**REPUBLIC OF TURKEY**
**ISTANBUL GELISIM UNIVERSITY**
**INSTITUTE OF GRADUATE STUDIES**

Department of Electrical and Electronics Engineering

# A COMPARATIVE STUDY FOR REAL TIME AND REMOTE HEART-RATE MEASUREMENT USING MAX30100 AND PULSE SENSOR BASED DEVICES

Master Thesis

**Peter Chidubem IBE**

Supervisor
Asst. Prof. Dr. Mehlika KARAMANLIOĞLU

**Istanbul – 2023**

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**Turkish Abstract** : Bu çalışmada, iki farklı kalp atış hızı sensörünün etkinliğini, doğruluğunu ve güç tüketimini etkili bir şekilde karşılaştırmak için iki farklı sensör içeren iki cihaz tasarlamayı amaçladık. Kullanılan sensörler MAX30100 ve Puls Sensör olup; Wi-Fi özellikli ESP32 Mikrodenetleyici, SD kart modülü, LCD ve alarm sistemi bu sensörlerle birlikte cihazların yapımında kullanılmıştır. Verilerin doğruluğunu analiz etmek için standart sapmalar hesaplanarak karşılaştırılmıştır. IoT platformu olan Blynk uygulaması, sensör ölçümlerini biyotelemetri uygulaması olarak Wi-Fi ile uzaktan izlemek için kullanılırken, anormal bir kalp atış hızında kişiyi uyarmak için bir zil de sisteme eklenmiştir. İki sensör tabanlı cihazın veri analizi, daha düşük bir standart sapma değerine sahip MAX30100'ün, daha yüksek bir standart sapma değerine sahip olan Puls Sensör'e kıyasla daha yüksek doğruluğa sahip olduğunu göstermiştir. MAX30100 içeren cihazın ölçümleri ise piyasadaki nabız oksimetre cihazına daha yakın çıkmıştır. Böylece iki sensör tabanlı cihazdan elde edilen sonuçlar, MAX30100 içeren cihazın Puls Sensor içerene göre daha güvenilir olduğunu, Puls Sensör'ün ise MAX30100'den daha az güç tükettiğini göstermiştir. Sonuçlar MAX30100 sensörlü cihazın biyomedikal parametrelerin kontrolü konusunda Puls Sensör'den bakım noktası (POC) testi için daha etkili olduğunu göstermektedir.

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*Peter Chidubem IBE*

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## DECLARATION

I hereby declare that in the preparation of this thesis, scientific, ethical rules have been followed, the works of other persons have been referenced in accordance with the scientific norms if used, there is no falsification in the used data, any part of the thesis has not been submitted to this university or any other university as another thesis.

Peter Chidubem IBE

01.06.2023

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The thesis study of Peter Chidubem IBE titled as A Comparative Study For Real Time and Remote Heart-Rate Measurement Using MAX30100 and Pulse Sensor Based Devices has been accepted as MASTER in the department of Electrical-Electronic Engineering by out jury.

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**SUMMARY**

Heart-rate monitoring is essential for diagnosing cardiovascular diseases. This research covers a comparative study for real time and remote heart-rate monitoring using ESP32 Development Board. Two sensor-based heart rate monitoring devices were designed for biomedical applications and their measurements were compared to a commercial pulse oximeter device. Devices developed in this research have both software and hardware components.

The hardware part includes the electronic and non-electronic solid materials used in the design and construction: MAX30100, Pulse Sensor, ESP32, 16x2 LCD, Buzzer, 3.7 V Lithium Battery, Veroboard, Switch, Powerbank Module, SD card module, 2G SD card. The ESP32 microcontroller reads and interprets signals from the sensors and communicates with every electronic component in the system. The MAX30100 and the Pulse Sensor are the two sensors that measure heartbeat per minute. The 16x2 LCD is used as a screen to display the pulse measurements. The SD card module with a 2G memory card stores the heart-rate in Excel sheet format *(.csv)*. Two 3.7 V lithium-ion batteries were used to supply power to each device. The Buzzer was used as an alarm in case of an abnormal rate. All the electronic components were soldered on the vero using soldering lead and female pin headers.

The software part includes Blynk Application and Arduino Integrated Development Environment (IDE). The Blynk app, an online IoT platform, was used to remotely monitor the heart-rate from the MAX30100 and Pulse Sensor-based devices via Wi-Fi built-in ESP32 for potential biotelemetry applications. The Arduino IDE is an open-source platform used to compile the sketches for the ESP32 microcontroller board. The standard deviation is calculated to analyze the data in the SD card.

The results showed that the biomedical device with MAX30100 sensor had better reliability than the Pulse Sensor, while the Pulse Sensor consumed less power than the MAX30100. The results also showed that the MAX30100 sensor is more effective than the Pulse Sensor since standard deviation of MAX30100 based device is lower and measurements of MAX30100 are closer to a commercial pulse oximeter device.

**KEYWORDS:** MAX30100, Pulse Sensor, ESP32, Biotelemetry, IoT, Blynk, Biomedical

# ÖZET

Nabız izleme, kardiyovasküler hastalıkların teşhisi için gereklidir. Bu araştırma, ESP32 Geliştirme Kartı kullanarak gerçek zamanlı ve uzaktan nabız izlemek için karşılaştırmalı bir çalışmayı kapsamaktadır. Bunun için biyomedikal uygulamalarda kullanılmak üzere iki farklı sensör tabanlı kalp atış hızı izleme cihazı tasarlanmıştır ve bu cihazların ölçümleri piyasada bulunan nabız oksimetresi ile karşılaştırılmıştır. Bu araştırmada yapılan cihazlarda hem yazılım hem de donanım kısımları bulunmaktadır.

Donanım kısmı, tasarım ve yapımda kullanılan elektronik ve elektronik olmayan malzemeleri içermektedir: MAX30100, Puls Sensörü, ESP32, 16x2 LCD, zil, 3,7 V Lityum Pil Veroboard, Switch, Powerbank Modülü, SD kart modülü, 2G SD kart. ESP32 mikrodenetleyicisi, sensörden gelen sinyalleri okuyup yorumlamaktadır ve sistemdeki diğer tüm elektronik bileşenlerle iletişim kurmaktadır. MAX30100 ve Puls Sensörü, dakikada kalp atışını ölçen iki sensördür. 16x2 LCD, nabız ölçümlerini görüntülemek için ekran olarak kullanılmaktadır. 2G bellek kartlı SD kart modülü, kalp atışı okumalarını Excel sayfa biçiminde (.csv) depolamaktadır. Her bir cihaza güç sağlamak için iki 3,7 V lityum iyon pil kullanılmıştır. Zil, anormal bir kalp hızı durumunda çalışacak bir alarm olarak kullanılmıştır. Tüm elektronik bileşenler, lehimleme kurşunu ve dişi pin başlıkları kullanılarak vero üzerine lehimlenmiştir.

