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Development of a High Blood Pressure and Hypoxemia Measuring Device

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Abstract

This paper presents the design and implementation of a high blood pressure and hypoxemia measuring device. High blood pressure and hypoxemia are major global health concerns, often leading to stroke, heart disease, disability, and death. Factors such as lifestyle, genetics, and environmental influences contribute to hypertension, affecting over 20% of adults worldwide. Hypertensive patients commonly experience stress, anxiety, depression, and heightened cardiovascular responses to stressors. Hypoxemia, particularly prevalent in Africa, is a significant cause of mortality, with a 13.3% prevalence rate in hospitalized children. Existing devices typically monitor either blood pressure or oxygen levels separately, which discourages consistent vital sign monitoring. To address this limitation, a device capable of simultaneously measuring both high blood pressure and hypoxemia is essential. This proposed device enables early detection and management of these conditions, potentially reducing death rates. The system is built using a microcontroller (ESP32), a power supply unit, a blood pressure sensor (VM50), a MAX30100 oxygen sensor, and an LCD display. Comparative testing between the developed device and standard hospital equipment was conducted on male and female subjects across various age groups. Results showed strong agreement between the devices, with discrepancies in oxygen level readings being less than 1%, which is clinically insignificant. Additionally, blood pressure measurements from the constructed device were compared with those from a hospital-used Omron blood pressure monitor on individuals aged 15–29. The percentage error in blood pressure readings was approximately ±3%, indicating acceptable accuracy. These outcomes confirm the device's reliability for monitoring both blood pressure and hypoxemia in clinical and non-clinical environments, offering a cost-effective and practical solution for continuous health monitoring.

Keywords: *Microcontroller, blood pressure sensor, MAX30100 sensor.*

1.0 Introduction

Worldwide, particularly in Africa, patients are dying from hypertension or high blood pressure due to a lack of prompt medical attention [1], [2]. Hypertension is defined as elevated blood pressure (BP) above 140 mmHg systolic and 90 mmHg diastolic when measured under conventional settings [3], [4]. According to the World Health Organization (WHO), 25 percent of adults worldwide are thought to suffer from hypertension, which is a major, chronic illness and a leading cause of death and disability in poorer nations [5], [6]. Blood pressure should consequently be maintained within acceptable ranges (<130 mmHg systolic, <80 mmHg diastolic) [7]. One prevalent, significant, and worldwide public health issue is hypertension. It has been determined that 28% of North Americans and 44% of Western Europeans are affected by it [2]. It has also been shown to be a threat to public health in sub-Saharan Africa and a major contributor to the region's morbidity and mortality [8]. There is growing evidence that the pattern of diseases in sub-Saharan Africa is changing. In 2000, non-communicable diseases (NCDs) accounted for roughly 22% of all deaths in the region, with cardiovascular disease alone accounting for 9.2% [9]. By 2025, emerging nations are predicted to account for approximately 75% of the global hypertensive population [10].

The World Health Organization defines hypoxemia as a condition in which arterial blood has low oxygen saturation, specifically when peripheral capillary oxygen saturation (SpO_2) falls below 90%. It is a frequent complication associated with pneumonia and other acute lower respiratory infections (ALRIs), and its prevalence varies significantly depending on the clinical severity and geographic region [11]. Hypoxemia is one of the strongest predictors of mortality among children suffering from pneumonia and other ALRIs. It is also a major side effect of disorders affecting the circulatory and respiratory systems. Hypoxemia is defined by the WHO as a disease state with fever, respiratory symptoms, and radiographic or clinical evidence of lung parenchyma involvement [12]. Doctors typically use manual methods to track blood pressure, which most patients are not familiar with. Therefore, there is a need for a device that allows patients to monitor their blood pressure and blood oxygen level, while enabling medical professionals or paramedics to track patients remotely. There are plenty of devices out

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there for monitoring the body, but many of them are expensive, bulky, and not very portable, which makes them hard to maintain or use regularly. To overcome these limitations, a blood pressure and hypoxemia monitoring device should be lightweight, portable, and easy to use, allowing patients to move freely while being constantly monitored. This device would assist in tracking a patient's blood pressure, oxygen levels and detecting anomalies. An LCD is used in this work to display the result of the high blood pressure and hypoxemia device. This prompt action may help prevent deaths.

