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**Research Paper**

# Intrinsic Design, Construction, Testing and Statistical Analysis of an Improvised Smart Oxy-Ratiometer

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***ABSTRACT***
*The Smart Pulse Oxy-ratiometer (also known as Pulse-rate Oximeter) is a non-invasive and easy test that measures oxygen saturation level in the blood. The pulse oxy-ratiometer is a small clip-like device that is attached to a body part, like toes, fingers or and earlobe. It uses max30100 heartbeat sensormodel which is the most efficient model to work with in terms of coding and wiring, and Arduino Nano board (an Internet of Things (IoT) technology). It utilizes an electronic processor and a pair of small light emitting diodes(LEDs) facing a photodiode through a translucent part of the patient's body, usually a fingertip or earlobe.*
*In order to achieve the portability design goals, the open source Arduino software was used to design the circuit and miniaturize the board to make it as small as possible. A Vero board was used as it allows flexibility in terms of fabrication. The components were successfully integrated into the circuit and a fully functional eco-friendly healthcare device was designed and developed for in-house patients who lack mobility to update doctors on their condition. The future scope of this project will be to modify this device such as to integrate it as a smart wrist watch capable of implementing the measurement in the comfort of one's room. People with respiratory or cardiovascular conditions, very young infants, and individuals with some infections may benefit from the smart pulse oxy-ratiometer.*
*This research work was aimed at accomplishing two goals: construction of a smart Pulse Oxy-ratiometer (also known as Pulse-rate Oximeter) as a form of an improvised version of the patented one. Secondly, to measure the level of accuracy and compliance of the constructed device in comparism with the patented device. Tests were carried out using the constructed device and the patented product and recommendations were made based on the output of the project. The data collected is displayed on the LCD. A two-tailed Pearson Correlation Coefficient method was employed to establish the level of significance between the readings of the two products tested. According to the analysis and results recorded based on the data collected, the end product works accordingly, in accordance with the WHO recommended standard for $SPO_2$ measurement (95%) and BPM (120/80) and the desired output is achieved (see results in Tables 1-2 and Figures 2-7).However, real-world accuracy may differ from accuracy in the lab setting. While reported accuracy is an average of all patients in the test sample, there are individual variations among patients. The $SpO_2$ reading should always be considered* an estimate *of oxygen saturation. For example,* ***if an FDA-cleared pulse oximeter reads 90%, then the true oxygen saturation in the blood is generally between 86-94%****. Pulse oximeter accuracy is highest at saturations of 90-100%, intermediate at 80-90%, and lowest below 80%. Due to accuracy limitations at the individual level, $SpO_2$ provides more utility for trends over time instead of absolute thresholds* ***(FDA Safety Communication, June 2022).***
*We therefore recommend its usage to every dick and harry, as well as, proposing to government, private companies and individual industrialists to invest in the local production of this device to discourage the foreign products which flood our market, thereby encouraging domestication of our technologies and improving our economy.*
***KEYWORDS:*** *Oximeter, max30100 heartbeat sensor, Arduino Nano Board, IoT, diodes, Pearson Correlation Coefficient, $SpO_2$, BPM, WHO, FDA*

NOMENCLATURE:

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## I. INTRODUCTION:

A monumental rise in health risk which threaten millions of lives across the globe is quite worrisome. Incardiovascular ailments such as hypertension, almost eight(8) million passing out yearly. Moreover, acute respiratory infections being one of the leading causes of deaths claims 142 lives out of 1000 births. Anyhealthy individual ordinarily should accomplish typical $SpO_2$ of 94% to 99%**(Amperor Direct 2022)**. For patients with mellow respiratory ailments, the $SpO_2$ ought to be 90% or above. Else, oxygen will be required forpatients with $SpO_2$level below 90%**(Amperor Direct 2022)**. It is important to observe the dearth of pulse oximeter in many lowincome countries and the inaccessibility of patients to a dependable, tough, and reasonable estimation gadget for precise diagnosis in single gadgets. Thus, a dire need for mobile device powered with rechargeable battery to overcome the problem of sudden power cut.

