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A Portable Pulse Oximeter Prototype with Wireless Monitoring Through Android Devices

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ABSTRACT The increase in obesity and cardiovascular disorders underscores the importance of health monitoring, particularly regarding oxygen saturation and heart rate. This study aims to design and develop a prototype pulse oximeter with monitoring capabilities via an Android application using Bluetooth technology. The system utilises the MAX30102 sensor to measure oxygen saturation (SpO_2) and heart rate (BPM), with the ESP32 microcontroller for data processing and connectivity. Measurement data are displayed on an OLED screen and an Android application built on Kodular. Testing involved comparing measurement results with a calibrated reference device, showing an accuracy rate of 98.15% for SpO_2 and 90.21% for BPM. An alarm feature was added to provide alerts if SpO_2 drops below 95%. The results indicate that this device offers a practical solution for portable and efficient health monitoring, supporting more responsive healthcare services. Identified weaknesses, such as sensitivity to movement and finger positioning on the sensor, serve as points for further development.

INDEX TERMS Android, BPM, Max30102, Pulse Oximeter, SpO_2.

I. INTRODUCTION

The progression of cardiovascular disease is becoming increasingly concerning, especially due to risk factors such as obesity and a sedentary lifestyle. Obesity not only affects the cardiovascular system by increasing blood pressure and thickening blood vessel walls, but it can also worsen heart conditions. Additionally, a lack of physical activity impacts the heart's ability to pump blood, making individuals who are obese and inactive more likely to experience complex cardiovascular issues compared to those who maintain an ideal weight and engage in regular exercise. [1].

The combination of obesity and lack of physical activity can ultimately lead to shortness of breath. This condition is often associated with a decline in lung capacity to deliver oxygen into the bloodstream. As a result, body tissues do not receive an adequate oxygen supply, forcing the heart to work harder to compensate for the deficiency. If left untreated, this condition can lead to more serious cardiovascular disorders, such as heart failure or coronary artery disease, requiring close monitoring of oxygenation levels and overall heart function [2].

Amid the increasing complexity of cardiovascular disorders, self-monitoring of health conditions is becoming increasingly important. One of the devices that supports this monitoring process is the pulse oximeter, which measures blood oxygen saturation levels and pulse rate non-invasively [3]. By knowing their blood oxygen levels, individuals can detect early signs of significant declines that require immediate intervention. Simultaneous pulse rate measurement also provides a general overview of the heart's workload, making it easier for healthcare professionals and patients to monitor the effects of lifestyle changes or prescribed therapies.

Thus, the use of a pulse oximeter becomes an integral part of cardiovascular disease prevention and management efforts. This device is not only relevant for individuals already diagnosed with heart conditions but also for those with high-risk factors such as obesity, lack of exercise, or recurrent shortness of breath. The combination of self-monitoring with a pulse oximeter, adopting a healthy lifestyle—including regular exercise and a balanced diet—and routine consultations with healthcare professionals is expected to reduce the risk of heart complications and improve overall quality of life [4].

Previous studies have developed a measurement device that displays blood oxygen saturation (SpO_2) using the Arduino Uno R3 microcontroller. [5]. This module can provide information on blood oxygen levels, but is still limited to a single function without additional features such as heart rate monitoring or broader connectivity. Subsequently, another study developed a device capable of measuring heart rate and SpO2 with basic internet connectivity, publishing data to an HTML web page. [6]. Its drawback is the reliance on an internet connection, whereas not all regions in Indonesia, such as large parts of Papua, have internet access.

Based on these developments, further innovation is needed in the advancement of a more modern pulse oximeter that can be accessed in real-time by healthcare professionals and the patient's family. One promising solution is a pulse oximeter prototype equipped with monitoring on Android. This device allows the patient's oxygen saturation and pulse rate data to be transmitted directly to an Android application via a Bluetooth connection, making the monitoring process more convenient for users.

Another advantage of this prototype is the ease of integration with mobile devices, which are currently one of the most commonly used devices by the public. With the Android-based application, users can easily access their health data if there is a significant decrease in oxygen levels. In the development of this prototype, Bluetooth technology is used as the communication medium between the pulse oximeter and the Android application. Bluetooth is chosen for its reliability in transmitting data over short distances with low power consumption, making it ideal for portable medical devices like the pulse oximeter.

In this fast-paced digital era, a pulse oximeter prototype equipped with monitoring on Android is not only a practical solution but also enhances efficiency in patient condition monitoring more responsively. Through this innovation, it is expected to improve the quality of healthcare services, reduce the risk of delays in handling serious medical conditions, and provide convenience for the patient's family to be more actively involved in health monitoring.