In the field of remote health monitoring, extensive research has been conducted. For instance, a mobile telemedicine-based electronic blood pressure monitoring system was developed, incorporating a Zigbee wireless transmission module for real-time data transfer [13]. However, Zigbee's low memory limits the volume of patient data it can handle. An intelligent remote blood pressure monitoring and control system was also proposed, where a wireless sensor transmits measurements to a mobile device using Wireless Application Protocol (WAP), though the reliance on WAP-capable devices is a limitation [14]. A remote temperature monitoring device was created using a WiFi wireless network and a patient–coordinator architecture; however, it is limited to temperature measurements and requires high power due to its complexity [15]. A low-cost blood pressure monitor was developed specifically for use in developing countries, using a mobile phone and a standard cuff [16], [6]. Though effective, reliance on a mobile phone limits usability. In contrast, the device presented in this study operates independently of a mobile phone, providing a more user-friendly and accessible alternative.

2.0 Methodology

2.1 System Overview

This section explains the overall flow of the development of a portable high blood pressure and hypoxemia measuring device. Figure 1 shows the block diagram describing the architecture of the system where all the sensors and peripherals are controlled by a central unit which is an ESP32 microcontroller to coordinate and sends the received and processed data to the attached display for visualization. The blood oxygen measurement is sensed by the use of an oxygen meter called the MAX30100 sensor which is a versatile optical sensor designed for measuring blood oxygen levels. It combines two LEDs, a photo detector, optimized optics, and low-noise analog signal processing to accurately detect physiological signals. The sensor operates on the principle of photo plethysmography (PPG), where light absorption by blood vessels changes as blood volume pulsates, allowing for non-invasive measurement of oxygen saturation.