"The $SpO_2$ reading should always be considered an *estimate* of oxygen saturation. For example, **if an FDA-cleared pulse oximeter reads 90%, then the true oxygen saturation in the blood is generally between 86-94%**. Pulse oximeter accuracy is highest at saturations of 90-100%, intermediate at 80-90%, and lowest below 80%. Due to accuracy limitations at the individual level, $SpO_2$ provides more utility for trends over time instead of absolute thresholds. Additionally, the FDA only reviews the accuracy of prescription use oximeters, not OTC oximeters meant for general wellness or sporting/aviation purposes" **(FDA SAFETY COMMUNICATIONS 2022 www.fda_hhs.gov)**.

Pulse oxy-ratio meter is a non-obtrusive and easy test that gauges your oxygen immersion level or the oxygen levels in your blood. It can quickly distinguish even

little changes in how effectively oxygen is being conveyed to the limits uttermost from the heart, including the legs and the arms. The pulse oximeter is a little, cut like gadget that appends to a body part, similar to toes or an ear cartilage. Its most usually put on a finger, and it's regularly utilized in a basic consideration setting like crisis rooms or medical clinics. The reason for pulse oximetry is to check how well your heart is siphoning oxygen through your body. It might be utilized to screen the strength of people with a condition that can influence blood oxygen levels. conditions such as constant obstructive pulmonary disease (COPD), asthma, pneumonia, lung disease, pallor, cardiovascular failure or breakdown and inherent heart diseases could be predicted by the use of pulse oximeter. The advent of the Internet of things (IoT) is rapidly impacting the world of global health through its integration into electronic circuit technology for optimum resultant outcomes. The circuit consists of a microcontroller (PIC18F452), transistor network, photoplethysmogram (PPG) amplifier, digital-to-analog converter (DAC), pulse oximeter probe and an LCD screen to display results. Coding has been written in C++ and also supports only limited C syntax. This is the major drawback of the already existing system and it has been overcome with the proposed system which has been implemented by using max30100. This romance of electronic sensors with the world wide web offer simple, seamless and personal implementation of many health diagnostic gadgets today. People can interact with the gadget to set them up, give them instruction or access the data. Hence, people can access the device anywhere and keep the data updated in real time. The gadget can help to monitor for the changing conditions of patients anytime. It comprises of all web empowered gadget that gathers, sends and follows up on the information they gain from their general surroundings utilizing implanted sensor, processors and correspondence equipment. For this project, the IoT device implemented was constructed so that the project can be used and results seen on the LCD screen.

### 1.1 STATEMENTS OF PROBLEM

People with low blood oxygen levels are often clueless about their condition. Majority of the patients don't have the time and resources to visit the doctor for medical check-ups. Going to the hospital for these check-ups are a hassle for older patients who are wheelchair bounded or immobile. The normal individual that utilizes a pulse oximeter is evaluated to associate with fifty years old. Therefore, the rechargeable Powered Pulse Oximeter Monitoring is constructed to assist in measuring the oxygen saturation level of patients remotely. This system enables the patient to detect their blood oxygen levels at home to ensure the heart rate is normal at different condition. Genuine respiratory disappointment happens when blood vessel immersion of hemoglobin falls beneath 90%, this rate generally extends between 85-90%. In this way, beat oximeters permit their patients to inhale simpler by estimating the oxygen immersion of blood vessel in their bodies. In addition, the system runs on a non-conventional source of energy which is ecological and cost-effective. This system will overcome the limits of the existing system as there is a certain level of innovation put into it.

**1.2 AIMS AND OBJECTIVES**

The aims and objectives of this project are:

1. Construct a smart pulse oxy-ratiometer locally, capable of measuring the oxygen saturation level ($SPO_2$) of the blood and beat per minute (bpm) of patients or individuals remotely
2. Test the constructed device to measure the conditions specified in (1) above, and compare the results with that of the commercially available product.
3. Ascertain the quality of the measurements with the WHO recommended standard and make recommendation for its usage and patenting.
4. Also, aid in the production of the device locally by 'who-would be' investors thereby promoting local content as the government policy stipulates.