With this background, this study aims to design and develop a pulse oximeter prototype equipped with monitoring on Android, as well as to test its effectiveness and reliability in real-time patient health monitoring.

A. HEART RATE

A normal heart rate is one of the key indicators of cardiovascular health and overall well-being. It reflects how effectively the heart pumps oxygen-rich blood throughout the body. Maintaining a heart rate within the normal range is crucial, as it is directly linked to efficient heart function and the body's systemic balance. Below is a detailed explanation of the importance of a normal heart rate:

1. Cardiovascular Efficiency

A normal heart rate reflects the heart's ability to pump blood efficiently throughout the body. When the heart rate is within the normal range, it indicates that the heart is functioning optimally, supplying adequate oxygen and nutrients to vital organs. An excessively high heart rate (tachycardia) or an abnormally low heart rate (bradycardia) may indicate underlying heart issues, such as myocardial dysfunction or impaired circulation.

2. General Health Indicator

Resting heart rate can be used as an indicator of a person's cardiovascular fitness. Healthy individuals, especially those who exercise regularly, often have a lower resting heart rate, which signifies that their heart does not need to work as hard to pump blood. On the other hand, a high resting heart rate may indicate stress on the cardiovascular system or a lack of physical fitness.

3. Oxygen and Nutrient Regulation

The heart is responsible for circulating oxygen- and nutrient-rich blood throughout the body. If the heart rate is not within the normal range, blood circulation may be suboptimal, potentially leading to issues such as dizziness, fatigue, shortness of breath, and even long-term organ damage. An excessively high or low heart rate means the body is not receiving sufficient oxygen supply to function properly.

4. Early Detection of Health Issues

Monitoring heart rate can help in the early detection of various medical conditions. An abnormal heart rate may indicate underlying health problems such as:

- Arrhythmia: Irregular heartbeats that can disrupt normal blood flow.
- Coronary Heart Disease: An abnormal heart rate may signal narrowed or blocked arteries.
- Hypertension (High Blood Pressure): A consistently high heart rate is often associated with high blood pressure, increasing the risk of heart attacks and strokes.
- Heart Failure: A weakened heart struggles to maintain a normal heart rate.

5. Response to Physical Activity and Emotions

Heart rate increases during physical activity or stressful situations to meet the body's higher oxygen demands. Monitoring heart rate during exercise is essential to ensure a safe and effective workout intensity. A significant rise in resting heart rate may indicate excessive emotional or mental stress.

6. Indicator of Fitness Level
For athletes or individuals who exercise regularly, a low resting heart rate (below 60 BPM) is normal. This occurs because of the heart's improved efficiency in pumping blood. A strong and well-conditioned heart can pump more blood with each contraction, reducing the need for a higher heart rate to meet the body's demands.
7. Monitoring the Effects of Medication
Certain medications, such as beta-blockers, are used to slow down the heart rate in individuals with high blood pressure or heart disease. Monitoring normal heart rate is essential to ensure that the medication is working effectively without causing the heart rate to become too low or too high.
8. Age-Related Changes
As a person ages, their heart rate tends to decrease because the heart muscle may weaken. Therefore, a normal heart rate varies depending on age. Regular heart rate monitoring is crucial for older individuals to detect early signs of heart conditions that may develop with ageing [7].

TABLE I
THE NORMAL HEART RATE RANGE BY AGE GROUP [8]

Age Group	Normal Heart Rate (BPM)
Newborn baby (0-1 month)	70-190
Baby (1-11 months)	80-160
Children (1-2 years)	80-130
Children (3-4 years)	80-120
Children (5-6 years)	75-115
Children (7-9 years)	70-110
Teenagers (10-15 years)	60-100
Adults (16 years and above)	60-100

From Table 1, factors that influence heart rate include physical condition, emotions, temperature, and medications. Individuals who exercise regularly tend to have a lower resting heart rate. Emotions such as anxiety, stress, or fear can increase heart rate, while a rise in body temperature also leads to an increased heart rate. Additionally, certain medications can either slow down or speed up the heart rate.

The number of heartbeats per minute, commonly known as beats per minute (bpm), is a widely used measure to assess whether a person's heart is healthy or not.

B. OXYGEN SATURATION
Oxygen saturation is a measurement that indicates how much oxygen is bound to haemoglobin in the blood. Haemoglobin is a protein in red blood cells responsible for carrying oxygen from the lungs to the rest of the body. This process is essential for supporting organ and tissue function. Oxygen saturation is measured as a percentage, providing insight into how efficiently the lungs and circulatory system are working [9].