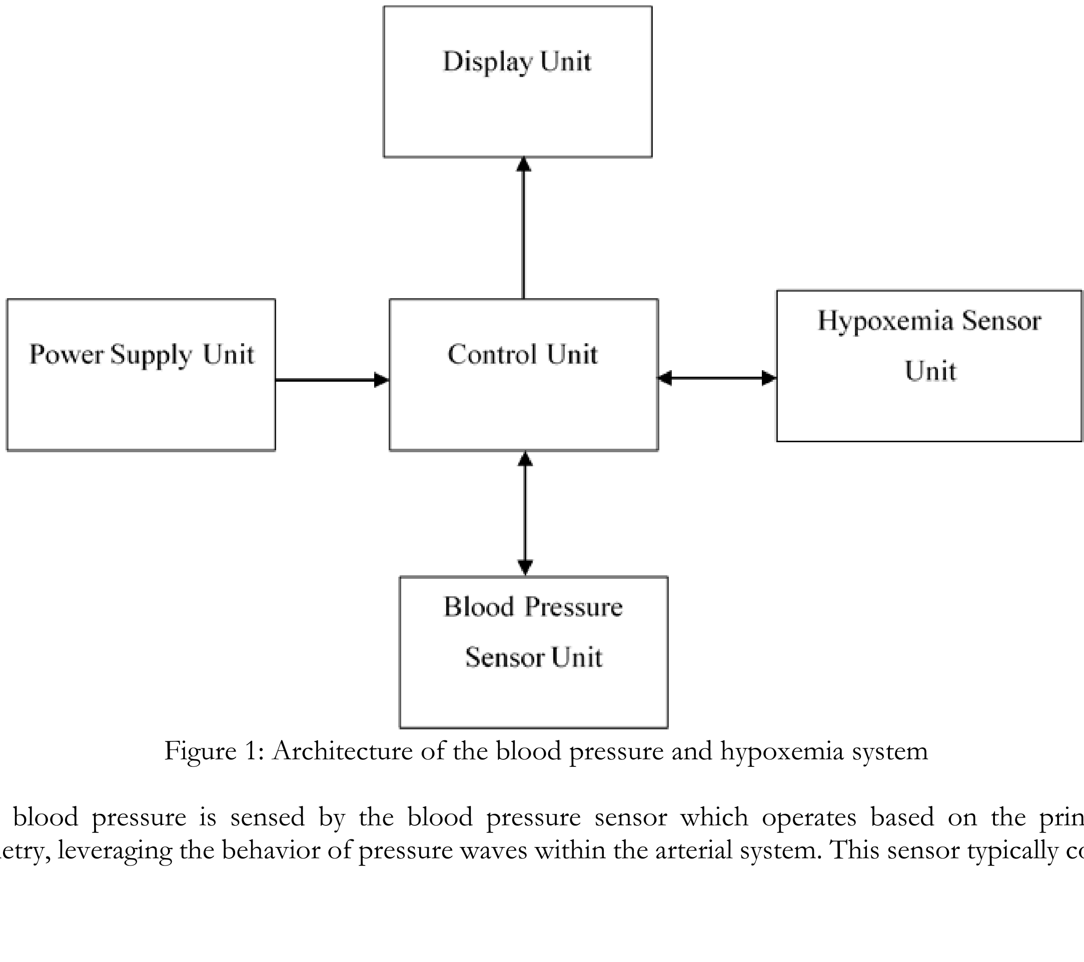

Figure 1: Architecture of the blood pressure and hypoxemia system

The blood pressure is sensed by the blood pressure sensor which operates based on the principles of oscillometry, leveraging the behavior of pressure waves within the arterial system. This sensor typically consists of a cuff, pressure transducer, amplifier, and the ESP32 microcontroller. When the cuff is inflated, it applies external pressure to the brachial artery, causing arterial flow to stop momentarily. As the cuff gradually deflates, the pressure on the artery decreases until it surpasses the systolic pressure, allowing blood to flow again. The pressure transducer detects oscillations in the cuff pressure caused by blood flow resuming, transmitting these signals to the amplifier.

These two sensors are connected to the ESP32 microcontroller (32-bit) through the I2C communication protocol and digital input pins of the ESP32 microcontroller. The microcontroller processes and interprets the electrical signals, calibrates the data, and then shows the final result on the screen. The power supply consists of power rails of 5V which is used by the MAX30100, Blood pressure sensor, ESP32 microcontroller and the LCD.

2.2 Hardware Implementation

The development of this high blood pressure and hypoxemia measuring device entails a meticulous integration of the Max30100 sensor, microcontroller, Blood Pressure sensor, 5V battery, and LCD using the C/C++ programming language. The methodology encompasses sensor interfacing, data processing, user interface design, power management, and error handling, ensuring a robust and accurate health monitoring solution.