**1.0 MATERIALS, DESIGN AND CONSTRUCTION**

**1.1 MATERIALS REQUIRED**

1. Arduino UNO is a microcontroller board based on the ATmega328P with Arduino Software (IDE) 1.0.

-It has 14 digital input/output pins (of which 6 can be used as PWM outputs),
-6 analog input pins,
-a 16 MHz quartz crystal,
-a USB connection,
-a power jack,
-an ICSP header and a reset button,
-Flash Memory 32 KB of which 0.5 KB used by bootloader,
-SRAM 2 KB,
-EEPROM 1 KB,
-Clock Speed 16 MHz
-powered by a computer with a USB cable or with an AC-to-DC adapter or battery to get started**.**

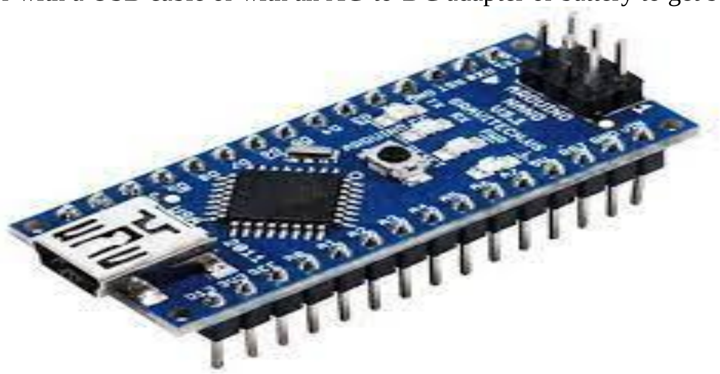


Fig.1: ARDUINO UNO BOARD

**Required Operating Current:**DC Current per I/O Pin 40 mA, DC Current for 3.3V Pin 50 mA.**Required Operating Voltages:** Operating Voltage 5V, Input Voltage (recommended) 7-12V, Input Voltage (limits) 6-20V.

**2.MAX30100**

The MAX30100 is an integrated pulse oximetry and heart rate monitor sensor solution. It combines two LEDs, a photo detector, optimized optics, and low-noise analog signal processing to detect pulse oximetry and heart-rate signals. **Required Operating Voltages:** The MAX30100 operates from 1.8V and 3.3V power supplies and can be powered down through software with negligible standby current, permitting the power supply to remain connected at all times.

## 1.2 DESIGN AND CONSTRUCTION

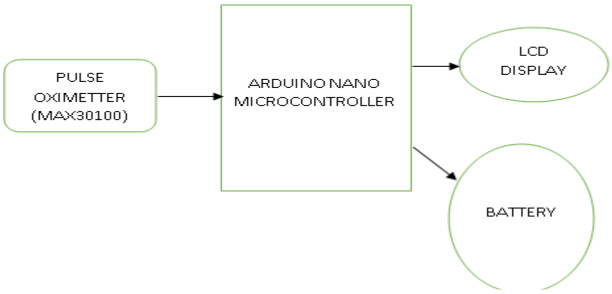



Fig.2: Design Diagram of the Pulse Oxy-Ratiometer

The circuit diagram of the pulse oxy-ratiometer monitoring is shown in figure 3. The circuit diagram consists of 16 × 2 LCD, microcontroller Atmega328, voltage regulator, oximeter sensor (max30100), potentiometer, and switch component. The circuit diagram is constructed by using Eagle software. First, the circuit or device power source voltage VCC is 5 Volt is applied. The microcontroller is powered up with 5 Volt voltages from power source. Besides that, the oximeter sensor, LCD and voltage regulator are connected in parallel from power source. After the microcontroller is starts to operate and it is initiates the oximeter sensor. The oximeter has SDA and SCL as inputs to the microcontroller. The output of the microcontroller pins 8, 9, 10 and 11 are connected to the input D4, D5, D6 and D7 of the LCD display. The LCD display pin 3 was used to add potentiometer for adjusting the contrast of the back light. Moreover, pins 12 and 13 from microcontroller is connected to the LCD pin 4(register select) and pin 6(enabled).