SpO_2 stands for Saturation of Peripheral Oxygen, which measures the percentage of oxygen saturation in the blood. The SpO_2 value reflects how much haemoglobin in the blood is bound to oxygen. In healthy adults, normal oxygen saturation levels typically range from 95% to 100%, indicating that the blood carries sufficient oxygen to meet the body's needs.

Hypoxemia is a condition characterised by low oxygen levels in the blood, particularly in the arteries. It is determined by measuring oxygen levels in a blood sample taken from an artery or by assessing blood oxygen saturation using a pulse oximeter. On the other hand, hypoxia refers to a lack of oxygen in body tissues, including vital organs.

If hypoxemia, low oxygen levels in the blood, persists and leads to insufficient oxygen supply to body tissues for metabolism, it progresses into hypoxia as seen in Table 2.. Ultimately, these two conditions are closely interconnected and cannot be separated from one another. [10].

TABLE II
OXYGEN SATURATION RANGE [11]

No.	Category	SpO2 Range (%)
1	Normal	95 – 100
2	A little low	91 – 94
3	Mild hypoxemia	86 – 90
4	Moderate hypoxemia	80 – 85
5	Severe hypoxemia	< 80

C. PULSE OXIMETER
A pulse oximeter is a non-invasive medical device used to measure blood oxygen saturation levels (SpO_2) and pulse rate. It works by attaching a sensor to a body part, typically the fingertip, earlobe, or foot, to detect changes in blood colour related to oxygen levels.

The pulse oximeter operates based on the principle of photometry, utilising two wavelengths of light: red (660 nm) and infrared (940 nm). The device emits light through the skin, and a sensor on the opposite side detects the intensity of light absorbed and transmitted by the tissue. Oxygenated haemoglobin (oxyhemoglobin) absorbs infrared light while allowing red light to pass through, whereas deoxygenated haemoglobin (deoxyhemoglobin) absorbs red light and permits infrared light to pass through. By comparing the proportion of light absorbed at these two wavelengths, the pulse oximeter calculates the percentage of oxygen-bound haemoglobin in the blood [12].

There are 2 methods for monitoring blood saturation using the non-invasive method.

1. Transmission Method
   In the transmission method, the LED and detector are positioned opposite each other. Light from the LED, both red (660 nm) and infrared (940 nm), is emitted through tissue, such as the fingertip. The blood within the blood vessels absorbs a portion of this light. Red light is primarily absorbed by deoxygenated haemoglobin (deoxyhemoglobin), while infrared light is mostly absorbed by oxygenated haemoglobin (oxyhemoglobin). The detector on the other side of the finger measures the intensity of light transmitted after passing through the tissue.
2. Reflectance Method
   In the reflectance method, the LED and detector are positioned side by side. Light emitted by the LED strikes the tissue, such as the fingertip, and is reflected to the sensor on the same side. This mode is useful when direct transmission is not possible, such as when used on the forehead or other hard-to-reach body parts. The detector captures the reflected light, and the device calculates oxygen saturation in the same way as in the transmission mode, based on differences in light absorption.

Photoplethysmography (PPG) in a pulse oximeter is a method used to detect blood flow rate. Therefore, this signal can be used to determine the cardiac cycle. The process works by having the detector in the pulse oximeter capture light passing through the tissue. As the heart beats, the volume of blood flowing through the arteries fluctuates, increasing and decreasing in sync with the cardiac cycle. This variation causes changes in the intensity of light detected by the sensor.

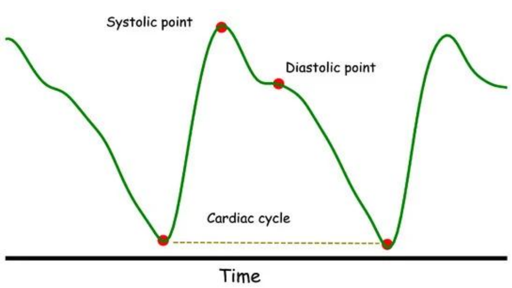

FIGURE 1. PPG Signal [13]

The explanation of the PPG signal in Fig. 1 is as follows:

1. Systolic Point
   The peak point on this graph is called the systolic point. It represents the peak of the PPG wave, which occurs when the heart's ventricles contract and pump blood out of the heart (systole). At this moment, the blood volume in the arterial vessels increases, leading to a rise in the intensity of the PPG signal.
2. Diastolic Point
   The lowest point after the systolic point is called the diastolic point. It occurs after the heart's contraction (during diastole), when the heart relaxes and refills with blood. As the blood volume in the arteries decreases, the intensity of the PPG signal also decreases.
3. Cardiac Cycle
   A complete cardiac cycle includes the contraction phase (systole) and the relaxation phase (diastole), both of which are reflected in the PPG signal. On the graph, one cycle is represented by the duration from one systolic point peak to the next.