Yazılım kısmı, Blynk Uygulaması ve Arduino Entegre Geliştirme Ortamı (IDE) içermektedir. Çevrimiçi bir IoT platformu olan Blynk uygulaması, kalp atış hızını MAX30100 ve Puls Sensörü tabanlı cihazlardan ESP32'nin Wi-Fi özelliği ile potansiyel biyotelemetri uygulamalarında uzaktan izleme amacıyla kullanılmıştır. Arduino IDE, ESP32 mikrodenetleyici kartı için kullanılan açık kaynaklı bir platformdur. Standart sapma, SD karttaki verileri analiz etmek için kullanılmıştır.

Sonuçlar, MAX30100 sensörü içeren biyomedikal cihazın, Puls Sensörü içerene göre daha güvenilir olduğunu, Puls Sensörün ise MAX30100'den daha az güç tükettiğini göstermektedir. Sonuçlar aynı zamanda MAX30100 sensörünün, Puls Sensöre göre daha etkili olduğunu da ortaya koymaktadır çünkü MAX30100 cihazının verileri arasındaki standart sapma daha düşük olup, ölçümleri piyasada bulunan nabız oksimetre cihazına daha yakın çıkmıştır.

**ANAHTAR KELİMELER:** MAX30100, Puls Sensörü, ESP32, Biyotelemetri, IoT, Blynk, Biyomedikal

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# ABBREVIATIONS

| | | |
|---|---|---|
| **IDE** | **:** | Integrated Development Environment |
| **IoT** | **:** | Internet of Things |
| **LCD** | **:** | Liquid Crystal Display |
| **LED** | **:** | Light Emitting diode |
| **SD** | **:** | Secure Data |

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# PREFACE

In the course of this project writing and preparations,i would like to express my sincere gratitude to God almighty for his favours. To my wife, Mrs Maureen Chiamaka Peters and my kids Jayden Peters and Uriel Peters for their daily support and prayers. Special thanks to my Asst Prof Dr Mehlika KARAMANLIOĞLU for her invaluable support from start to the finish of the entire project.I would like to thank my friend Victor Efrune also for always encouraging me throughout this work.

# INTRODUCTION

Cardiovascular diseases have been one of the leading causes of death worldwide. Therefore, continuous heart rate monitoring can be necessary for an early diagnosis of a cardiovascular disease. Moreover, continuous heart rate monitoring can be necessary for athletes as well. There are biomedical devices to continuously monitor electrocardiograms, i.e., electrical signals of the heart and pulse. However, these devices, such as Holter Monitors, are not readily accessible and can be challenging to use. Therefore, there is a need for a simple, accurate, user-friendly, and low-cost heart rate monitor (HRM) device that can be used as a point-of-care (POC) testing system. Different sensors in POC devices are used extensively since they can carry out measurements non-invasively.

In the proposed study, we aim to compare two different heart rate sensors, MAX30100 and Pulse Sensor, for two HRM devices. These devices' effectiveness, reliability, and power consumption are compared. ESP32 board with built-in Wi-Fi is used as the microcontroller. The proposed device will store and transfer the data for remote monitoring and will be implemented with an alarm system to alert the user promptly in case of excessive heart-rates. This system can be used by risk groups with cardiovascular diseases, athletes, and anyone who wants to monitor their heart rates.

# CHAPTER ONE

# PURPOSE OF THE THESIS

## 1.1. Background of the study

Monitoring vital biomedical signs in humans, such as heart-rate, is a crucial aspect of healthcare, both in clinical settings and at home (Athavale & Krishnan, 2017). Heart-rate monitoring has emerged as a convenient and accessible way to monitor physiological activity, and therefore, heart-rate monitoring sensors have gained widespread popularity. Non-invasive sensor-based devices can measure biomedical parameters in humans without piercing the body or using implants or surgical procedures. Due to non-invasive devices' availability and ease of use, getting physiological parameters has become much easier.

Continuous heart-rate monitoring devices are designed for comfort and can be easily worn every time to detect abnormal cardiovascular signs. Continuous heart-rate monitoring also helps get a comprehensive view of the situation of the heart both at rest and during physical activity (Linden et al., 1997). In case of hemodynamic, respiratory or neurologic distress, continuous heart-rate monitoring for cardiac issues is necessary.

Technological advancements greatly impacted the development of heart-rate monitoring devices due to the availability of advanced and sophisticated microcontrollers like the ESP32 Board and the Internet of Things (IoT). Developing real-time and remote monitoring systems have been made possible. Remotely monitored sensors and sensor-based devices like heart-rate monitoring system have been made user friendly. Recently, there has been an increase in using IoT devices to monitor physiological parameters.

The Internet of Things, or IoT, provides unique identities to interrelated computing devices, machines, objects, and animals with the ability to transfer data over a network without requiring human interaction (Alexander n.d). IoT devices range from simple sensors to sophisticated systems with broad industrial applications in healthcare, transportation, and manufacturing.

The ESP32 Board is a low-cost and powerful microcontroller-wide application in IoT due to its WIFI and Bluetooth connection capabilities and low-power consumption. The ESP32 Board is one of the latest technology for IoT systems and has various applications, including heart-rate monitoring. The ESP32 Board provides a range of connection options making it a suitable platform for real-time and remote heart-rate monitoring. Using the Secure Data (SD) card module to store data is an age-long practice in embedded systems. The signal from the sensor or other input sources is read by the microcontroller and is stored in an SD card through the SD card module in a readable format. This data can be collected with the help of a card reader for different purposes like analysis or to be displayed on Liquid Crystal Display (LCD).

### 1.2. Problem Statement

The outbreak of COVID-19 and other cardiovascular diseases have made heart-related diseases one of the main causes of human death worldwide. Therefore, there is a need to continuously monitor the heart for an early diagnosis of heart-related diseases. Regular heart rate monitoring is beneficial for athletes, as the state of their heart is essential during exercises (Goffart et al., 2004). Though there are biomedical devices to continuously measure the heart-related parameters such as the electrical signal of the heart and the heart rate, the availability, cost and ease of use of these devices are also essential factors to be considered.

