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Performance Evaluation of a Locally Produced Pulse Oximeter

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ABSTRACT: Most aftermarket pulse oximeters (POs) sold usually have peripheral blood oxygen saturation (SpO_2) sensors with short life spans and the lack of specialized personnel to carry out the repairs result in frequent failures and replacement of the device. The study aims to solve the problems by developing a cheap, durable, easy to operate, and enhanced reflectance pulse oximeter (RPO). The testing of the device involved the SpO_2 and heart rate (HR) measurements of Forty (40) healthy volunteers. From the performance evaluation, the measured data and its accuracy were satisfactory with an average accuracy and error rates of 99.7 % and 0.3 % for SpO_2 while that of the HR was 97.7 % and 2.3 % respectively. Furthermore, analysis from the Bland - Altman Plot for both the SpO_2 and HR showed that the locally developed PO could be used as a substitute to measure oxygen saturation and pulse rate in patients.

KEYWORDS: Pulse Oximeter, Biomedical Devices, Peripheral Oxygen Saturation (SpO_2), Heart Rate (HR)

1. INTRODUCTION

Oxygen saturation remains a very important element when managing and administering patient care. It gives the amount of hemoglobin that is currently bound to oxygen as compared to the amount of hemoglobin not bound to oxygen. In line with the opinion of Bhatia (2021), most aftermarket oximeters sold usually have Peripheral Blood Oxygen Saturation (SpO_2) sensors with short life spans and the lack of specialized personnel to carry out the repairs result infrequent failures and replacement of the device. In addition, many of the cheap pulse oximeters (POs) readily available to customers often give incorrect and unreliable readings.

This research focused on development of a new PO that can serve as a local substitute for the foreign assembled oximeters. The locally developed oximeter will aid the development of the Nigeria local content policy in the field of Biomedical Instrumentation. Biomedical devices have exploited the benefits accruing from the alliance between engineering and medicine and they have become very important instruments in present - day healthcare due to their transformative abilities in areas such as diagnosis, patients observation, treatment, and even in empowering patients and, thereby, resulting in the overall improved healthcare, increased accessibility, and enlightened individuals who now participate in their own well - being (Hasan, 2023).

Pulse oximetry is a non-invasive technique for measuring peripheral oxygen saturation (SpO_2) that is based on the differential absorption of red and infrared light by oxygenated hemoglobin in a small tissue segment (Duke, et al., 2009). Oxygen enters the blood by passing through the lungs. This oxygenated blood (hemoglobin) is now transported through the flow of blood to the various organs in the body. During a pulse oximetry, a small clamp - like device is attached to a finger, earlobe, or toe (Newton, 2024)

According to Frederic et al. (2021), technological advancements in pulse oximetry have not only gone beyond just the monitoring of SpO_2 but are also likely to influence improved quality care in patients suffering from acute respiratory failure. Jawin, et al. (2015), asserted that the expanded use of pulse oximetry has imparted positively in the lives of both low and middle income countries most especially when developing strategies to reduce neonatal mortality and morbidity. In the view of Nitzan, et al. (2014), improvements in pulse oximetry accuracy can be significantly achieved only when modifications are carried out at the fundamental levels.

In the opinion of Bamigboye and Bello (2021), Biomedical Engineering (BME) growth in Nigeria is bedeviled by many issues and some of them include paucity of funds, inadequate healthcare technologies, limited access to expert knowledge, meager budgetary allocations to health and education sectors, etc. It is already an established fact that a world without technology is unlikely and as a result, health systems must always be influenced by these technologies in providing excellent health system - related technologies to communities on a sustainable basis employing the use of cost - effective means to mitigate against the challenges associated with financial implications of acquiring these technologies (Bhatia, 2021). Based on these reasons, this study designs a new PO that is enhanced, less expensive, and easy to maintain.

2. MATERIALS AND METHODS

The block diagram for the PO as shown in Figure 1 was specifically designed to be used in the production of the RPO. An arduino uno, an open - source platform microcontroller board (Louis, 2016) that can also used in industrial - based control systems, was selected as the microcontroller (see Figure 2).The only constraint in Arduino is that it does not have Safety Instrumented Level (SIL) features. It should be added yourself (Taufiq et al., 2015). For the operation of the locally developed RPO, oled ssd1306 i2c 128 x 64 display, as shown in Figure 3, was selected for displaying the measured values of SpO_2 and HR (Fuller, 2022) The pulse sensor, as shown in Figure 4, was used for the measurement of the oxygen saturation in blood and heart rate (Suprayitno, et al., 2019). This wireless connection, as shown in Figure 5, was used for short range communications (high speed transmission of data using radio waves) between many different types of devices including phones, computers, and other electronics (Umapathy, et al., 2021).