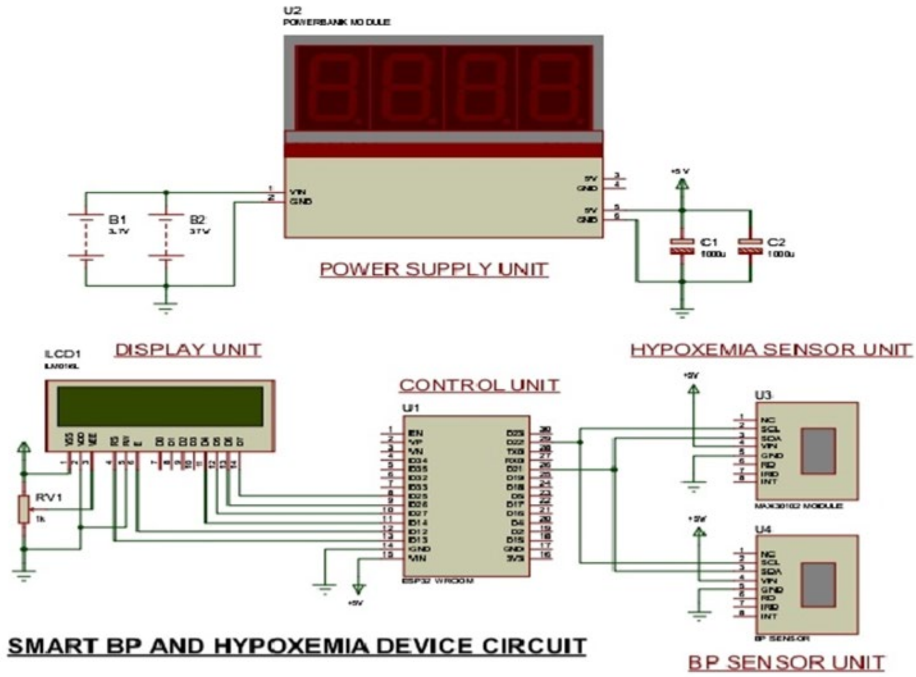

Figure 2: Circuit diagram of the high blood pressure and hypoxemia device

Figure 2 shows the Max30100 sensor, known for its accuracy in hypoxemia measurement, interfaced with the microcontroller using C/C++ programming language to ensure efficient data acquisition. The hypoxemia sensor which is the max30100 is interfaced to the microcontroller which the control unit is using I2C communication protocol and digital pins which are the pin 21, and pin 22 on the microcontroller (ESP32). The LCD is interfaced using parallel connection between the pin on the left hand side of the microcontroller board which are the pin 13, pin 14, pin12, pin27, pin 26 and pin 25.The Blood pressure sensor is interfaced using the input/output pin GPIO of the microcontroller.The power supply is designed using lithium ion battery and a power charging/power bank module for charging the battery and it also have a display for displaying the battery percentage. The microcontroller acts as the central processing unit, managing sensor data and executing algorithms to calculate blood pressure and hypoxemia. The Blood pressure sensor is employed to enhance the accuracy of BP measurements. The 5V battery serves as a reliable power source, ensuring uninterrupted device functionality. Careful consideration is given to power management strategies to optimize battery life. The LCD is utilized as the user interface, providing real-time feedback on blood pressure and oxygen levels, enhancing user accessibility and engagement.

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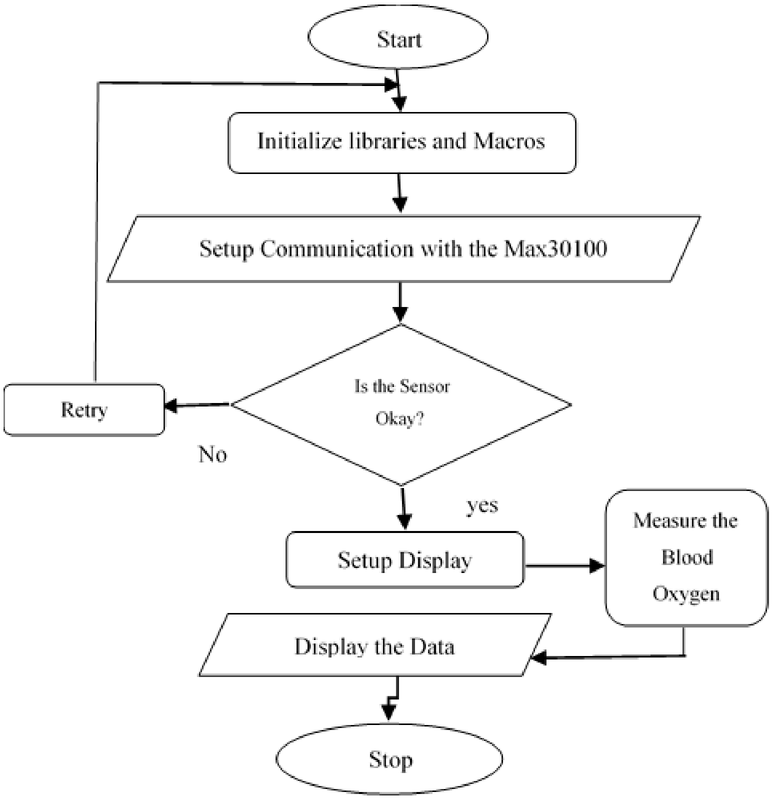

