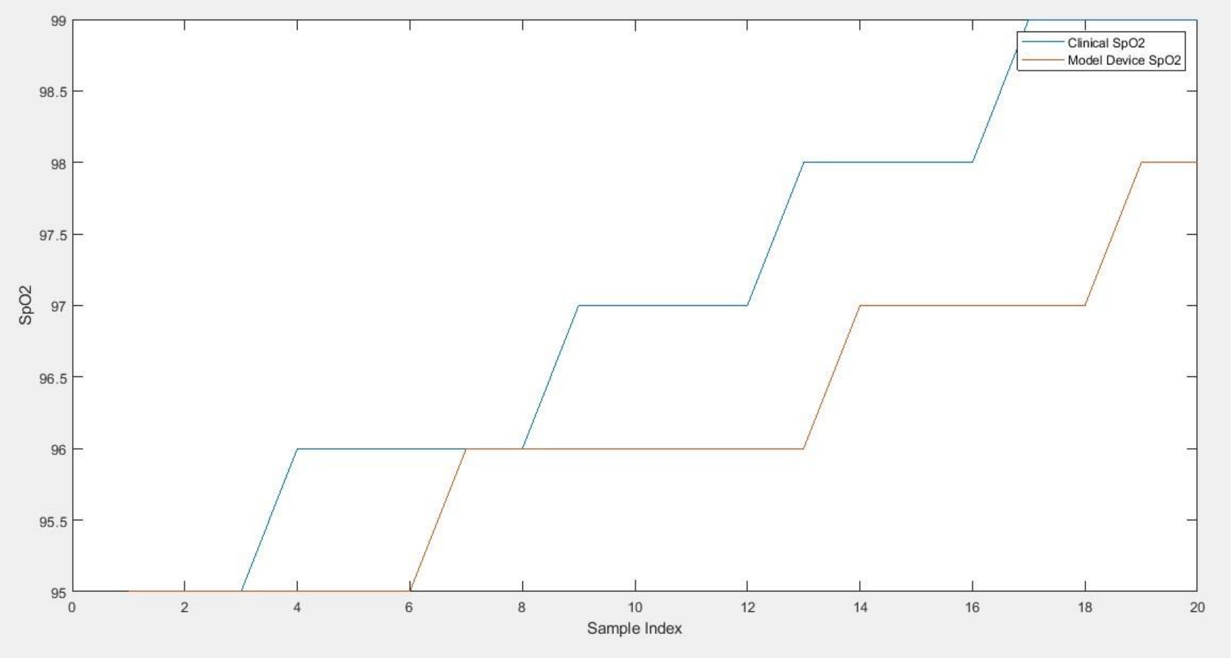

Figure 6: Visual Plot of the $SpO_2$ reading for the Clinical and Designed Model of Pulse Oximeter

### 4.4 Root Mean Square Error Analysis

Also, the RMSE value of 3.233 obtained for the heart rate indicate the successful performance of the developed PO.

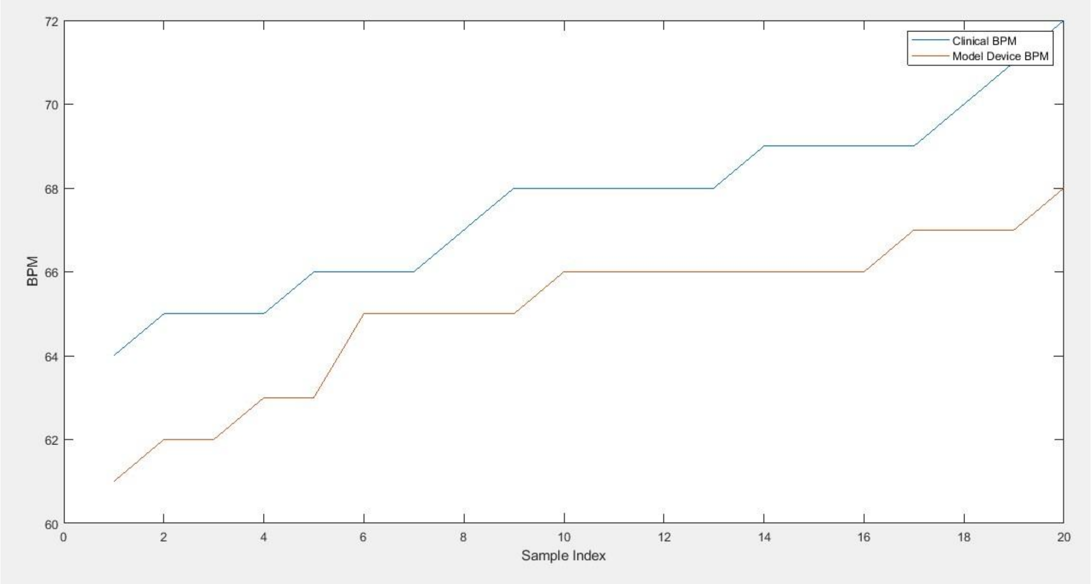

Figure 7: Visual Plot of the BPM reading for the Clinical and Designed Model of Pulse Oximeter

Figure 7 is a simulation graph showing the heart rate obtained from the designed pulse oximeter and that of a clinical model. From the figure, it can be observed that the RMSE values of both methods are within the aceptable range. This implies that the perfromance of the developed PO is efficient in carrying out proper patient monitoring and tests in hospitals and as such, mitgate the wide spread exposure of doctors to COVID-19.

## 5. Conclusion

The recent outbreak of the global Nobel Covid-19 pandemic has undoubtedly ex-ray the need to take proactive measure in order to effectively combat infectious diseases. This is because an outbreak of these diseases poses great threat to human lives as can be seen from the statistical records of the dead toll. To this end, this research has developed an enhanced locally made pulse oximeter. The developed oximeter was tested to be efficient and reliable in its operation in terms of SPO2 and heart rate as it ensured that the measurements obtained were a true indication of what the actual problem was with the affected patient. Also, it can be noted that the temperature matter relating to the measurement of the pulse oximetry within the Nigerian context and Africa which introduces error in reading is solved to a large extent.

## 6. Acknowledgment

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## Patent

The research is patented with the number: RP:NG/PT/NC/2023/7100.

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