Science and technology advancements have led to the development of many sensor-based heart rate monitoring devices (Ghamari, 2018). Therefore, there is a need to examine and compare heart rate monitoring devices' accuracy, effectiveness, and power consumption. These devices' effectiveness, accuracy, and power consumption have not been studied extensively to assist patients and healthcare practitioners.

This study compares two different heart rate sensors, MAX30100 and Pulse Sensor, for their effectiveness, accuracy and power consumption using the ESP32 Board. Comparative tests are carried out under the same conditions to determine which sensor is more suitable and have a comparative advantage.

### 1.3. Aims and Objectives

The aims of this study are:

- To develop two real-time and remote heart-rate monitoring systems: The first device will include an ESP32 Board, MAX30100 Sensor, Blynk IoT App, Buzzer, Liquid Crystal Display

(LCD), and an SD card module. In the second device, the same components will be used. However, Pulse Sensor will be used instead of MAX30100.

- To compare the accuracy, efficiency, and battery life of the heart-rate measurements obtained from MAX30100 and Pulse Sensors in real-time and remote monitoring scenarios.
- To determine the most accurate and efficient device for continuous heart rate monitoring that can be used as a point-of-care (POC) testing system.

This research aims to suggest a better-sensor-based non-invasive heart rate monitoring system between MAX30100 and Pulse Sensor. The favourable device will be determined by comparing the efficiency, performance, and power consumption of the two heart rate sensors. Standard deviation will be used for comparisons. Sensor readings will be streamed on a Blynk App to monitor the patients' real-time heart rate parameters remotely.

## 1.4. Importance of the study

There are several reasons why researching and comparing different heart-rate sensors for accuracy, effectiveness and power consumption are essential:

- Continuous and real-time heart rate monitoring can be necessary for an early diagnosis of cardiovascular diseases and also can be necessary for athletes.
- Knowing the efficiency, capacity, and power consumption of different sensor-based heart rate monitoring devices can help in accurate heart rate monitoring. A heart rate monitoring device with more efficiency will offer more accurate readings, which is crucial for precise heart rate monitoring for athletes or individuals with certain medical conditions.
- A heart rate monitoring device's capacity and power consumption can help understand how long the device can operate before recharging. These capacity and power life can be significant when the device is used for extended periods, such as during a long workout or race.
- Understanding the efficiency and capacity of a heart rate monitoring device can help determine if the device is cost-effective. A less efficient or lower-capacity device may be less expensive but not provide the accuracy or longevity needed.
- This study compares two heart-rate sensors, MAX30100 and Pulse Sensor, to determine the better-sensor-based non-invasive heart rate monitoring system.

- The study aims to suggest a simple, low-cost, user-friendly and power-efficient POC testing system for heart-rate monitoring. This system will also store the data and transfer the data as a biotelemetry device, differentiating the system from smart watches and pulse oximeters on the market.
- Overall, the findings of this study will provide insights into the comparative effectiveness of MAX30100 and Pulse sensors in real-time and remote heart-rate monitoring. These will help healthcare professionals and researchers to make informed decisions when selecting heart-rate sensors for monitoring patients remotely and/or in real-time, mainly when using MAX30100 and Pulse sensor-based monitoring devices. It will also help to determine which of the two sensors, MAX30100 and Pulse sensor-based devices, has better battery life under the same conditions. Also, the research will develop heart-rate monitoring devices with more user-friendly properties, accuracy, and reliability.

### 1.5. Scope of the Research

The scope of this research involves a comparative study of two different devices containing heart-rate sensors for accuracy, effectiveness and power consumption using the ESP32 board. The work focuses exclusively on comparing the MAX30100 and Pulse Sensors, widely used in heart-rate monitoring devices.

The research covers design and construction of two sensor-based heart-rate monitoring systems using the ESP32 Board as the microcontroller with built-in Wi-Fi and 3.7 V lithium-ion battery as the power source and MAX30100 Sensor and the Pulse Sensor. The two systems are designed to give readings in both real-time and remote. The two systems' accuracy, reliability and battery life will be compared.

Volunteers participated for testing of the devices and the results are evaluated to determine the performance of the two devices with different sensors. Standard deviation was calculated for quantitative evaluation.

### 1.6. Key Research Contributions

The critical research contributions of this study can be summarized below:

- This study provides a comparative analysis of two devices with different heart-rate sensors. MAX30100 and Pulse Sensors are evaluated in terms of their accuracy, effectiveness, and battery life, providing insights into their comparative effectiveness.
- The study involves the development of heart-rate monitoring systems to monitor measurements in real-time and remote monitoring scenarios. Real-time monitoring is where the health care practitioner can monitor the patient's heart parameters simultaneously with the measurements. In remote monitoring, the patient's heart parameters are transmitted to the health care practitioner remotely with the help of wireless communication protocols like WI-FI or Ethernet. Remote monitoring does not need the patient in the medical facilities. Biotelemetry uses technology to remotely monitor and transmit physiological data from patients to healthcare providers for diagnostic purposes. This technology allows healthcare professionals to monitor a patient's vital signs, such as heart rate, blood pressure and breathing rate from a distance. Biotelemetry uses IoT technology to transmit data and biomedical parameters to a healthcare practitioner through a remote terminal. It is highly employed in cardiology, sleep medicine, cardiology and a remote patient monitoring aspect of a health care practice. Biotelemetry devices come in the form of wearable sensors or implanted devices where data can be remotely transferred from source to monitoring point or cloud platform. Benefits of biotelemetry include improved patient outcomes, reduced hospital admissions, and increased efficiency and cost-effectiveness of healthcare delivery.
- The results of this study would be helpful for healthcare professionals and researchers to make informed decisions about selecting heart-rate sensors for monitoring patients as the health practitioner can readily know which sensor-based heart rate monitoring device has the highest accuracy, is more effective, and has better battery life.
- This study will contribute to technological advancements since heart-rate monitoring systems that utilize the ESP32 Board, a popular platform for IoT devices, are developed. This study offers insights into the potential effect of IoT devices on the development of cost-effective heart-rate monitoring systems and healthcare practice.
- The results of this study would improve healthcare by providing insights into the comparative effectiveness of different heart-rate sensor based devices. Healthcare professionals and researchers would develop better heart-rate monitoring systems to improve patient care and reduce healthcare costs.