Figure 1: Block diagram for a RPO

Figure 2: Arduino uno microcontroller **Figure 3: oled ssd1306 i2c 128 x 64 display**

Figure 4: The max30100 pulse sensor **Figure 5: Bluetooth module hc – 05**

The use of TINKERCAD (a free web app for 3D design, electronics, and coding developed by AUTODESK) in the production of the 3D circuit diagrams as shown in Figure 6.

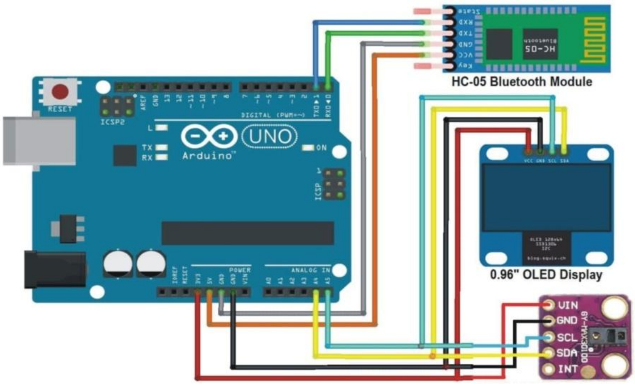

Figure 6: Circuit diagram for the RPO

3. EXPERIMENTAL PROCEDURE TO MEASURE ACCURACY AND ERROR

The aim of this experiment was to measure the SpO_2 and HR of two different pulse oximeters - the locally produced RPO and that of a PO bought over - the - counter (OTC) and compare the readings. The tests were carried out on forty (40) people and the readings were taken after one (1) minute as measured by a stop watch as shown in Figures (4) and (5). The tests were done three (3) times for each individual and recorded. The average readings for both the SpO_2 and HR were calculated. A Bland - Altman Plot for both the SpO_2 and HR were to be generated from the calculated parameters for the comparison of measurements done by both devices to determine the agreeability of both measuring devices. The OTC PO used was the FingerTip (Model: V408/V409, Serial: V4089103335) which was a transmissive pulse oximeter (TPO).

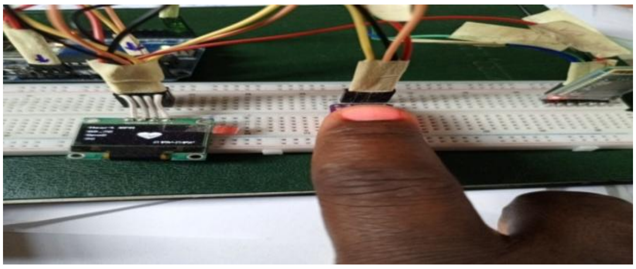

Figure 4: A view of the locally produced pulse oximeter displaying SpO_2 and HR readings

Figure 5: Displayed SpO_2 and HR readings on an OTC pulse oximeter

From the experiment carried out, the overall average error in the measurement was established and used to determine the overall average accuracy of the locally developed RPO. The calculated average SpO_2 measured by the locally constructed RPO was done using equation (1). It was expressed as:

$$SpO_{2(avr)}^{C} = \frac{Test\ (1) + Test\ (2) + Test\ (3)}{3} \quad (1)$$

Where

$SpO_{2(avr)}^{C}$ = Calculated average SpO_2 measured by locally constructed RPO (%)

The calculated average SpO_2 measured by "over – the - counter" (OTC) bought TPO was done using equation (2). It was expressed as:

$$SpO_{2(avr)}^{OTC} = \frac{Test\ (1) + Test\ (2) + Test\ (3)}{3} \quad (2)$$

Where

$SpO_{2(avr)}^{OTC}$ = Calculated average SpO_2 measured by OTC bought TPO (%)

The difference between the calculated averages of SpO_2 measured by both the locally constructed and the OTC pulse oximeters was done using equation (3). It was expressed as:

$$SpO_{2(avr)}^{d} = SpO_{2(avr)}^{C} - SpO_{2(avr)}^{OTC} \quad (3)$$

Where

$SpO_{2(avr)}^{d}$ = Difference between the calculated averages of SpO_2 measured by both the locally constructed and the OTC pulse oximeters (%) respectively

The mean value of the calculated averages of SpO_2 measured by both the locally constructed and the OTC pulse oximeters was done using equation (4). It was expressed as:

$$SpO_{2(avr)}^{\dot{x}} = \frac{SpO_{2(avr)}^{C} + SpO_{2(avr)}^{OTC}}{2} \quad (4)$$

Where

$SpO_{2(avr)}^{\dot{x}}$= Mean value of the calculated averages of SpO_2 measured by both the locally constructed and the OTC pulse oximeters (%) respectively.