Figure 3: Hypoxemia software implementation flowchart

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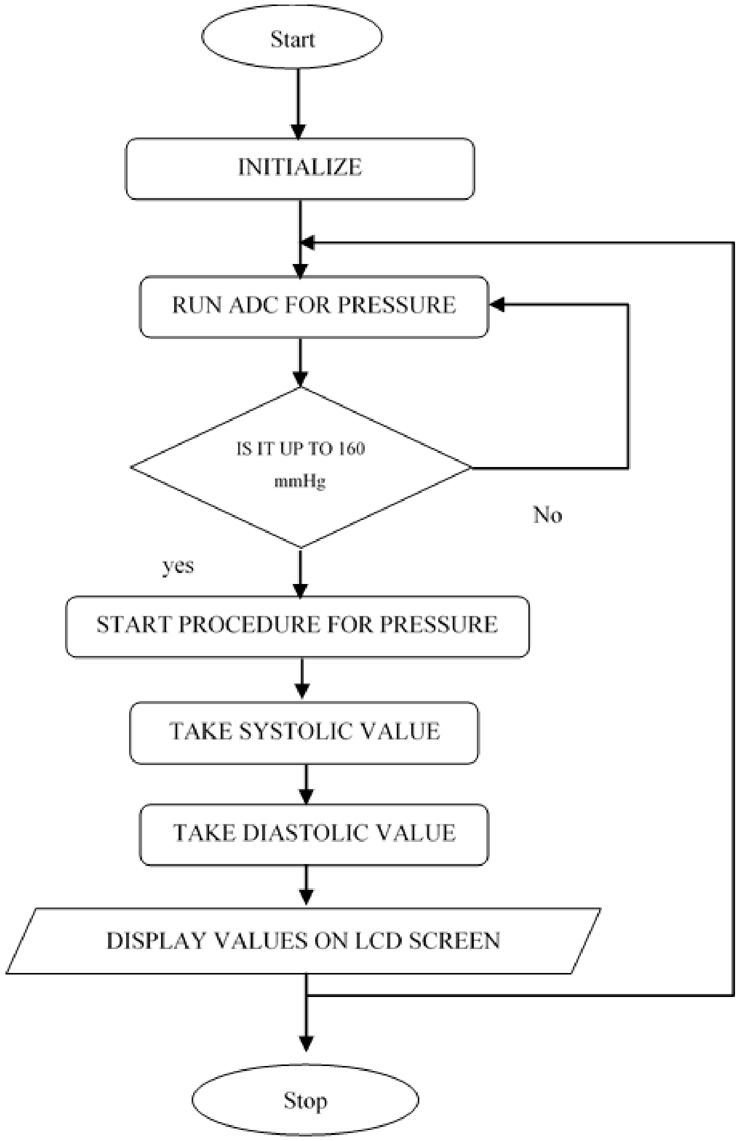

Figure 4: Flowchart of high blood pressure

Figures 3 and 4 shows the flow of the functionalities of how the systems starts to initialize all the peripheral and libraries and then establishing communication with the MAX30100 sensor to measure the blood oxygen and also the blood pressure sensor which is used to measure the blood pressure. As the sensors senses and sends the data to the microcontroller, the microcontroller which is the ESP32 processes the parameters from the sensors and displays it on the LCD

2.3 Experimental Setup

To validate the performance of the developed device for measuring high blood pressure and hypoxemia, a controlled experimental setup was designed and implemented. The goal of the experiment was to test the device's ability to accurately detect and display the blood pressure and peripheral oxygen saturation (SpO_2) in real-time.