### 1.7. Thesis Outline

The remainder of this research is arranged as follows:

Chapter One covers the study background, the purpose, the problem statement, aims and objectives, importance, the scope of the work and the critical contributions of the thesis.

In the Second Chapter, we offer an overview of the heart-rate sensor monitoring systems, the literature review, the theoretical foundation and other aspects of the heart-rate sensor monitoring systems. The materials and communication system used in the work are discussed. Additionally, components used in this research are compared with the literature.

Chapter Three presents the methodology of the thesis. The signal and logic flow is explained using block diagrams, circuit diagrams and flow charts. The step-by-step procedures of how the ESP32 Board is connected with MAX30100, Pulse Sensor, LCD buzzer, and SD card module is explained. It also covers how to stream the data from the sensors on the Blynk IOT platform and display on LCD. Furthermore, it explains using the standard deviation to analyze data stored on SD cards.

Chapter Four covers the test results. Here we itemize how to test the devices and how to evaluate the obtained results. Results are analyzed and discussed. Devices are compared with a commercial pulse oximeter.

Finally, Chapter Five gives the conclusion of the analysis of this study along with recommendations for future work.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1. Introduction

The heart is an essential organ in the cardiovascular system and it is the organ that distributes blood through the human body via the circulatory system (The Heart | NHLBI, NIH, 2022). The volume of blood pumped depends on the heart's rate; hence it is necessary to monitor heart-rate which is the detection of how often the heart beats in one minute, i.e., beats per minute (bpm).

The history of circulatory system monitoring dates back to the early 18$^{th}$ Century when Santorio developed the first device to measure pulse rate which was a simple pendulum that recorded the heartbeat per minute (De Grijs & Vuillermin, 2017). Karl Von Vierordt, 1854, invented sphygmograph as a non-invasive blood pressure measurement device and then, this device was improved to magnify the pulse waves (Dudgeon, 1882). Electrocardiograph was developed as a string galvanometer in 1901 which revolutionized heart monitoring. Electrocardiography is a test that measures the electrical activity of the heart along with pulse and is now widely used in medicine for heart-related diagnosis (Electrocardiogram (ECG or EKG) - Mayo Clinic, 2022).

There has been an increased development of more accurate and user-friendly devices to monitor heart-rate as a result of technological advancements. There are wearable devices, smart watches, etc., which operate through IoT.

### 2.1.1. Importance of Heart Rate Monitoring

Heart-rate monitoring is of immense importance in the sense that it helps in the early detection of any cardiovascular diseases which are the diseases of the blood vessels and the heart. Conditions like hypertension, heart failure and arrhythmias can easily be monitored as changes in heart-rate which can indicate other underlining conditions. Monitoring can help identify potential complications or the need for further medical intervention.

Heart-rate monitoring also helps athletes to determine their heart condition during exercise. Heart-rate monitoring determines exercise intensity for an athlete to operate within their expected heart-rate threshold. Heart rate monitoring is also helpful in tracking sleep to provide insight into an individual's sleep order and general health. Heart-rate undergoes several cardiovascular changes during sleep; therefore, adequate monitoring can help diagnose some health conditions and sleep disorders.

Heart rate monitoring can also useful in stress management. The monitoring helps individuals be conscious of their physiological stress response and aware of the activities that can trigger stress. According to research, some biofeedback machines use a heart rate monitor to help individuals become more aware of their heart rate and, therefore, help control their physiological responses (Biofeedback - Mayo Clinic, 2023). It effectively reduces stress and anxiety levels in people with an individualized anxiety disorder (Biofeedback - Mayo Clinic, 2023).

### 2.1.2. Point-of-Care-Testing

Point-of-Care-Testing (POCT), also known as bedside testing, near-patient testing and rapid diagnostics, is a form of testing in which the analysis is done where health care is provided close to the patient and no sophisticated laboratory equipment is required. POCT is very useful as medical care progresses to prevention, early detection and chronic condition management. POCT provides results in real-time, allowing for quicker diagnosis and treatment decisions to be carried out. It can also reduce the need for follow-up and in-medical facility testing, which can save costs for both patients and providers as the patient can be remotely monitored with the help of IoT systems. A handheld pulse oximeter device is an example of POC. This POCT device measures vital signs like heart rate and oxygen saturation in patients with respiratory and cardiac conditions.

There has been tremendous advancements regarding using POCT in heart rate monitoring. Osborn et al. (2019) conducted a study to determine the accuracy and precision of two POCT devices for the assessment of hemoglobin along with pulse rate. They concluded that both POCT devices tested in their study were accurate (Osborn et al., 2019).

### 2.1.3. Biotelemetry

Biotelemetry (or medical telemetry) transmits biomedical data from one place to another to remotely monitor vital biomedical signs (Güler et al., 2002). The most common operation for biotelemetry is in cardiac care telemetry units or step-down units in hospitals. Although nearly any physiological signal could be transmitted, biotelemetry is generally used in cardiac monitoring and blood oxygen saturation ($SpO_2$) analysis. The devices can be wearable or attachable. The history of biotelemetry systems is dated back to the 20th Century in spaceflights, where physiological signals from passengers were transmitted back to Earth for analysis (Wikipedia contributors, 2022)

The use of biotelemetry for heart rate monitoring in clinical infrastructure is very effective in detecting heart rate changes and alerting healthcare providers of potential cardiac situations. Biotelemetry also allows continuous monitoring of people with medical conditions and provides information more improved than traditional methods.

According to a study on the efficiency of biotelemetry for data transmission, it was found that people with Chronic Obstructive Pulmonary Disease, COPD, can be monitored remotely; however, results should be interpreted with caution (Nagase et al., 2022 ).

Due to technological innovations being adopted into our everyday life, the use of software and hardware devices to manage health has dramatically increased. Intelligent electronic devices can be wearable as accessories or ingrained into clothes. These can be smartwatches, rings, wristbands, etc., with high processing ability. Heart rate monitoring devices can also come in wearable technology like wristwatches and bracelets, making them more accessible. These devices rely on modern technology and high-speed processors to read heart rate levels with the help of embedded sensors. They either display the value on the screen or transmit data to an online platform.

### 2.1.4. Internet of Things (ToT)

The Internet of Things (IoT) is a technology that allows devices like electronic systems to be added to an inert object, whereby environmental data can be generated. The data can be transmitted in a communication protocol  (What Is the Internet of Things? | DeVry University, n.d.). IoT can connect wearable and non-wearable devices with embedded sensors and screens to monitor heart rate and the data transmitted to an online platform in a local or vast area network. With IoT-enabled devices, it is easy for patients to monitor their heart rate and remotely transmit the data to their healthcare personnel for prompt intervention.