The error value in the measurement from the difference between the average values of SpO_2 measured by both the locally constructed and the OTC pulse oximeters was calculated using equation (5). It was expressed as:

$$SpO_{2(avr)}^{Err} = \frac{SpO_{2(avr)}^{d}}{SpO_{2(avr)}^{C}} \times 100 \quad (5)$$

Where

$SpO_{2(avr)}^{Err}$ = Error value in the measurement from the difference between the average values of SpO_2 measured by both the locally constructed and the OTC pulse oximeters (%)

The accuracy value in the measurement between the average values of SpO_2 measured by both the locally constructed and the OTC pulse oximeters was calculated using equation (6). It was expressed as:

$$SpO_{2(avr)}^{Acc} = 100 - SpO_{2(avr)}^{Err} \quad (6)$$

Where

$SpO_{2(avr)}^{Acc}$ = Accuracy value in the measurement between the average values of SpO_2 measured by both the locally constructed and the OTC pulse oximeters (%)

The overall error value in the measurement from the difference between the average values of SpO_2 measured by both the locally constructed and the OTC pulse oximeters was calculated using equation (7). It was expressed as:

$$SpO_{2(avr)}^{OAE} = \frac{\sum_{i=1}^{N} SpO_{2(avr)}^{Err}}{N} \quad (7)$$

Where

$SpO_{2(avr)}^{OAE}$= Overall average error value in the measurement from the difference between the average values of SpO_2 measured by both the locally constructed and the OTC pulse oximeters (%)

N = Number of people tested (40)

The overall average accuracy value in the measurement from the difference between the average values of SpO_2 measured by both the locally constructed and the OTC pulse oximeters was calculated using equation (8). It was expressed as:

$$SpO_{2(avr)}^{OAA} = 100 - SpO_{2(avr)}^{OAE} \quad (8)$$

Where

$SpO_{2(avr)}^{OAA}$= Overall average accuracy value in the measurement between the average values of SpO_2 measured by both the locally constructed and the OTC pulse oximeters (%)

The bias of SpO_2 (mean of all the differences of the calculated averages values of SpO_2 measured by both the locally constructed and the OTC pulse oximeters) was calculated using equation (9). It was expressed as:

$$SpO_{2(avr)}^{\mu} = \frac{\sum_{i=1}^{N} SpO_{2(avr)}^{d}}{N} \quad (9)$$

Where

$SpO_{2(avr)}^{\mu}$ = Bias of SpO_2 (mean of all the differences of the calculated averages of SpO_2 values measured by both the locally constructed and OTC pulse oximeters) (%)

The difference (difference between "the difference between calculated average values of SpO_2 measured by both the locally constructed and the OTC pulse oximeters" and "the bias for SpO_2") was calculated using equation (10). It was expressed as:

$$A = SpO_{2(avr)}^{d} - SpO_{2(avr)}^{\mu} \quad (10)$$

Where

A = The difference (%)

The square of "The difference" was calculated using equation (11). It was expressed as:

$$B = (A)^2 \quad (11)$$

Where

B = Square of "The difference" $(\%)^2$

The standard deviation of the calculated average values of the SpO_2 was calculated using equation (12). It was expressed as:

$$Spo_{2(avr)}^{\sigma} = \sqrt{\frac{\sum_{i=1}^{N}(B)}{N-1}} \quad (12)$$

Where

$Spo_{2(avr)}^{\sigma}$ = Standard deviation of the calculated average values of the SpO_2 (%)

N = Number of people tested (40)

The upper limit of agreement (Bland and Altman, 1999) for SpO_2 was calculated using equation (13). It was expressed as:

$$U_{LoA}^{SpO_{2(avr)}} = Spo_{2(avr)}^{\mu} + \left(1.96 \times Spo_{2(avr)}^{\sigma}\right) \quad (13)$$

Where

$U_{LoA}^{SpO_{2(avr)}}$ = Upper limit of agreement for the Bland – Altman Plot for SpO_2 (%)

The lower limit of agreement (Bland and Altman, 1999) for SpO_2 was calculated using equation (14). It was expressed as:

$$L_{LoA}^{SpO_{2(avr)}} = SpO_{2(avr)}^{\mu} - \left(1.96 \times Spo_{2(avr)}^{\sigma}\right) \quad (14)$$

Where

$L_{LoA}^{SpO_{2(avr)}}$ = Lower limit of agreement for the Bland – Altman Plot for SpO_2 (%)

The calculated average HR measured by the locally constructed pulse oximeter was done using equation (15). It was expressed as:

$$HR_{(avr)}^{C} = \frac{Test\ (1) + Test\ (2) + Test\ (3)}{3} \quad (15)$$

Where

$HR_{(avr)}^{C}$ = Calculated average HR measured by locally constructed pulse oximeter (BPM)

The calculated average HR measured by pulse oximeter bought "over-the-counter" was done using equation (16). It was expressed as:

$$HR_{(avr)}^{OTC} = \frac{Test\ (1) + Test\ (2) + Test\ (3)}{3} \quad (16)$$

Where

$HR_{(avr)}^{OTC}$ = Calculated average HR measured by pulse oximeter bought "over-the-counter" (BPM)