The PPG signal consists of an AC component, which reflects the dynamic fluctuations in blood volume related to the heartbeat. This is represented by the periodic waves on the graph (peaks and troughs). Meanwhile, the DC component is a stable baseline that represents the non-pulsatile component of blood. [13].

D. MAX30102 SENSOR

The MAX30102 is an optical sensor designed to measure heart rate (BPM) and blood oxygen saturation (SpO_2) non-invasively. The MAX30102 sensor uses the reflectance method, rather than transmission, making it incompatible with pulse oximeter calibrators that rely on transmission-based testing.

This sensor is an improvement over the MAX30100, offering several enhancements and advantages, including:

1. Better responsiveness in low-light conditions and improved filtering of motion-related interference.
2. More efficient red and infrared LEDs compared to the MAX30100, enabling more accurate measurements with lower power consumption.

3. Improved noise handling, enhanced object detection sensitivity, and faster response times.

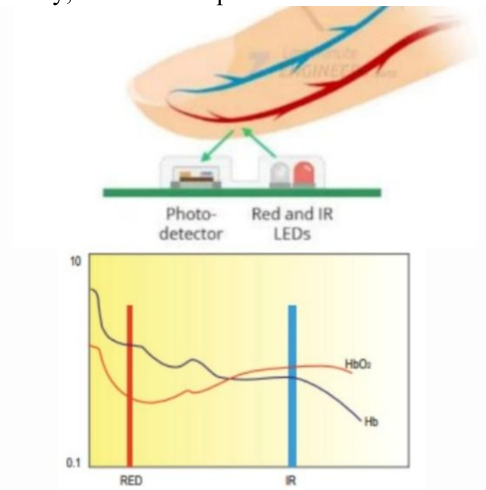

FIGURE 2. How the MAX30102 sensor works [14]

The MAX30102 operates based on the photoplethysmography (PPG) principle, where light emitted by LEDs passes through body tissue and is either absorbed or reflected, depending on blood flow as seen in Fig 2. The intensity of the reflected light fluctuates with the heartbeat, which is then converted into digital data for BPM and SpO_2 measurements.

The explanation of the image of how the MAX30102 sensor works is as follows:

1. Light Emission
   The red LED and infrared LED emit light into the body tissue. The red LED operates at a wavelength of approximately 660 nm, while the infrared LED emits light at around 880 nm.
2. Light Reflection Detection
   The emitted light penetrates the body tissue, and a portion of it is reflected. The amount of reflected light depends on the blood volume in capillaries and the oxygenation level of the blood. A photodetector captures the reflected light and measures its intensity.
3. Changes in Light Intensity
   As blood flows through the capillaries, the intensity of the reflected light fluctuates due to changes in blood volume and oxygen content with each heartbeat. By measuring variations in reflected light intensity at two wavelengths (red and infrared), the sensor can differentiate between oxygenated and deoxygenated haemoglobin.
4. SpO_2 and BPM Calculation
   Based on the ratio of reflected light intensities at red and infrared wavelengths, the sensor calculates blood oxygen saturation (SpO_2). It also tracks changes in capillary blood volume with each heartbeat, allowing it to measure heart rate (BPM).
5. Light Absorption Graph
   - Oxygenated haemoglobin (HbO_2) and deoxygenated haemoglobin (Hb) absorb light at two different wavelengths: red and infrared (IR). At the red wavelength, deoxygenated haemoglobin (Hb) absorbs more light, while oxygenated haemoglobin (HbO_2) absorbs less.
   - At the infrared (IR) wavelength, the absorption pattern is reversed; oxygenated haemoglobin (HbO_2) absorbs more light than deoxygenated haemoglobin (Hb). This difference in light absorption allows the device to calculate the ratio between oxygenated and deoxygenated haemoglobin. Using this ratio, the device determines oxygen saturation (SpO_2).

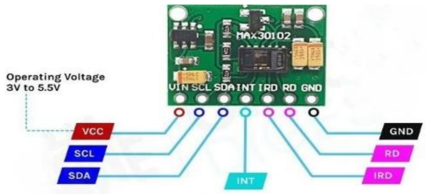

FIGURE 3. max30102 sensor [14]

Pin Functions on the MAX30102 Module in Fig 3 are:

- VCC
Provides power to the MAX30102 module. The operating voltage range is 3V to 5.5V.