A study evaluated the accuracy of smartwatch-based IoT devices in monitoring heart rate during physical activity and it was concluded that the devices were reliable and accurate in providing real-time data that could be used in monitoring and adjusting physical activity levels of patients with heart conditions (New Study Show Popular Smart Watches Accurately Measure Rapid Heart Beat, n.d.).

Many studies investigated the sensitivity of different sensors for non-invasive ECG monitoring. One review by Bayoumy et al. (2021) highlighted the basic engineering principle of wearable sensors and how they are prone to error. They also evaluated the role of these devices in the remote monitoring of cardiovascular cases (Bayoumy et al. 2021). They finally concluded that many challenges, such as the devices' validity and accuracy, affect wearable technology to be used in clinical practice and recommended the gradual introduction of such devices into healthcare practice (Bayoumy et al. 2021).

Castaneda et al., (2018) has a comprehensive review of wearable photoplethysmography (PPG) sensors and how they can be incorporated into healthcare. They studied advancements in PPG sensor devices and outlined their potential in monitoring biomedical parameters like blood oxygen saturation, heart rate, and blood pressure (Castaneda et al., 2018c).

Another report presented by Rahman et al. (2021) studied the use of the ESP32 microcontroller board due to the availability of onboard Wi-Fi as a modern IoT tool and developed a system that can be used remotely for ECG and heart rate signals. They focused on wireless setup communication using an ESP32 board to transmit real-time ECG and heart rate data (Rahman et al. 2021).

Priyanka and Reji (2019) worked on biomedical parameters monitoring in the healthcare system using the Blynk Application. They focused on creating communication between the Blynk Application, ESP32 and the heart-rate monitoring sensor (Priyanka and Reji 2019). The communication they created between the Blynk app and the ESP32 board was used to track and monitor biomedical parameters like blood pressure, temperature, and heartbeat and they displayed the values obtained on the Blynk Application for monitoring and analysis (Priyanka and Reji 2019).

## 2.2. Components Used in this Research

Many components are used in this study which include software and hardware.

### 2.2.1. Software:

- Arduino IDE
- Blynk platform

### 2.2.2. Hardware:

- ESP32,
- LCD
- MAX30100
- Pulse sensor
- Lithium-ion battery
- Buzzer
- SD card module

## 2.3. Standard Deviation

A standard deviation is a statistical tool that explains how to spread a set of values from their mean. It is the square root of the variance, which measures the mean square deviation. A lower standard deviation suggests that the data points are not far from the mean, but a higher standard deviation shows that the dataset is from the mean.

The standard deviation has applications in many fields like economics, natural sciences. It is helpful for researchers in testing the consistency, accuracy, reliability, and precision of data.
This research uses the standard deviation to evaluate the datasets from MAX30100, the Pulse Sensor, and Pulse Oximeter for accuracy. The standard deviation of the values from each device at specific measurements is compared to predict a more accurate device between MAX30100 and the Pulse Sensor.

#### 2.2.1.1 Blynk

Blynk is a platform that can operate on many hardware modules such as Arduino, ESP, Raspberry Pi, and many other devices with Android and IOS apps (Blynk). It allows developers to easily create custom mobile and web applications to control IoT devices (Introduction - Blynk Documentation, n.d.).

Martínez and Manrique carried out a study evaluating using the Blynk platform-based mobile application for remote heart rate conditions in patients with heart conditions. In the study, the mobile software was shown to monitor real-time data of the heart rate, which allowed professionals to monitor the patients remotely (Martínez & Manrique, 2020)

#### 2.2.1.2 Arduino Integrated Development Environment (IDE)

Arduino Integrated Development Environment (IDE) or Arduino software is an open-source platform for writing and compiling sketches (code) for Arduino microcontroller boards. It is preloaded with Arduino boards. It can also be post-loaded to program boards like ESP32, STM, etc., classified as unofficial third-party boards. The software is user-friendly, easy to navigate, and has a library with example sketches and embedded functions that can be used to control various sensors and components.

The IDE supports simplified programming language based on C/C++, making it easier for even beginners to use. The IDE comes embedded with sensor and components plugins, making it flexible for robotics, home automations, and the Internet of Things (IoT).

#### 2.2.2.1 MAX30100

MAX30100 has two Light Emitting Diodes (LEDs), integrated pulse oximetry, and a heart-rate sensor. It measures both pulse rate shown in beat-per-minute (bpm) and blood oxygen saturation ($SpO_2$ ) as a percentage. In general, its readings may range from 60 to 100 bpm for pulse; and 80-100% for $SpO_2$ (Suprayitno et al., 2019). It has an LED driver, a photodetector, and an analog front-end (AFE). The LED driver controls and determines the diodes emit the amount of light, and the photodetector captures the light that passes through the tissues. AFE amplifies the signal filtered by the photodetector to a digital form that a microcontroller can process. The sensor measures changes in light absorption caused by blood flow and uses an algorithm to calculate heart rate based on these changes.

Huang and Guo (2021) designed and implemented a pulse oximeter to display $SPO_2$ and pulse rate values using MAX301000. The results were compared with standard equipment for accuracy, and they observed that $SpO_2$ had an error percentage of 0.81% while BPM had an error of 0.87% (Huang & Guo, 2021).

#### 2.2.2.2 Pulse Sensor

A pulse sensor is a detector that monitors blood volume changes when the heart pumps blood. This sensor uses the photoelectric method, which involves both transmission and reflection of optical sensors for heart rate monitoring. The transmission type measures the pulse wave when it emits light and detects changes in blood flow when the heart pumps blood. This method has limitations as it can be significantly affected by external light. In contrast, the optical type is based on the amount of light reflected when a light ray shines on the surface.

#### 2.2.2.3 Battery

The life span of a battery is a significant factor of consideration when it comes to heart rate monitoring devices. For accuracy, these devices must always be ON for continuous monitoring and data transmission, especially where the data is averaged over time. Longer battery life is necessary for more prolonged use and is preferable due to batteries' negative environmental impact when they are disposed of. The life span or durability of the battery capacity is always affected by the frequency of use, the type of battery and the intensity of monitoring. The durability, life span, and dense energy level make lithium-ion batteries readily used in heart rate monitoring.