The difference between the calculated averages of HR measured by both the locally constructed and the OTC pulse oximeters was done using equation (17). It was expressed as:

$$HR_{(avr)}^{d} = HR_{(avr)}^{C} - HR_{(avr)}^{OTC} \quad (17)$$

Where

$HR_{(avr)}^{d}$ = Difference between the calculated averages of HR measured by both the locally constructed and the OTC pulse oximeters (BPM) respectively

The mean value of the calculated averages of HR measured by both the locally constructed and the OTC pulse oximeters was done using equation (18). It was expressed as:

$$HR_{(avr)}^{\dot{x}} = \frac{HR_{(avr)}^{C} + HR_{(avr)}^{OTC}}{2} \quad (18)$$

Where

$HR_{(avr)}^{\dot{x}}$= Mean value of the calculated averages of HR measured by both the locally constructed and the OTC pulse oximeters (BPM) respectively

The error value in the measurement of HR measured by the locally constructed RPO (BPM) was calculated using equation (19). It was expressed as:

$$HR_{(avr)}^{Err} = \frac{HR_{(avr)}^{d}}{HR_{(avr)^C}} \times 100 \quad (19)$$

Where

$HR_{(avr)}^{Err}$ = Error value in the measurement of HR measured by the locally constructed RPO (BPM)

The accuracy value in the measurement of HR measured by the locally constructed RPO was calculated using equation (20). It was expressed as:

$$HR_{(avr)}^{Acc} = 100 - HR_{(avr)}^{Err} \quad (20)$$

Where

$HR_{(avr)}^{Acc}$ = Accuracy value in the measurement of HR measured by the locally constructed RPO (BPM)

The overall average error value in the measurement of HR measured by the locally constructed RPO (BPM) was calculated using equation (21). It was expressed as:

$$HR_{(avr)}^{OAE} = \frac{\sum_{i=1}^{N} HR_{(avr)}^{Err}}{N} \quad (21)$$

Where
$HR_{(avr)}^{OAE}$= Overall average error value in the measurement of HR measured by the locally constructed RPO (BPM)
N = Number of people tested (40)

The overall average accuracy value in the measurement of HR measured by the locally constructed RPO was calculated using equation (22). It was expressed as:

$$HR_{(avr)}^{OAA} = 100 - HR_{(avr)}^{OAE} \quad (22)$$

Where
$HR_{(avr)}^{OAA}$= Overall average accuracy value in the measurement of HR measured by the locally constructed RPO (BPM)

The bias for heart rate (mean of the differences between all the calculated average values of HR measured by both the locally constructed and the OTC pulse oximeters) was calculated using equation (23). It was expressed as:

$$HR_{(avr)}^{\mu} = \frac{\sum_{i=1}^{N} HR_{(avr)}^{d}}{N} \quad (23)$$

Where
$HR_{(avr)}^{\mu}$ = Bias for HR (mean of all the differences of the calculated averages of HR values measured by both the locally constructed and OTC pulse oximeters) (BPM)

The difference (difference between “the difference between calculated average values of HR measured by both the locally constructed and the OTC pulse oximeters” and “the bias for HR”) was calculated using equation (24). It was expressed as:

$$X = HR_{(avr)}^{d} - HR_{(avr)}^{\mu} \quad (24)$$

Where
X = The difference (BPM)

The square of “The difference” was calculated using equation (25). It was expressed as:

$$Y = (X)^2 \quad (25)$$

Where
Y = Square of “The difference” $(BPM)^2$
The standard deviation of the calculated average values of the HR was calculated using equation (26). It was expressed as:

$$HR_{(avr)}^{\sigma} = \sqrt{\frac{\sum_{i=1}^{N}(Y)}{N-1}} \quad (26)$$

Where
$HR_{(avr)}^{\sigma}$ = Standard deviation of the calculated average values of the HR (BPM)
N = Number of people tested (40)

The upper limit of agreement (Bland and Altman, 1999) for heart rate was calculated using equation (27). It was expressed as:

$$U_{LoA}^{HR(avr)} = HR_{(avr)}^{\mu} + \left(1.96 \times HR_{(avr)}^{\sigma}\right) \quad (27)$$

Where
$U_{LoA}^{HR(avr)}$ = Upper limit of agreement for the Bland – Altman Plot for heart rate (BPM)

The lower limit of agreement (Bland and Altman, 1999) for heart rate was calculated using equation (28). It was expressed as:

$$L_{LoA}^{HR(avr)} = HR_{(avr)}^{\mu} + \left(1.96 \times SD\ of\ HR_{(avr)}\right) \quad (28)$$

Where
$L_{LoA}^{HR(avr)}$ = Lower limit of agreement for the Bland – Altman Plot for heart rate (BPM).

4. RESULTS AND DISCUSSION

The measurements were obtained from forty (40) patients and the results were presented and tabulated. Tables 1 and 2 showed the measured data taken from the test and calculated data from the test, and the calculated data used for the standard deviation, and comparison of the measured results for the average values of both SpO_2 and HR obtained from both pulse oximeters that were calculated for and tabulated respectively.