- SCL (Serial Clock Line)
The Inter-Integrated Circuit (I2C) is a communication protocol used for data exchange between microcontrollers, sensors, or other devices. I2C is designed to connect multiple devices within a system using a shared communication line. This is one of the two I2C communication pins used by the module to communicate with the microcontroller. It sends clock signals (timing pulses) in the I2C protocol, managing the timing of communication between the sensor and the microcontroller.

- SDA (Serial Data Line)
The second pin for I2C communication. Data is transmitted and received through this pin between the MAX30102 module and the microcontroller. All information, such as heart rate (BPM) and SpO_2 measurements, is communicated through this pin.

- INT (Interrupt Pin)
Generates an interrupt signal to the microcontroller when new data is available for processing. This pin notifies the microcontroller that new data is ready to be read, helping to save power and minimise continuous data polling.

- RD (Red LED Control)
Controls the red LED, which is used in SpO_2 measurement. It provides a control signal to turn the red LED on and off in the MAX30102 module. The red LED helps in determining blood oxygen levels (SpO_2).

- IRD (Infrared LED Control)

Controls the infrared LED, which is used for heart rate (BPM) measurement by detecting blood flow in blood vessels.
- GND (Ground)
Connects the circuit to the ground system.

E. ESP32

ESP32 is a high-performance microcontroller developed by Espressif Systems. It is designed to be a power-efficient solution, making it ideal for various IoT (Internet of Things) applications. This microcontroller integrates a powerful dual-core processor, along with Wi-Fi and Bluetooth connectivity, into a single chip. Additionally, the ESP32 supports multiple interfaces, such as I2C, SPI, UART, and PWM.

One of the main advantages of the ESP32 over Arduino is its wireless networking capability. While most Arduino boards do not come with built-in Wi-Fi or Bluetooth, the ESP32 features both Wi-Fi and Bluetooth, enabling it to communicate directly with other devices over a network without requiring additional modules.

In terms of performance, the ESP32 features a dual-core processor with a speed of up to 240 MHz and 520 KB of RAM, which is significantly larger than a standard Arduino (for example, the Arduino Uno only has a 16 MHz processor and 2 KB of RAM). This performance enables the ESP32 to handle more complex tasks, such as real-time sensor data processing.

The ESP32 uses a 32-bit architecture. Its processor is based on the Xtensa LX6 from Tensilica, which supports 32-bit operations, meaning that the ESP32 can process 32-bit data and instructions in a single cycle. This 32-bit architecture provides more powerful and efficient processing compared to 8-bit or 16-bit microcontrollers, such as many Arduino models like the Arduino Uno, which uses an 8-bit processor. Additionally, the ESP32 is more power-efficient. This microcontroller is designed with various sleep modes that enable significant energy savings. These modes are particularly useful in IoT applications that rely on battery power, where devices need to operate for extended periods without frequent recharging. [15].

II. RESEARCH METHODS

A. RESEARCH DESIGN

This study aims to develop and test a pulse oximeter prototype equipped with monitoring on Android. The pulse oximeter prototype system uses the ESP-32, a microcontroller capable of wirelessly transmitting the patient's heart rate and oxygen saturation data to an Android device via a Kodular application. The research stages are explained in Fig. 4 as follows.