A study by Zhang et al. (2021) defined lithium-ion batteries' State of Health (SOH) as their ability to store charge. In their report, they suggested that there is a need for accurate monitoring of the SOH of the battery to allow for maximum utilization; and they also point out that the key to prolong the battery is to estimate its SOH accurately (Zhang et al. 2021).

Using lithium-ion batteries with higher energy life can extend the battery life of heart-rate monitoring devices. The battery capacity cycle is the number of charges and drains it can go in its lifetime. According to a report, a battery with an energy density of about 350 Wh/kg retained 75% of its capacity over 600 cycles (Lavars, 2021).

#### 2.2.2.4 Wi-Fi

The Wi-Fi communication protocol is a wireless network whereby devices can connect to exchange or transmit data within a network. It creates an internet piconet for exchanging information without a physical connection. It works with the help of radio waves to exchange data. The data is exchanged by sensing data to the router. According to IEEE; the most frequently used Wi-Fi protocol is IEEE 802.11 (Sookdeo, 2023). Wi-Fi is an essential part of remote heart rate monitoring for IoT. In heart-rate devices, the data acquired from sensors can be transmitted through Wi-Fi to a platform or database.

In conclusion, it is observed research has been done in the aspect of heart-rate monitoring with different sensors. These sensors range from MAX30100, Pulse Sensor, AD8232, etc., with different results and effects. These sensors were also used in different platforms for different patients.

Also, different communication protocols like Wi-Fi, Bluetooth, ZigBee, Radiofrequency (R.F.), etc., were used in heart-rate monitoring devices. The use of Wi-Fi protocol in remote heart-rate monitoring has been the dominant transmission protocol due to its reliability, speed, and widespread availability. It is also widely available in hospitals, homes, and public places.

Furthermore, IoT in heart-rate monitoring systems has also been well studied as it allows for remote and continuous data monitoring. Though it has its limitations in power consumption and requiring sophisticated technology to operate, its advantages have outweighed its demerit. Therefore, it is suitable for remote monitoring.

However, this research aims to compare the effectiveness, battery life, and accuracy of MAX30100 and Pulse Sensor-based devices. Therefore, the two sensors are used to design and construct two different heart rate detection devices. These devices are tested and the data acquired is saved on an SD and stream, Blynk platform and displayed on LCD. The different data acquired from the devices are then analyzed using the standard deviation to compare their effectiveness, accuracy and battery life.

# CHAPTER THREE

# MATERIALS AND METHODS

This chapter is divided into materials and methods. The materials used are comprised of hardware and software.

## 3.1. Hardware Materials

Several hardware materials are used to design and construct the two heart rate monitoring devices. They are ESP32, MAX30100 sensor, Pulse Sensor, 16x2 LCD, Buzzer, Lithium-ion batteries, power bank module, switch, and micro SD card module.

### 3.1.1. ESP32 Board

ESP32, among other boards by Espressif, is a sophisticated microcontroller designed for IoT applications. It is a system that contains many SoC (Systems on a Charge) with low cost and less power consumption modules. It is an upgrade on ESP8266 with inbuilt Wi-Fi and Bluetooth connections. In this study,Wi-Fi connection will be implemented.

The ESP32 Board also supports communication protocols like Message Queuing Telemetry Transport (MQTT), Constrained Application Protocol (CoAP ), and Hypertext Transfer Protocol (HTTP ), which makes integrating the Board with platforms and cloud services easy.
ESP32 has many General Purpose Input and Output (GPIOs) pins with various communication pins like I2C, SPI, UART, etc., inbuilt.

Serial Peripheral Interface is a four-wire communication protocol based on master and slave protocol. The protocols are;

Master-Out-Slave-In (MOSI) is the pin the master uses to communicate with the slave.

Master-In-Slave-Out (MISO) is the pin the slave uses to communicate with the master.

The serial Clock is the clock pin for signal synchronization between the master and the slave.

Chip Select (CS) pin is used to select the slave for communication and is done by turning the slave to a low signal.

Inter-Integrated Circuit (I2C) is a wired communication protocol available in an embedded system for communication between the slave and master using just two wires. The protocol is sometimes called two Two Wire. On the ESP32 board, these pins are Serial Data (SDA) (21) and Serial Clock (SCL) (22) and are used to communicate with slave components.

The ESP32 board is a 3-V board, meaning it operates with a voltage level of 3 V. The UART, SPI, and I2C pins can tolerate 5 V, meaning they can stand at the voltage level of 5 as against other GPIOs pins (Espressif Systems, 2017).

The Board can be programmed using a variety of languages and IDEs. Arduino IDE, a C++ language-based compiler, is used for this design and construction work. The ESP32 board should be installed to the Arduino IDE to program it since it is a third-party board.

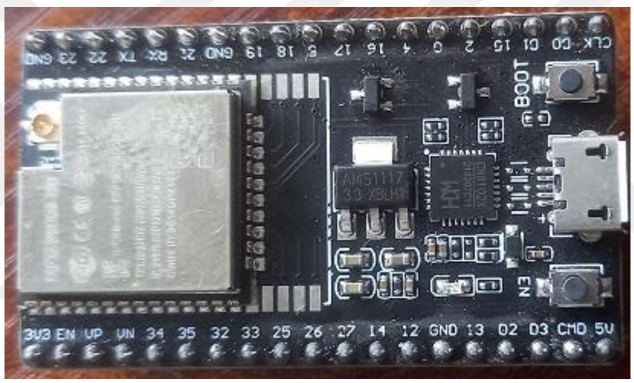


**Figure 1.** ESP32 Microcontroller Board

### 3.1.2. MAX30100 Sensor

MAX30100 is a sensor for pulse oximetry and heart-rate monitoring applications. MAX30100 shows pulse rate in beats per minute (bpm) and blood oxygen saturation ($SpO_2$) as a percentage. MAX30100 sensor has four subsystems which are red and infrared LEDs, photodetector, analog front-end, and digital signal processor.

The sensor emits red and infrared LEDs, and the rays are projected on the skin, and the blood tissues absorb the rays. The photodetector measures the intensity of the ray transmitted through the tissues, and the signal is converted into a digital signal by the analog front end for processing by Digital Signal Processor.

The sensor communicates with the ESP32 board using the I2C communication protocol in a master-slave system. The sensor has the follwing pins: SDA, SCL, VCC, GND, and INT.
Serial Data (SDA): SDA pin is for data transfer in the I2C communication protocol. The SDA pin is connected to pin 21 of the ESP32 Board for data transfer from the sensor to the microcontroller in the circuit.