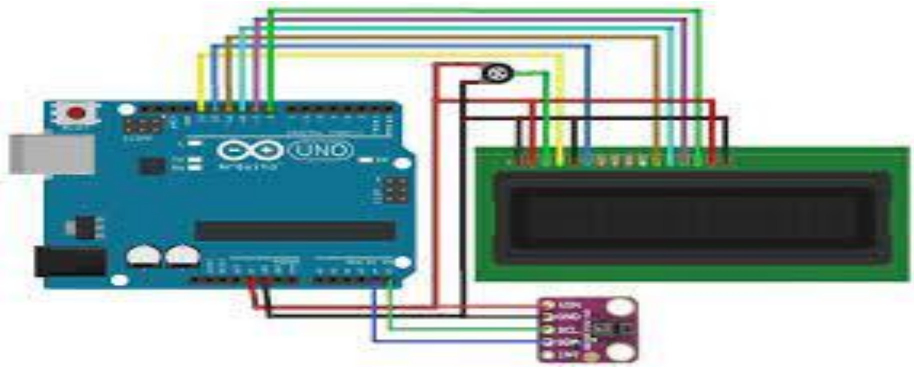



Fig.3: Circuit Diagram of the Oxy-Ratiometer

A pulse oximeter is basically a device which can measure your pulse and oxygen saturation in your blood. It is made up of two LEDs emitting light: the one in Red spectrum (650nm) and the other one in Infrared (950nm). This sensor is placed on your finger or earlobe, essentially anywhere where the skin is not too thick so both light frequencies can easily penetrate the tissue. Once both of them are shined through your finger for example, the absorption is measure with a photodiode. And depending on the amount of oxygen you have in your blood the ratio between the absorbed red light and IR led will be different from this ratio it is possible to "easily" calculate your oxygen level in your hemoglobin.