The test procedure involved using the assembled prototype on a group of volunteers under normal conditions. Each participant was seated comfortably in an upright position with the cuff securely wrapped around the upper arm for blood pressure measurement. Simultaneously, the pulse Oximeter sensor was clipped onto the fingertip

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to monitor blood oxygen levels. The microcontroller was programmed to process the electrical signals from both sensors, calibrate the readings, and display the results on the LCD screen.

Power was supplied to the system using a rechargeable battery, and all components were enclosed in a compact 3D-printed casing for portability. Before testing, the system was allowed to initialize, and baseline readings were recorded. Multiple readings were taken from each volunteer at regular intervals to ensure consistency and to account for fluctuations due to movement or positioning.

To verify accuracy, measurements from the developed device were compared with readings from a standard commercial digital Omron blood pressure monitor and a certified fingertip pulse Oximeter. Environmental factors such as room temperature and lighting were kept consistent to minimize sensor interference.

3.0 Results and Discussion

After the design and construction of the device, the device was used to read the blood pressure of ten persons presented in Table1, and Hypoxemia (oxygen level) of ten persons presented in Table 3. The test was conducted with a hospital device (Omron blood pressure monitor) sold in the market in Nigeria and a Pulse Oximeter used in hospitals.

Table 1: Result of blood pressure meter test constructed and result using Omron Blood Pressure Monitor

S/N	Name of Persons	Gender	Age	Result for Constructed Device Standard Pressure (mmHg)	Result Using the Omron Blood Pressure Monitor (mmHg)	Systolic Error	Diastolic Error
1	A	Male	15	110/70	107/72	2.8%	-2.8%
2	B	Male	17	120/80	118/82	1.7%	-2.4%
3	C	Female	29	120/80	122/82	-1.6%	-2.4%
4	D	Male	27	110/70	111/72	-0.9%	-2.8%
5	E	Male	23	110/70	109/72	0.9%	-2.8%
6	F	Female	28	115/75	116/78	-0.9%	-3.8%
7	G	Male	25	120/80	121/82	-0.8%	-2.4%
8	H	Male	24	115/75	114/78	0.9%	-3.8%
9	I	Male	19	110/70	108/72	1.9%	-2.8%
10	J	Male	22	118/78	120/80	-1.7%	-2.5%

Table 2: Table showing the percentage error between the developed device and Omron Monitor

S/N	Name	Gender	Age	Standard Pressure (mmHg)	Systolic Diastolic (%)
1	A	Male	15	2.8%	-2.8%
2	B	Male	17	1.7%	-2.4%
3	C	Female	29	-1.6%	-2.4%
4	D	Male	27	-0.9%	-2.8%
5	E	Male	23	0.9%	-2.8%
6	F	Female	28	-0.9%	-3.8%
7	G	Male	25	-0.8%	-2.4%
8	H	Male	24	0.9%	-3.8%
9	I	Male	19	1.9%	-2.8%
10	J	Male	22	-1.7%	-2.5%

The percentage error between the Developed Device and Omron Monitor is calculated as:

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$$\frac{\text{Blood Pressure Sensor} - \text{Omron Device}}{\text{Omron Device}} \, x\, 100$$

Table 3: Result of the hypoxemia test of constructed device and Pulse Oximeter

S/N	Name	Gender	Age	(SpO2) Result of Constructed Device	(SpO2) Result of Pulse Oximeter Device Used in Hospitals
1	A	Male	15	98.5%	99.2%
2	B	Male	17	98.2%	99.0%
3	C	Female	29	97.9%	98.7%
4	D	Male	27	97.6%	98.4%
5	E	Male	23	97.3%	98.1%
6	F	Female	28	97.0%	97.8%
7	G	Male	25	96.7%	97.5%
8	H	Male	24	96.4%	97.2%
9	I	Male	19	96.1%	96.9%
10	J	Male	22	98.2%	99.0%

Table 4: Table showing the percentage error between the Developed Device and Hospital used Pulse Oximeter

S/N	Name	Gender	Age	Percentage Error of Both Device (SpO2)
1	A	Male	15	0.7%
2	B	Male	17	0.8%
3	C	Female	29	0.9%
4	D	Male	27	0.8%
5	E	Male	23	0.7%
6	F	Female	28	0.6%
7	G	Male	25	0.5%
8	H	Male	24	0.4%
9	I	Male	19	0.3%
10	J	Male	22	0.8%