Table 1: Measured data taken from the tests and calculated data from the test

S/N	***Name***	***Sex***	SpO_2^C *(%)*			HR^C *(BPM)*			SpO_2^{OTC} *(%)*			HR^{OTC} *(BPM)*			$SpO^C_{2(av}$ *(%)*	$HR^C_{(avr}$ *(BPM)*	$SpO^{OTC}_{2(av}$ *(%)*	$HR^{OTC}_{(avr)}$ *(BPM)*
			Test (1)	Test (2)	Test (3)	Test (1)	Test (2)	Test (3)	Test (1)	Test (2)	Test (3)	Test (1)	Test (2)	Test (3)				
1	Adams	M	98	97	98	88	82	88	97	97	98	77	80	83	97.7	82.3	97.3	80.0
2	John	M	98	97	97	77	75	74	97	97	98	73	75	76	97.3	75.3	97.3	74.7
3	Godfrey	M	97	97	97	80	77	78	97	97	97	78	74	76	97.0	78.3	97.0	76.0
4	Kunle	M	98	97	98	76	76	74	98	97	98	71	72	72	97.7	75.3	97.7	71.3
5	Jacob	M	97	97	97	71	68	73	96	97	97	71	70	69	97.0	70.7	96.7	70.0
6	Tobi	M	97	97	98	81	81	81	97	98	97	79	81	81	97.3	81.0	97.3	80.3
7	Tosho	M	97	95	96	67	77	69	94	96	95	68	73	68	96.0	71.0	95.0	68.7
8	Oteikwu	M	98	98	98	66	64	66	98	98	98	65	65	66	98.0	65.3	98.0	65.3
9	Chidi	M	97	98	97	80	80	80	97	97	97	80	80	76	97.3	80.0	97.0	78.7
10	Alhaji	M	98	98	96	81	83	81	97	98	97	80	82	80	97.3	81.7	97.3	80.7
11	Biala	M	98	98	97	86	81	73	98	97	97	75	75	81	97.7	90.0	97.3	89.0
12	Blessing	M	98	97	97	95	87	88	97	97	97	90	89	88	97.3	90.0	97.0	89.0
13	Dan	M	97	97	97	83	84	82	97	95	96	78	80	79	97.0	83.0	96.0	79.0
14	Dauda	M	98	97	97	82	81	80	97	97	97	80	82	81	97.3	81.0	97.0	81.0
15	Aregbe	M	97	97	97	72	80	74	97	97	97	76	74	72	97.0	75.3	97.0	74.0
16	Jamiu	M	97	97	97	96	98	98	97	97	97	95	96	94	97.0	97.3	97.0	95.0
17	Wasiu	M	99	98	97	76	74	68	97	97	97	73	70	72	97.7	72.7	97.0	71.7
18	Ismail	M	97	98	97	68	64	65	96	97	95	64	64	66	97.3	65.7	96.0	64.7
`19	Dominic	M	97	97	97	82	84	80	97	97	97	78	78	76	97.0	82.0	97.0	77.3
20	Akeem	M	98	97	98	84	85	83	98	98	97	80	82	78	97.7	84.0	97.7	80.0
21	Abayo	M	98	97	98	88	82	88	97	97	98	77	80	83	97.7	82.3	97.3	80.0
22	Lara	F	98	97	97	77	75	74	97	97	98	73	75	76	97.3	75.3	97.3	74.7
23	IG	M	97	97	98	80	77	78	98	97	98	78	74	76	97.7	78.3	97.7	76.0
24	Abel	M	97	97	98	76	76	74	98	97	97	71	72	72	97.3	75.3	97.3	71.3
25	Alfa	M	97	97	97	71	68	73	96	97	97	71	70	69	97.0	70.7	96.7	70.0
26	Abe	M	97	97	98	81	81	81	97	98	97	79	81	81	97.3	81.0	97.3	80.3
27	Oguns	M	97	95	96	67	77	69	94	96	95	68	73	68	96.0	71.0	95.0	68.7
28	Ibro	M	98	98	98	66	64	66	98	98	98	65	65	66	98.0	65.3	98.0	65.3
29	Willie	M	97	98	97	80	80	80	97	97	97	80	80	76	97.3	80.0	97.0	78.7
30	Noel	M	98	98	96	81	81	83	97	98	97	80	82	80	97.3	81.7	97.3	80.7
31	Benard	M	97	97	97	86	81	73	96	96	96	75	75	81	97.3	90.0	97.0	89.0
32	Tawa	F	98	97	97	95	87	88	97	97	97	90	89	88	97.3	90.0	97.0	89.0
33	Saheed	M	97	97	97	83	84	82	97	95	96	78	80	79	97.0	83.0	96.0	79.0