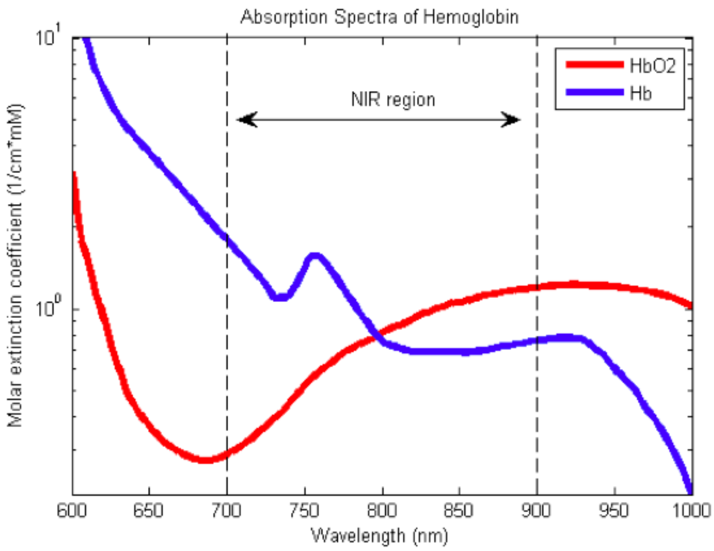





**Fig.3: Absorption Spectra of Haemoglobin**

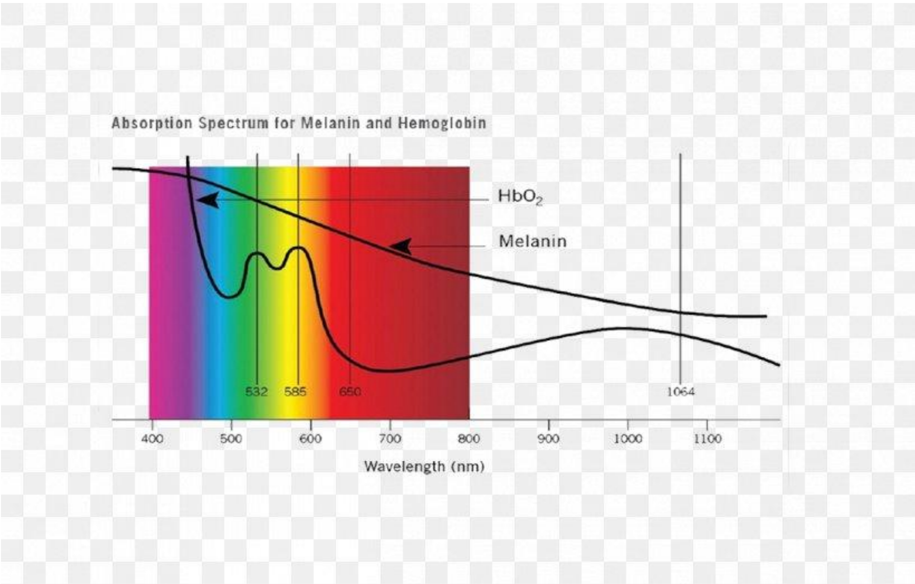



Fig.4: HAEMOGLOBIN LIGHT ABSORPTION DIAGRAM

## 1.3 OPERATION

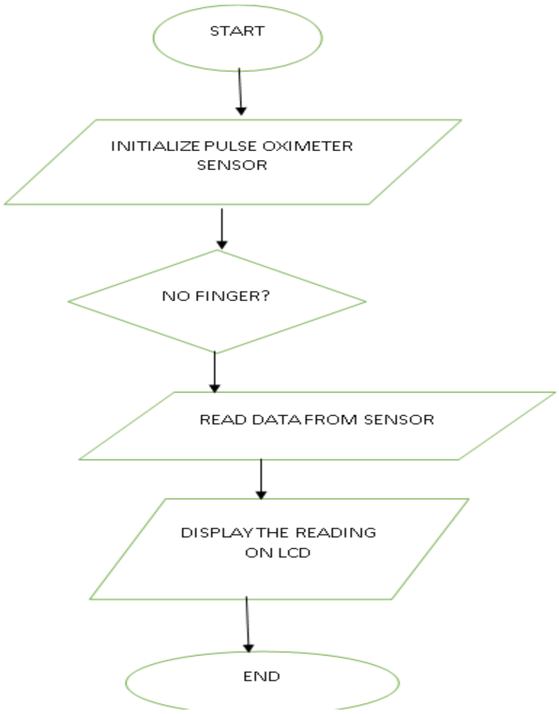



**Fig.5: Operational Flowchart of the Pulse Oxy-Ratiometer (Oximeter)**

The battery will initiate the pulse oximeter sensor. When the oximeter is initiated the red LED will emit. Then, it shows that the pulse oximeter is ready for use. The pulse oximeter can either be placed on a fingertip or ear lobe. The placement of the pulse oximeter on the body part is according to the design of the device. When the pulse oximeter is not attached to the body part, it is not initiated. However, the process cannotbe completedif you remove the sensor from the body attachment. Therefore,the process will start from the beginning in order to complete the process of initialization and be ready to collect data. when the sensor is attached to a specific body part,since the sensor is a reflective type, there will be some fixed light reflection back to the sensor from the body part. When the infrared light absorbs by oxygenated blood and the de-oxygenated blood absorbs more red light,the signal will be transmitted to the microcontroller. The amount of infrared and red lights absorbed in the blood is compared. Then, it will calculate the amount of oxygen ratio in the blood. After the data is collected, the data will be displayed on the LCD. Patient can read the data immediately and response to the result can now be made.

## 2.0 METHODS/TECHNIQUES FOR TESTING AND ANALYSIS

A commercially produced oximeter was purchased as a standard system while the constructed system was made based on the global design specification using Arduino Uno board and the Arduino IDE was used to program the code into the microcontroller to carry out the data processing and data display.

Two methods were used in the testing and analysis: The**Empirical test** and the **Statistical test**.

### 2.1 EMPIRICAL TESTING

In the process of testing the Pulse Oxy-Ratiometer, the steps of initialization were completed successfully (with the red LED light emitted and beep code displayed on the LCD screen). A minimum of ten (10) patients were tested using both the commercially produced system and the constructed system and their results were recorded as displayed on the systems' screens. The systems have been programmed to measure the amount of infrared and red lights absorbed in the blood and make comparism. Then, it will calculate the amount of oxygen ratio in the bloodof the patient which prompted the displayed result on the screen.