The percentage error between the Developed Device and Hospital used Pulse Oximeter is calculated as:

$$\frac{\text{MAX30100 Sensor} - \text{Hospital Pulse Oximeter}}{\text{Hospital Pulse Oximeter}} \, x\, 100$$

3.1 Discussion

The developed Device and an Omron blood pressure device were used to monitor ten persons as presented Table 1. It showed that there was slight variation in the values between the developed device and the Omron monitor but the results are sufficient to say that the developed monitor is accurate for blood pressure monitoring. In this work, a digital blood pressure device was designed and developed. It can be used to measure digital blood pressure of people easily without any hindrance. A comparison of measurement of blood pressure between the developed monitor and the Omron monitor available in the market shows a percentage error of approximately ±3% presented in Table 2. Literature has it that because of the patient's position, his anxiety or expectations coupled with the unstable pulse rate of the human heart, no two blood pressure measurements taken immediately after the other will give exactly the same results (Taram and Mike, 2012). Even when a conventional blood pressure monitor is used to measure a patient's blood pressure at two consecutive times, the measurement will not have exactly the same values. Also based on the data derived from the MAX30100 Sensor demonstrates accurate oxygen level measurements compared to the hospital- used pulse oximeter with an average percentage error of

approximately 0.65% presented in Table 4. This indicates that the developed device is reasonably accurate for blood pressure and hypoxemia monitoring.
Beyond accuracy, the developed device holds advantages in terms of cost-effectiveness, portability, and the integration of two critical health parameters in one system. Unlike the compared commercial devices, which are typically designed for single-parameter monitoring or require separate units, our prototype combines both functions seamlessly in a single handheld unit.

4.0 Conclusion, Limitations and Recommendations

4.1 Conclusion

In this study, the high blood pressure and hypoxemia device were designed and implemented. The proposed system was completed and tested on different persons. The result for the blood pressure and hypoxemia were obtained and demonstrated that the proposed device achieved the main goal of measuring the blood pressure and hypoxemia of individuals transmitting these values and displaying them on the LCD of the device.

4.2 Limitations

Despite its promising performance, the developed device has a few notable limitations. The sensors used are not of clinical-grade quality, which may lead to slight inaccuracies, especially in patients with irregular heartbeats or poor circulation. The device lacks wireless connectivity, making it difficult to store or transmit data for remote monitoring or follow-up care. It also operates with a basic battery system that does not support long-term use or indicate power levels. The system uses a general calibration setting without accounting for individual variations such as age, body size, or health condition. The display is limited to basic numerical readings, offering no historical tracking, alerts, or visual feedback that could help users or caregivers interpret the results more effectively.

4.3 Recommendations

The following are recommended:

i. **Integration of Medical-Grade Sensors**: Future iterations should incorporate clinically certified sensors for both blood pressure and SpO_2. This would improve the device's accuracy, reliability, and approval potential for hospital or regulatory use.
ii. **Incorporation of Wireless Data Transmission**: Adding Bluetooth, Wi-Fi, or GSM modules would allow the device to sync data with mobile apps, cloud storage, or remote health platforms. This would support remote patient monitoring, especially for those in rural or underserved areas.
iii. **User Profile Management and AI Calibration**: Introduce a smart calibration system that adapts to individual users by learning their normal vitals over time. This could include user selection, age-based calibration, and possibly AI-driven health trend analysis.
iv. **Extended Power Management System**: Implement a rechargeable lithium-ion battery with power-saving features, battery level indicators, and possibly solar charging options to ensure reliable operation in off-grid or emergency scenarios.
v. **Advanced Interface with Alerts and Logging**: Upgrade the user interface to include a touch screen or app-based display showing historical data, graphical trends, and real-time alerts for abnormal readings. This would make the device more user-friendly and medically actionable.

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