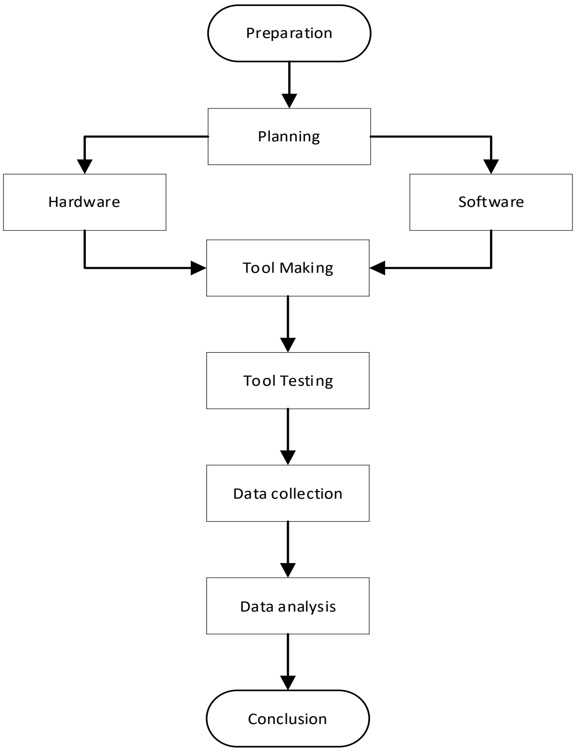

FIGURE 4. Research stages

B. DESIGN PLANNING OF THE DEVICE

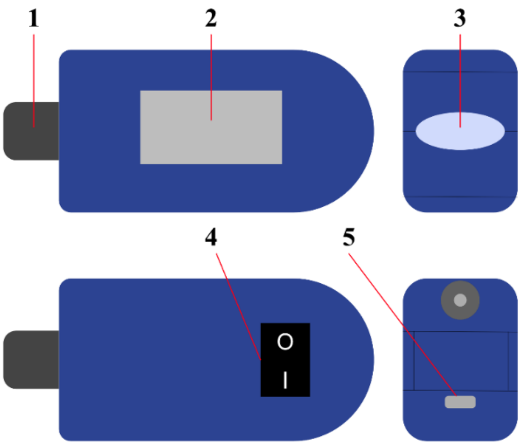

FIGURE 5. Top, bottom, front, and back views of the module

From Fig. 5, it can be explained that the design functions of each part are as follows:

1. The buzzer functions as an alarm for sound notifications
2. The LCD serves as a display for measurement results from the sensor
3. The MAX30102 sensor functions as an oxygen level and heart rate sensor
4. The ON/OFF switch button is used to turn the device on and off
5. The Micro USB port functions as a battery charger adapter

C. BLOCK DIAGRAM PLANNING

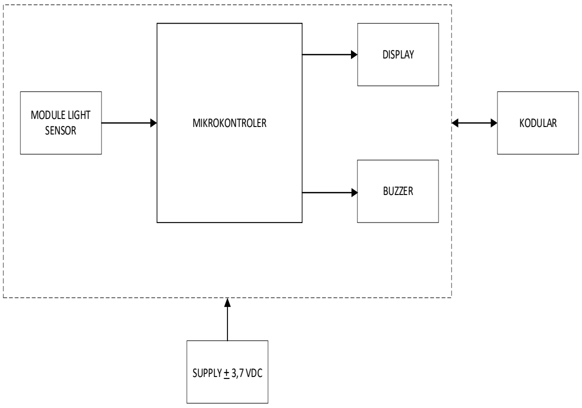

FIGURE 6. Block diagram

Each circuit block in Fig. 6 has a different function. The functions of each block diagram are as follows:

1. The power supply circuit uses a ±3.7 VDC battery, which functions to provide power to the entire circuit.
2. The buzzer circuit functions to produce an alarm sound.
3. The light sensor circuit functions to detect the range of incoming light, which is then converted into a voltage. The sensor then reads any changes that occur with each increase or decrease in light intensity based on the response of oxygen flow in the blood within the finger.
4. The ESP32 microcontroller circuit functions to process and analyse data from the light sensor, allowing it to be displayed on the OLED screen.
5. The display circuit functions to show the processed results from the microcontroller.
6. The Kodular circuit functions to wirelessly display the processed results from the microcontroller.

D. FLOWCHART PLANNING

Figure 7 explains the flowchart program in Arduino. When the ON/OFF button is pressed, the device will power on and perform initialisation, which is displayed on the LCD. Once the initialisation is complete, the MAX30102 sensor will measure the oxygen level in the blood. The generated data is then transmitted to the ESP32 microcontroller for processing into digital data, which will be displayed on the LCD. If the SpO2 value is below 95% for 1 minute, the buzzer will sound. The readings displayed on the LCD are also sent to the Kodular application on Android.