### 2.2 STATISTICAL TESTING

The Correlation statistical method was employed and the test results were fed into a specialized software (SPSS) which read and carried out the analysis based on the data produced by the commercially available and the constructed Oximeters respectively.

## 3.0 ANALYSING RESULTS AND DISCUSSION

**COMPARISON BETWEEN STANDARD AND DESIGNED SYSYEM**

Once the Pulse Oximeter device has been designed and developed, it is crucial to conduct a comparative analysis between the designed and the standard pulse oxy-ratio meter device. Thus, the analysis will prove the reliability of the test results produced by the designed Pulse Oximeter device. For this purpose, some students and individual staff were selected for the bit per minute (BPM) and oxygen saturation ($SpO_2$) comparative test procedure. The test results were obtained via the Standard System and Designed System at the same time under three different conditions such as (at the point of arrival at the lab, after rest and before leaving the lab). The conditions were kept the same for the eleven (11) persons who participated in this device testing. The results were given below:

**TABLE 1: STANDARD (COMMERCIALLY PROCURED) SYSTEM MEASUREMENT**

| TIME | NAMES | BPM | $SPO_2$(%) |
|---|---|---|---|
| **Arriving at the lab** | **Miss Ayomide** | **95** | **95** |
| | **Miss Abigail** | **97** | **97** |
| | **Miss Abosede** | **79** | **79** |
| | **Miss Abidemi** | **99** | **99** |
| | **Miss Racheal** | **92** | **92** |
| | **Miss Aramide** | **88** | **88** |
| | **Miss Esther** | **98** | **98** |
| | **Miss Ejiro** | **86** | **86** |
| | **Miss Mariam** | **61** | **61** |
| | **Miss Rebecca** | **96** | **96** |
| | **MrAmusa** | **95** | **95** |
| **After rest** | **Miss Ayomide** | **86** | **90** |
| | **Miss Abigail** | **99** | **95** |
| | **Miss Abosede** | **85** | **86** |
| | **Miss Abidemi** | **94** | **105** |
| | **Miss Racheal** | **85** | **89** |
| | **Miss Aramide** | **96** | **99** |
| | **Miss Esther** | **93** | **80** |
| | **Miss Ejiro** | **85** | **94** |
| | **Miss Mariam** | **109** | **95** |
| | **Miss Rebecca** | **88** | **96** |
| | **MrAmusa** | **89** | **94** |
| **Before leaving the lab** | **Miss Ayomide** | **91** | **92** |
| | **Miss Abigail** | **109** | **89** |
| | **Miss Abosede** | **85** | **92** |
| | **Miss Abidemi** | **84** | **95** |
| | **Miss Racheal** | **69** | **93** |
| | **Miss Aramide** | **79** | **94** |
| | **Miss Esther** | **86** | **75** |
| | **Miss Ejiro** | **88** | **94** |
| | **Miss Mariam** | **128** | **99** |
| | **Miss Rebecca** | **86** | **95** |