Serial Clock (SCL) is used to synchronize the data transfer between master and slave, which is generated by the master, the ESP32 Board. The SCL pin is connected to pin 22 of the ESP32 Board in the circuit.

The VCC is supplied 5 V from the power bank module and the ground to the 0 V of the power bank module. The INT pin is not in use in the circuit. MAX30100 operates at 1.8 V and 3.3 V and has a current consumption approximately 0.02 A when in active operation (MAX30100 Pulse Oximeter and Heart-Rate Sensor Module | Ampere Electronics, 2023).


**Figure 2.** MAX 30100 Sensor Module

### 3.1.3. Pulse Sensor

A Pulse Sensor is a small electronic device for detecting heart-rate by measuring blood flow through the veins. It has a light-emitting diode (LED), a photodetector, and a circuit to process the signal (What Is a Pulse Sensor - Bing, n.d.). The LED on the pulse sensor emits light directed at the veins such as the ones in the finger tips. As blood flows through the vein when the heart pumps blood, the ambient light sensor will detect more light reflected by the blood that the heart pumps. The changes in light received are analyzed to determine heart rate (Components101. n.d).

The sensor is commonly used in designing wearable fitness trackers, sleep tracking, anxiety monitoring, advanced gaming consoles, medical instruments, and other applications where heart rate monitoring is essential. It has three pins which are for powering and signal output. The device operates from +5V to +3V.

The pulse sensor in this project work is powered by 5 V from the power bank, and the ESP32 reads the analog signal from the signal pin through pin 34.

**Figure 3.** Pulse Sensor

### 3.1.4. LCD Module

The 16x2 LCD module is an electronic component that displays ASCII alphanumeric characters up to 32 and simple graphics in an embedded system. It has a light at the back that keeps the screen illuminated and liquid crystal which creates the characters. It contains the LCD panel and driver board.

The LCD uses sixteen inter-integrated circuit interfaces to communicate with microcontrollers and other electronics. This interface includes pins for power, data transmission, ground pin, register select, enable, and rewrite.

In this design, the interface's pins, Serial Data (SDA) and Serial Clock (SCL) are connected to the ESP32 board on pins 21 and 22. The VCC and GND pins are connected to 5V from the power bank module in this circuit.

**Figure 4.** 16x2 LCD

### 3.1.5. SD Card Module

Secure Digital (SD) card module is an electronic device that allows using SD cards with microcontrollers or other embedded systems. It has an SD card niche, pins for connecting to the host microcontroller, and an interfacing circuit. The interfacing circuit transfer data between the SD card and the host system.

The SD card module generally communicates with the host system (microcontroller) as the slave device using the SPI (Serial Periodical Interface) protocol, which is based on a master-slave relationship and allows fast and effective data transfer (Babiuch et al., 2019).

It has six pins which are, and this work is connected as stated below:

**MOSI** (master out slave in), which is the pin master uses to communicate with the slave and is on pin 23 of the ESP32 board.

**MISO** (master in, slave out) is the slave used to communicate with the master and is on pin 19 of the ESP32 board.

**Serial Clock** (SCK) is connected to pin 18 of the ESP32 board and synchronizes data transfer between the master and slave in the communication.

**Chip Select** (CS) pin is connected to pin 5 of the Board, and the selected pin goes low when there is communication between the master and slave.

It is powered with 5 V from the power bank module through its VCC and GND and has a 2G memory card to store the data from the ESp32 microcontroller.


**Figure 5.** Micro SD Card Module

### 3.1.6. Lithium Ion Battery

Lithium-ion batteries are rechargeable batteries that transfer energy between electrodes using lithium-ions. This type of battery has a cathode, which is of a lithium compound, and an anode which is of granite electrodes that separate the terminals. Lithium ions move from the negative terminal through the electrolyte to the positive terminal during the charging.

The lithium-ion battery has high energy density and can store large quantum of energy in small size and weight. The battery is 3.7 V rated with varying amperage.

**Figure 6.** 3.7 V Lithium-ion battery

### 3.1.7. Buzzer

A buzzer is an electronic component that produces sound using the piezoelectric effect (Wikipedia contributors, 2023). This effect is the ability of electronic devices to induce electric charge proportional to mechanical stress and vice versa to produce sound as the inverse piezoelectric effect.

Buzzers are small electronic devices with two wires for signal and ground. They are small, lightweight, and compact piezo buzzers for security systems, alarms, electronic toys, musical instruments and timers.

In this design and construction, it is used as an alarm to signal abnormal heart-rate levels.

### 3.1.8. Switch

An electronic switch is a device that can allow or break a power supply to an electronic system. It controls power flow from one point to another. It separates two wires from contacting or it allows power flow. In most electronic devices, switches turn on and off an electronic device.

In this research work, a switch is used to turn on and off the heart monitoring devices by connecting and disconnecting the power supply from the power bank to the electronic circuit.

### 3.1.9. Power Bank Module

A power bank module contains a charging circuit, output terminal and a screen to display the battery level percentage at every time. The power bank module takes 3.7 V and outputs 5 V. This output voltage can be used to energize any electronics circuit or components powered with 5 V. The power bank module is rated 5 V 2 A, which means it can supply 2 A of current in one hour at 5 V.

In this research, two lithium-ion batteries are parallel connected to increase the current supply. The voltage remains unchanged at 3.7 V. An increased current implies the battery will supply electricity over more time.


**Figure 7.** 5 V 2 A Power bank module

### 3.2. Software

The software part includes Arduino IDE and Blynk Application as explained below:

This work used Arduino IDE as the compiler to write and program sketch for the ESP32 microcontroller board. This design's instructions or code are written in embedded C++ and compiled using the Arduino IDE.

The Blynk platform is an easy-to-use IoT interface for displaying values for remote monitoring as a biotelemetry application. The Blynk platform streams the heart-rate values from MAX30100 and Pulse Sensor in this design. These values can be monitored remotely by a medical personnel.