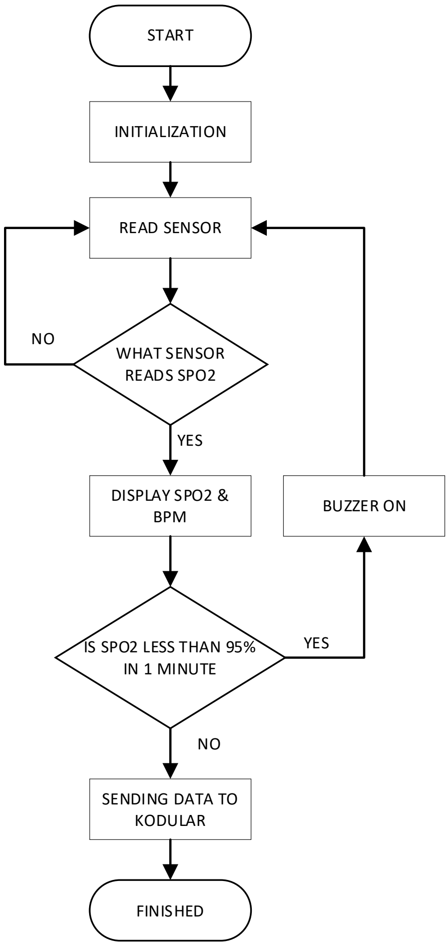

FIGURE 7. Flowchart

E. ELECTRONIC CIRCUIT DESIGN

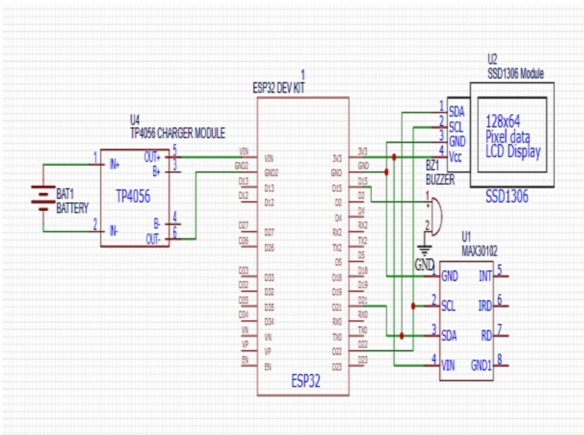

FIGURE 8. Pulse oximeter prototype circuit

In Fig. 8, there is a charging module for recharging the battery. The battery supplies a voltage of 3.7V to the ESP32. The ESP32 provides a 3.3V input voltage to the MAX30102 sensor, buzzer, and LCD. The MAX30102 sensor functions to read heart rate and oxygen saturation, utilising a red LED and an infrared LED as emitters and a photodetector as the signal receiver. The photodetector captures the reflected signals read by the

LEDs, and the results are then displayed on the LCD. If the SpO_2 value falls below 95% for 1 minute, the ESP32 activates the buzzer as an alarm.

F. DEVICE SPECIFICATIONS

The pulse oximeter prototype with Android monitoring has the following specifications:

1. Input Voltage: 3.7 VDC 1000 mAh Battery
2. Microcontroller: ESP32
3. Sensor: MAX30102
4. Alarm: 5V DC Buzzer
5. Display: 0.96-Inch OLED
6. Application: Kodular

G. DATA COLLECTION TECHNIQUES

After designing the module and the Kodular application, the next step is to compare the heart rate and oxygen saturation data obtained from the module via the Kodular application with a calibrated pulse oximeter. This comparison is conducted to verify whether the design and planning meet expectations. Data calculation is then performed to determine any necessary corrections for the module.

III. RESULTS AND DISCUSSION

In this chapter, the author will explain the results of the analysis and discussion of the developed module. At this stage, after the module has been completed, several measurements have been conducted. The author will present the data obtained from these measurements.

A. PHYSICAL FORM OF THE DEVICE

FIGURE 9. Module display

Fig. 9 shows the completed device, assembled according to the planned design.

The top view features an LCD that shows the measurement status. The bottom view includes a power on/off button to turn the module on and off. The back view has a buzzer for alarm activation and a micro-USB port for battery charging. The Kodular application displays the measurement status of heart rate and SpO_2.

B. DEVICE FUNCTION TESTING

Before conducting performance testing on the module and data analysis, a functionality test is required to ensure that each part of the device operates correctly. The result showed at Table III

TABLE III
DEVICE FUNCTIONALITY TEST

No.	Device Components	Test Results
1	ON/OFF switch	Functioning
2	Buzzer	Functioning
3	Sensor MAX30102	Functioning
4	LCD	Functioning
5	Charger module	Functioning
6	Battery	Functioning

The detailed explanation of the functionality test in Table III is as follows:

1. The ON/OFF switch functions properly, indicated by the device powering on.
2. The buzzer functions properly, indicated by a sound alarm when SpO2 is below 95% for 1 minute.
3. The MAX30102 sensor functions properly, indicated by the red LED lighting up.
4. The LCD functions properly, as it turns on when the device is first powered on.
5. The charging module functions properly, indicated by a blinking red light on the side of the device during charging.
6. The battery is functioning, indicated by the device powering on when the switch is set to ON.

C. STANDARD OPERATING PROCEDURE (SOP)

Standard Operating Procedure (SOP) is a set of written rules that regulate how a specific process or method should be carried out on a device. SOPs are designed to ensure measurement quality and device safety. The Standard Operating Procedure (SOP) for the designed device is as follows:

1. Press the ON switch to turn on the device.
2. Wait a few moments until the text 'Finger Please' appears.
3. Turn on Bluetooth on the Android tablet, open the Kodular application, select 'Connect Devices,' and choose 'ESP32_SpO2.'