34	Yinka	M	98	97	97	82	81	80	97	97	97	80	82	81	97.3	81.0	97.0	81.0
35	Yusuf	M	97	97	97	72	80	74	97	97	97	76	74	72	97.0	75.3	97.0	74.0
36	T.Mgr	M	97	97	97	96	98	98	97	97	97	95	96	94	97.0	97.3	97.0	95.0
37	L. OPS	M	99	98	97	76	74	68	97	97	97	73	70	72	97.7	72.7	97.0	71.7
38	L. HSE	M	97	98	97	68	64	65	96	97	95	64	64	66	97.3	65.7	96.0	64.7
39	L. LPG	M	97	97	97	82	84	80	97	97	97	78	78	76	97.0	82.0	97.0	77.3
40	Svr. Nur	F	98	97	98	84	85	83	98	98	97	80	82	78	97.7	84.0	97.7	80.0

Table 10: Comparison of the measured results for the average values of both SpO_2 and HR obtained from both pulse oximeters.

S/N	$SpO_{2(av}^{\dot{x}}$ (%)	$SpO_{2(av}^{d}$ (%)	$SpO_{2(av}^{Acc}$ (%)	$SpO_{2(av}^{Err}$ (%)	$HR_{(av}^{\dot{x}}$ (BPM)	$HR_{(av}^{d}$ (BPM)	$HR_{(avr}^{Acc}$ (%)	$HR_{(a}^{Er}$ (%)	$SpO^{d}_{2(avr)} - SpO^{\mu}_{2}$ *A (%)*	$HR^{d}_{(avr)} - HR^{\mu}_{(}$ *X (BPM)*	*A^2 B ((%)^2)*	*X^2 Y ((BPM)^2)*
1	97.5	0.4	99.6	0.41	81.2	2.3	97.17	2.83	0.1	0.52	0.01	0.2704
2	96.0	0.0	100.0	0.00	75.0	0.6	99.20	0.80	-0.3	-1.18	0.09	1.3924
3	97.0	0.0	100.0	0.00	77.2	2.3	97.02	2.98	-0.3	0.52	0.09	0.2704
4	97.7	0.0	100.0	0.00	73.3	4.0	94.54	5.46	-0.3	2.22	0.09	4.9284
5	96.9	0.3	99.7	0.31	70.4	0.7	99.01	0.99	0.0	-1.08	0.00	1.1664
6	96.7	0.0	100.0	0.00	80.7	0.7	99.13	0.87	-0.3	-1.08	0.09	1.1664
7	95.5	1.0	99.0	1.05	69.9	2.3	96.71	3.29	0.7	0.52	0.49	0.2704
8	98.0	0.0	100.0	0.00	65.3	0.0	100.00	0.00	-0.3	-1.78	0.09	3.1684
9	97.2	0.3	99.7	0.31	79.4	1.3	98.36	1.64	0.0	-0.48	0.00	0.2304
10	97.3	0.0	100.0	0.00	81.2	1.0	98.77	1.23	-0.3	-0.78	0.09	0.6084
11	97.5	0.4	99.6	0.41	89.5	1.0	98.88	1.12	0.1	-0.78	0.01	0.6084
12	97.2	0.3	99.7	0.31	89.5	1.0	98.88	1.12	0.0	-0.78	0.00	0.6084
13	96.5	1.0	99.0	1.04	81.0	4.0	95.06	4.94	0.7	2.22	0.49	4.9284
14	97.2	0.3	99.7	0.31	81.0	0.0	100.00	0.00	0.0	-1.78	0.00	3.1684
15	97.0	0.0	100.0	0.00	74.7	1.3	98.26	1.74	-0.3	-0.48	0.09	0.2304
16	97.0	0.0	100.0	0.00	96.2	2.3	97.61	2.39	-0.3	0.52	0.09	0.2704
17	97.4	0.7	99.3	0.72	72.2	1.0	98.61	1.39	0.4	-0.78	0.16	0.6084
18	96.7	1.3	98.7	1.34	65.2	1.0	98.47	1.53	1.0	-0.78	1.00	0.6084
19	97.0	0.0	100.0	0.00	79.7	4.7	94.10	5.90	-0.3	2.92	0.09	8.5264
20	97.7	0.0	100.0	0.00	80.2	4.0	95.01	4.99	-0.3	2.22	0.09	4.9284
21	97.5	0.4	99.6	0.41	81.2	2.3	97.17	2.83	0.1	0.52	0.01	0.2704
22	97.3	0.0	100.0	0.00	75.0	0.6	99.20	0.80	-0.3	-1.18	0.09	1.3924
23	97.7	0.0	100.0	0.00	77.2	2.3	97.02	2.98	-0.3	0.52	0.09	0.2704
24	97.3	0.0	100.0	0.00	73.3	4.0	94.54	5.46	-0.3	2.22	0.09	4.9284
25	96.9	0.3	99.7	0.31	70.4	0.7	99.01	0.99	0.0	-1.08	0.00	1.1664
26	97.3	0.0	100.0	0.00	80.7	0.7	99.13	0.87	-0.3	-1.08	0.09	1.1664
27	95.5	1.0	99.0	1.05	69.9	2.3	96.71	3.29	0.7	0.52	0.49	0.2704