**TABLE 2: DESIGNED (CONSTRUCTED) SYSTEM MEASUREMENT**

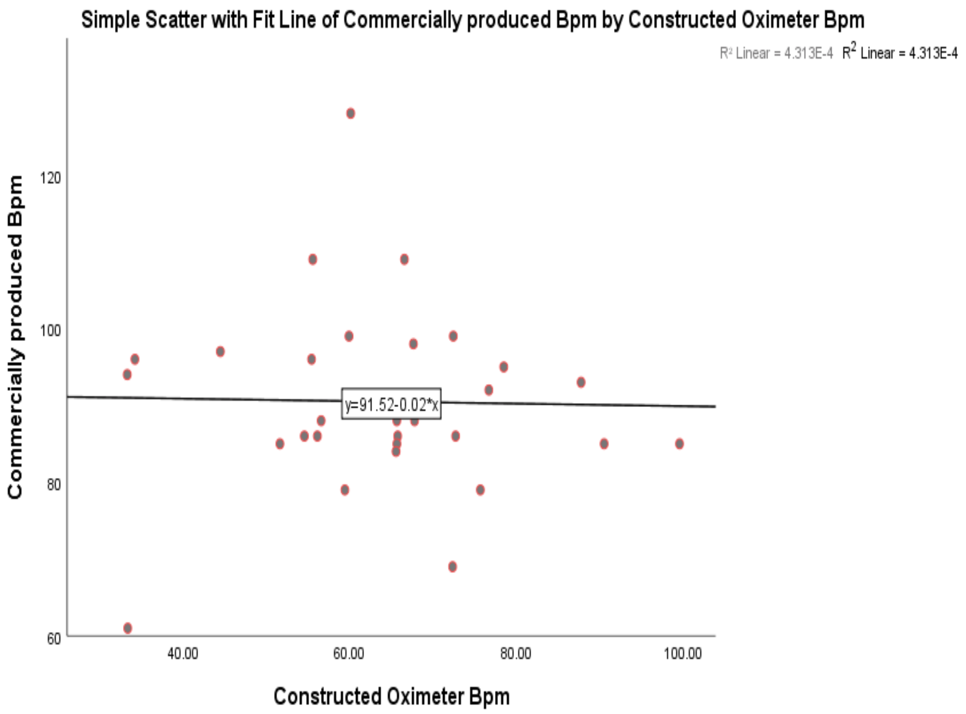
| TIME | NAMES | BPM | SPO2 (%) |
|---|---|---|---|
| Arriving at the lab | **Miss Ayomide** | 78.48 | 95 |
| | **Miss Abigail** | 44.49 | 94 |
| | **Miss Abosede** | 59.42 | 94 |
| | **Miss Abidemi** | 59.91 | 97 |
| | **Miss Racheal** | 76.69 | 94 |
| | **Miss Aramide** | 56.58 | 96 |
| | **Miss Esther** | 67.64 | 93 |
| | **Miss Ejiro** | 54.56 | 94 |
| | **Miss Mariam** | 33.38 | 202 |
| | **Miss Rebecca** | 34.24 | 97 |
| **After rest** | **Miss Ayomide** | 65.76 | 89 |
| | **Miss Abigail** | 72.42 | 76 |
| | **Miss Abosede** | 90.51 | 96 |
| | **Miss Abidemi** | 33.32 | 96 |
| | **Miss Racheal** | 51.63 | 94 |
| | **Miss Aramide** | 55.43 | 95 |
| | **Miss Esther** | 87.75 | 94 |
| | **Miss Ejiro** | 99.56 | 95 |
| | **Miss Mariam** | 55.57 | 96 |
| | **Miss Rebecca** | 65.65 | 97 |
| | **MrAmusa** | 70.15 | 95 |
| **Before leaving the lab** | **Miss Ayomide** | 65.56 | 95 |
| | **Miss Abigail** | 66.56 | 96 |
| | **Miss Abosede** | 65.66 | 95 |
| | **Miss Abidemi** | 65.56 | 94 |

| | | | |
|---|---|---|---|
| | **Miss Racheal** | 72.34 | 97 |
| | **Miss Aramide** | 75.67 | 94 |
| | **Miss Esther** | 72.70 | 89 |
| | **Miss Ejiro** | 67.78 | 95 |
| | **Miss Mariam** | 60.12 | 97 |
| | **Miss Rebecca** | 56.12 | 98 |

**Correlations**

| | | Commercially produced Bpm | Constructed Oximeter Bpm |
|---|---|---|---|
| Commercially produced Bpm | Pearson Correlation | 1 | -.021 |
| | Sig. (2-tailed) | | .912 |
| | N | 32 | 31 |
| Constructed Oximeter Bpm | Pearson Correlation | -.021 | 1 |
| | Sig. (2-tailed) | .912 | |
| | N | 31 | 31 |

The result above is the correlation table between the BPM recorded by the commercially produced Oximeter and that of the constructed oximeter. The correlation coefficient is -0.02 (2%), which implies that there is a weak negative relationship between the Bpm recordings of the commercially produced Oximeter and that of constructed oximeter. Also, since the p-value=0.912 > 0.05, hence we say there is no significant relationship between them.