4. Ensure your finger is clean, then open the pulse oximeter prototype and place one finger correctly on the sensor.
5. Wait a few moments; the heart rate and oxygen saturation readings will appear on the LCD screen.
6. The alarm will sound if SpO2 is below 95% for 1 minute. To turn off the alarm, remove your finger from the pulse oximeter prototype.
7. After use, open the Kodular application on the Android tablet and select 'Disconnect Devices.' Then, press the OFF switch on the pulse oximeter prototype to turn off the device.

C. TESTING AND DATA ANALYSIS

The module testing was conducted using a calibrated pulse oximeter as a comparison tool, specifically the Beurer brand, model PO30, with serial number 2022H12/002570. Each parameter was measured 10 times for SpO_2 and Heart Rate (BPM). The module measurements were taken on the researcher's right index finger, while the comparison device was placed on the right middle finger as shown in Fig. 10.

After measuring each parameter, the recorded data were documented. During testing, observations were made regarding the sensor's response to readings and potential differences in measurement results for each parameter. The recorded measurement data was processed using formulas to analyse the accuracy of the designed module. The results of this testing serve as an analysis to determine the accuracy percentage of the developed module.

FIGURE 10. Data collection activities

E. SPO2 DATA COLLECTION

Data collection was carried out by comparing the SpO2 measurement results of the reference device with the SpO2 measurements from the module. The results showe in Table IV.

TABLE IV
SPO2 MEASUREMENT RESULTS

Data Collection No. -	Measurement Results (%)		Error / Correction
	Comparison Device	Module	
1	96	97	1
2	97	99	2
3	97	99	2
4	96	99	3
5	98	98	0
6	97	90	7
7	97	99	2
8	98	97	1
9	97	97	0
10	97	97	0
Average	97	97,2	1,8
% Error	1,85%		
% Accuracy	98,15%		

In Table IV, SpO2 measurement results table, a comparison between the reference device and the module shows an accuracy of 98.15% and an error of 1.85%. The SpO2 readings are sometimes unstable, influenced by finger movement and improper finger positioning on the sensor.

F. HEART RATE DATA COLLECTION

Data collection is carried out by comparing the heart rate measurement results of the reference device with the heart rate measurement results of the module as shown in Table V.

TABLE V
HEART RATE MEASUREMENT RESULTS

Data Collection No. -	Measurement Results (BPM)		Error / Correction
	Comparison Device	Module	
1	68	65	3
2	69	72	3
3	64	61	3
4	65	67	2
5	73	61	12
6	69	55	14
7	72	68	4
8	68	63	5
9	71	64	7
10	66	57	9
Average	68,5	63,3	6,2
% Error	9,79%		
% Accuracy	90,21%		

In the heart rate measurement results table, a comparison between the reference device and the module shows an accuracy of 90.21% and an error of 9.79%. The heart rate readings are sometimes unstable due to finger movement and improper finger positioning on the sensor.

G. KODULAR CONNECTION TESTING

The results of Kodular testing are shown in Table VI. It can be seen that there is no delay time for sending data.

TABLE VI
OBSERVATION OF DATA TRANSMISSION TIME ON AN ANDROID TABLET

Data Collection No. -	Stopwatch (Seconds)	Sent Time (Seconds)
1	0,81	0,81
2	2,52	1,71
3	4,41	1,89
4	6,44	2,03
5	8,40	1,96
6	10,43	2,03
7	12,53	2,10
8	14,56	2,03
9	16,40	1,84
10	18,50	2,10
Average time of data transfer from the module to the Android tablet		1,85

H. CONCLUSION

This study successfully developed a pulse oximeter prototype integrated with an Android-based application for real-time monitoring. The system's hardware and software components functioned effectively, enabling accurate physiological data acquisition and wireless transmission. Validation results showed that the prototype achieved an oxygen saturation (SpO_2) measurement accuracy of 98.15%, with a mean error rate of 1.85% when compared to a calibrated reference device. Heart rate measurements yielded a lower accuracy of 90.21%, corresponding to an error rate of 9.79%. The average data transmission time from the device to the Android tablet was 1.85 seconds per transmission, demonstrating satisfactory performance for real-time monitoring applications. These findings indicate that the proposed system holds promise for portable health monitoring, especially in remote or resource-limited environments, although further refinement is needed to enhance heart rate measurement accuracy.

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