28	98.0	0.0	100.0	0.00	65.3	0.0	100.00	0.00	-0.3	-1.78	0.09	3.1684
29	97.2	0.3	99.7	0.31	79.4	1.3	98.36	1.64	0.0	-0.48	0.00	0.2304
30	97.3	0.0	100.0	0.00	81.2	1.0	98.77	1.23	-0.3	-0.78	0.09	0.6084
31	97.2	0.3	99.7	0.31	89.5	1.0	98.88	1.12	0.0	-0.78	0.00	0.6084
32	97.2	0.3	99.7	0.31	89.5	1.0	98.88	1.12	0.0	-0.78	0.00	0.6084
33	96.5	1.0	99.0	1.04	81.0	4.0	95.06	4.94	0.7	2.22	0.49	4.9284
34	97.2	0.3	99.7	0.31	81.0	0.0	100.00	0.00	0.0	-1.78	0.00	3.1684
35	97.0	0.0	100.0	0.00	74.7	1.3	98.26	1.74	-0.3	-0.48	0.09	0.2304
36	97.0	0.0	100.0	0.00	96.2	2.3	97.61	2.39	-0.3	0.52	0.09	0.2704
37	97.4	0.7	99.3	0.72	72.2	1.0	98.61	1.39	0.4	-0.78	0.16	0.6084
38	96.7	1.3	98.7	1.34	65.2	1.0	98.47	1.53	1.0	-0.78	1.00	0.6084
39	97.0	0.0	100.0	0.00	79.7	4.7	94.10	5.90	-0.3	2.92	0.09	8.5264
40	97.7	0.0	100.0	0.00	80.2	4.0	95.01	4.99	-0.3	2.22	0.09	4.9284
	Total	**11.8**	**3987.70**	**12.30**		**71.0**	**3909.61**		**90.39**		**6.11**	**75.916**

4.1 SpO_2 analysis of the RPO

Table 11 showed the calculated SpO_2 parameters for performance evaluation of the locally developed RPO and they were calculated using equations (1) to (8). It was found that the overall average accuracy of the locally developed RPO in measuring SpO_2 as compared to the OTC was 99.7 % while the overall average error was 0.3 %. Table 12 showed the calculated SpO_2 parameters for Bland – Altman Plot which were calculated using equations (9) to (14).

Table 11: Calculated SpO_2 parameters for performance evaluation of the locally developed RPO

S/N	Parameters	Definition	Value	Unit
1	$SpO^{OAA}_{2(avr)}$	Overall Average Accuracy for SpO_2	99.7	%
2	$SpO^{OAE}_{2(avr)}$	Overall Average Error for SpO_2	0.3	%

Table 12: Calculated SpO_2 parameters for bland – altman plot

S/N	Parameters	Definition	Value	Unit
1	$Spo^{\mu}_{2(avr)}$	Mean of difference of average calculated SpO_2 (Bias)	0.30	%
2	$SpO^{\sigma}_{2(avr)}$	Standard Deviation for calculated SpO_2	0.40	%
3	$U^{SpO_{2(avr)}}_{LoA}$	Upper Limit (95 % of Agreement)	1.08	%
4	$L^{SpO_{2(avr)}}_{LoA}$	Lower Limit (95 % of Agreement)	-0.48	%

Figure 6 showed the Bland - Altman plot of the SpO_2 component of the pulse oximeter. Which was generated to analyze the agreeability of both pulse oximeters.

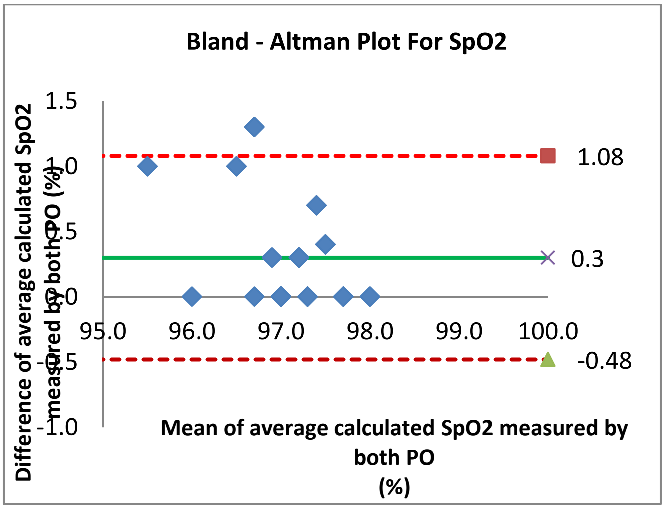

Figure 6: Bland - Altman plot of the SpO_2 component of the pulse oximeter

From the above graph, it could be seen that the data points were close to the mean of difference (Bias) which indicated a good correlation between the two measuring methods. Also, almost all the data points were scattered within the 95 % area of limits of agreement which further indicated a good correlation between both measuring methods.