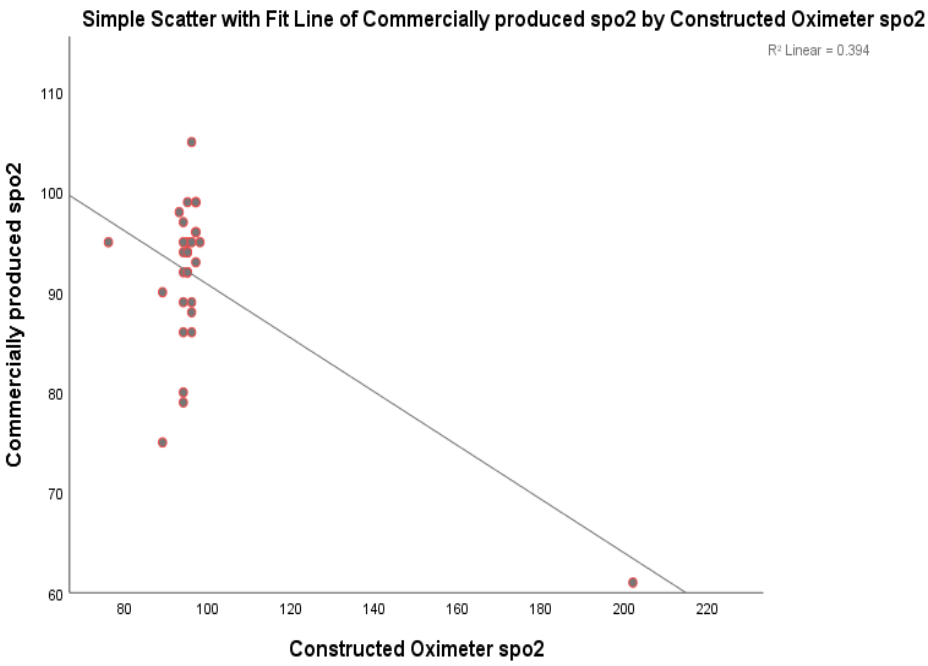

The plot above also support the interpretation above since the points spreads far from the line and the line moves in an opposite direction. It shows that there are indeed a negative weak correlation between the commercially produced Bpm and the constructed oximeter Bpm.

**Correlations**

| | | Commercially produced spo2 | Constructed Oximeter spo2 |
|---|---|---|---|
| Commercially produced spo2 | Pearson Correlation | 1 | -.628** |
| | Sig. (2-tailed) | | .000 |
| | N | 32 | 31 |
| Constructed Oximeter spo2 | Pearson Correlation | -.628** | 1 |
| | Sig. (2-tailed) | .000 | |
| | N | 31 | 31 |

**. Correlation is significant at the 0.01 level (2-tailed).

The result above is the correlation table between the commercially produced spo2 and the constructed oximeter spo2. The correlation coefficient is -0.628 (63%), which implies that there are strong negative relationship between commercially produced spo2 and constructed oximeter spo2. Also, since the p-value=0.000 < 0.05, hence we say the relationship are significant at 5% level. In addition, considering the WHO standard recommendation, since 63% is below 90%, then it shows the beneficial oxygen ought to be utilized.




The plot above also supports the interpretation above since the points are closely together (although there is a presence of an outlier). It shows that there is indeed a strong negative correlation between the commercially produced spo2 and the constructed oximeter $SpO_2$.
***Source:*** SPSS

Fig. 7: Commercially Produced Oximeter Fig.8: Constructed Pulse Oxy-Ratiometer

**5.0 CONCLUSION AND RECOMMENDATIONS**

People with respiratory or cardiovascular conditions, very young infants, and individuals with some infections may benefit from the pulse oxy-ratiometer.

We therefore recommend its usage to every dick and harry, as well as, proposing to government, private companies and individual industrialists to invest in the local production of this device to discourage the foreign products which flood our market, thereby encouraging domestication of our locally designed products and improving our economy.

**CONFLICT OF INTEREST**
The authors declared that there is no conflict of interest regarding the publication of this manuscript.
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