4.2 HR analysis of the pulse oximeter

Measurements were also obtained from the Forty (40) patient and the results were presented and tabulated. The range of acceptable BPM value for normal patient is 60 - 100 BPM. Table 13 showed the calculated HR parameters for performance evaluation of the locally developed reflectance pulse oximeter and they were calculated using equations (15) to (22). It was found that the overall average accuracy of the locally constructed RPO in measuring HR (BPM) as compared to the OTC was 97.7 % while the overall average error was 2.3 %. Table 14 showed the calculated parameters for the HR component for Bland – Altman Plot which were calculated using equations (23) to (28).

Table 13: Calculated HR parameters for performance evaluation of the locally constructed RPO

S/N	Parameters	Definition	Value	Unit
1	$HR^{OAA}_{(avr)}$	Overall Average Accuracy for HR	97.7	BPM
2	$HR^{OAE}_{(avr)}$	Overall Average Error for HR	2.3	BPM

Table 14: Calculated HR parameters for bland - altman plot

S/N	Parameters	Definition	Value	Unit
1	$HR^{\mu}_{(avr)}$	Mean of difference of average calculated HR (Bias)	1.78	BPM
2	$HR^{\sigma}_{(avr)}$	Standard Deviation for calculated HR	1.40	BPM
3	$U^{HR(avr)}_{LoA}$	Upper Limit (95 % of Agreement)	4.52	BPM
4	$L^{HR(avr)}_{LoA}$	Lower Limit (95 % of Agreement)	-0.96	BPM

Figure 7 showed the Bland – Altman plot of the HR component of the pulse oximeter generated to analyze the agreeability of both pulse oximeters.

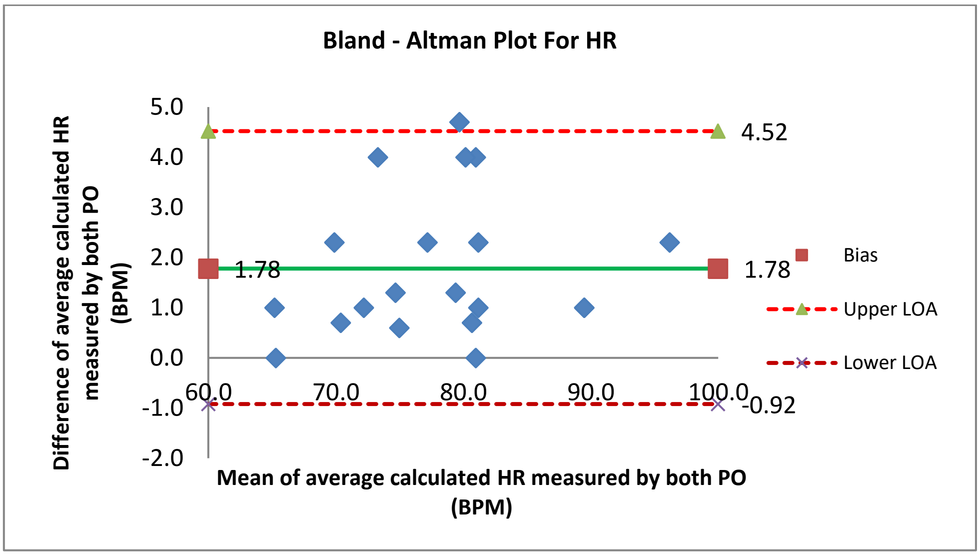

Figure 7: Bland - Altman plot of the HR component of the pulse oximeter.

From the above graph, it could be seen that the data points were close to the mean of difference (Bias) and almost all the data points are within the 95 % limit of agreement which also indicated a good correlation between the two measuring methods.

5. CONCLUSIONS

At the end of the design, construction, and evaluation of the PO, the following conclusions were drawn:

In terms of performance, a portable and easy to use oximeter was locally produced that required no expert medical personnel to measure the SpO_2 and HR. Due to the incorporated wireless device for easy connectivity, the designed device had the ability to send the measured data through the Bluetooth module to mobile phones to in order get advice or treatment from doctors who reside in remote areas without any physical or on-site visits.

The measured data and its accuracy were satisfactory as compared to the standard commercial devices bought from the drug stores with an average accuracy and error rates of 99.7 % and 0.3 % for SpO_2 while that of the HR was 97.7 % and 2.3 % respectively. From the Bland - Altman Plot for both the SpO_2 and HR, it can be concluded that the locally developed RPO could be used as a substitute for the foreign assembled FingerTip TPO and can also be used in homes and primary healthcare centres for measurement of patients' oxygen saturation and pulse rate.

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