### 3.3. Method

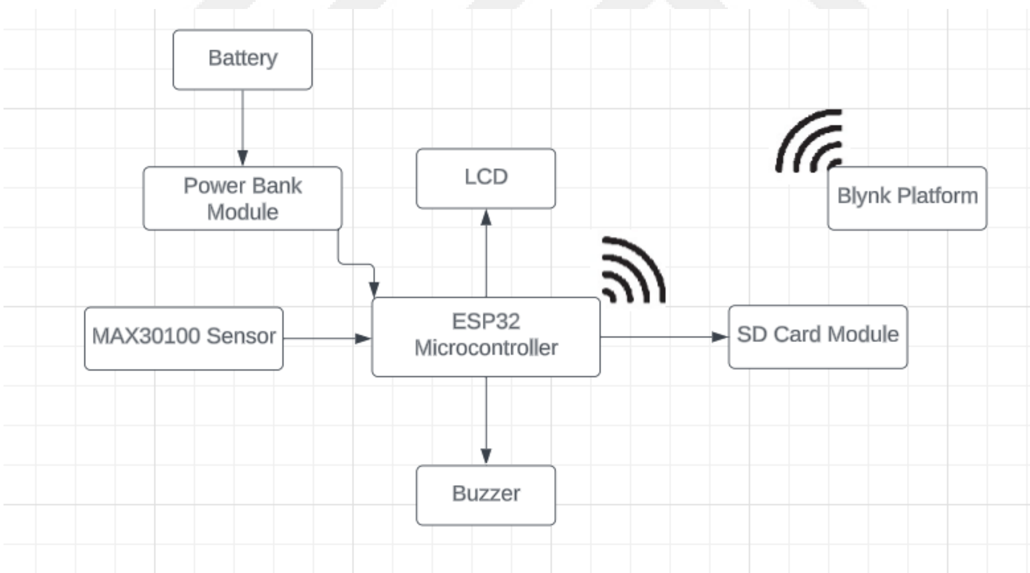


**Figure 8.** MAX30100 based block diagram

As seen above, Figure 8 is the block diagram that shows how signal flows in the MAX30100-based heart rate monitoring system. The ESP32 board, which contains the instruction code programmed with Arduino IDE downloaded into it, is the microcontroller that coordinates all the activities in the system.

The MAX30100, the slave device, measures the heart rate signal when a finger is placed on and sends data through the I2C protocol to the ESP32 board for processing. A value of less than 60 BPM is considered an abnormal heart rate.

The 16x2 LCD, which implies sixteen columns and two rows, can display 32 text characters. It communicates with the ESP32 board through the I2C communication protocol (SDA and SCL). It is a master and slave system. The LCDs the value from the heart rate sensor at every time.

The micro SD card module with a 2G SD card communicates with the ESP32 board through SPI protocol as a slave. It stores the data from MAX30100 in text format. The stored data can be accessed by putting the SD card in a card reader or USB.

The sensor data is transmitted to the Blynk platform through the onboard Wi-Fi on the ESP32 Microcontroller, with the help of the Blynk library. The steps that are followed:

- Blynk library in the Arduino IDE was installed
- A new Blynk project in the Blynk platform with the authentication token was generated
- The necessary widget to display the sensor reading was added
- Blynk library and the Wi-Fi credentials of the server (Phone Hotspot) to the ESP32 code were added
- Virtual pin (V2) was selected in the Blynk project created to receive signal from pin 5 of the ESP32 Board.

The 80db Buzzer is connected to pin5 of the ESP32 board. It is programmed to go HIGH when it receives a signal from the Board. At any point, the sensor senses a value less than 60 or greater than 100 and is triggered to indicate a warning to the healthcare attendant about an abnormal heart rate condition.

The power bank module is connected to two 3.7 V lithium-ion batteries in parallel. The power bank module serves as the power source for the heart rate monitoring device. It has a type-B charging port where the battery is charged with any 5 V adapter. The screen on the module show at every point in time the battery level in percentage.

Pulse Sensor-based block diagram, similar to MAX30100, is given in Figure 9.

Flow charts of each device are given in Figure 10 and 11. Circuit diagrams are given in Figure 12 and image of each device is given in Figure 13.

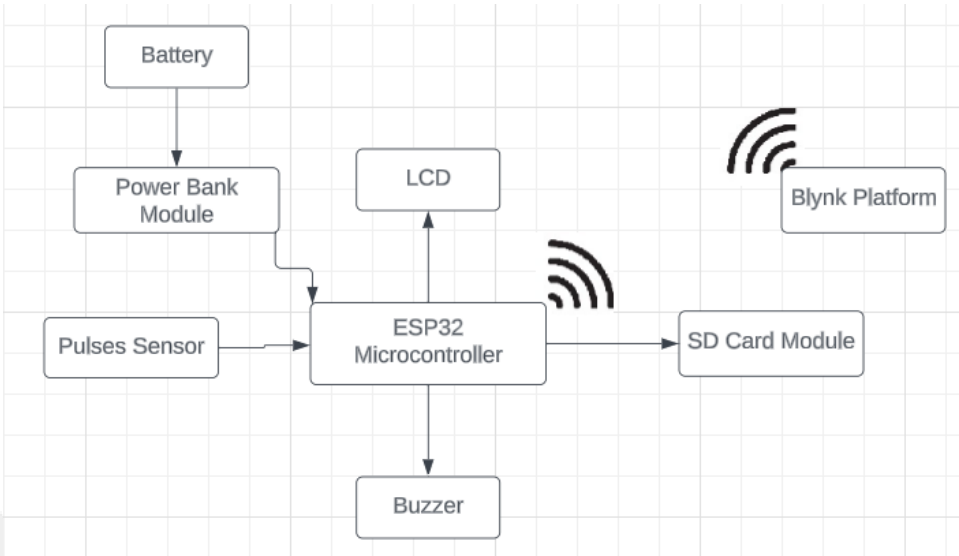


**Figure 9.** Pulse Sensor-based block diagram

### 3.3.2. Measurements

In order to carry out the measurements, volunteers placed their index finger on the devices and waited 10 seconds for the readings to normalize.

Pulse was measured for each device containing MAX30100 sensor and the Pulse Sensor; and a commercial DetelPro Fingertip Pulse Oximeter device (India) in beats per minute, at rest, after light walking and after exercise. For each state, 3 measurements were carried out immediately with each device. The standard deviations of these values are calculated and compared with each other.

### 3.3.3. Standard Deviation Calculation

Standard deviation measures the dispersion of sets of values from a reference point. A low standard deviation implies the values are closer to the average of the data and higher standard deviation shows that the values are far from the mean of the data.

The steps to calculate standard deviation are:

- Calculate the mean of the values

- Calculate the sum of the square of the difference of the values from the mean
- Divide the sum by the total number minus 1
- Take the square root

$$\text{Standard Deviation} = \sqrt{\frac{(x-mean)^2}{n-1}}$$

X: value(s)

Mean: mean of the numbers

n: number of values

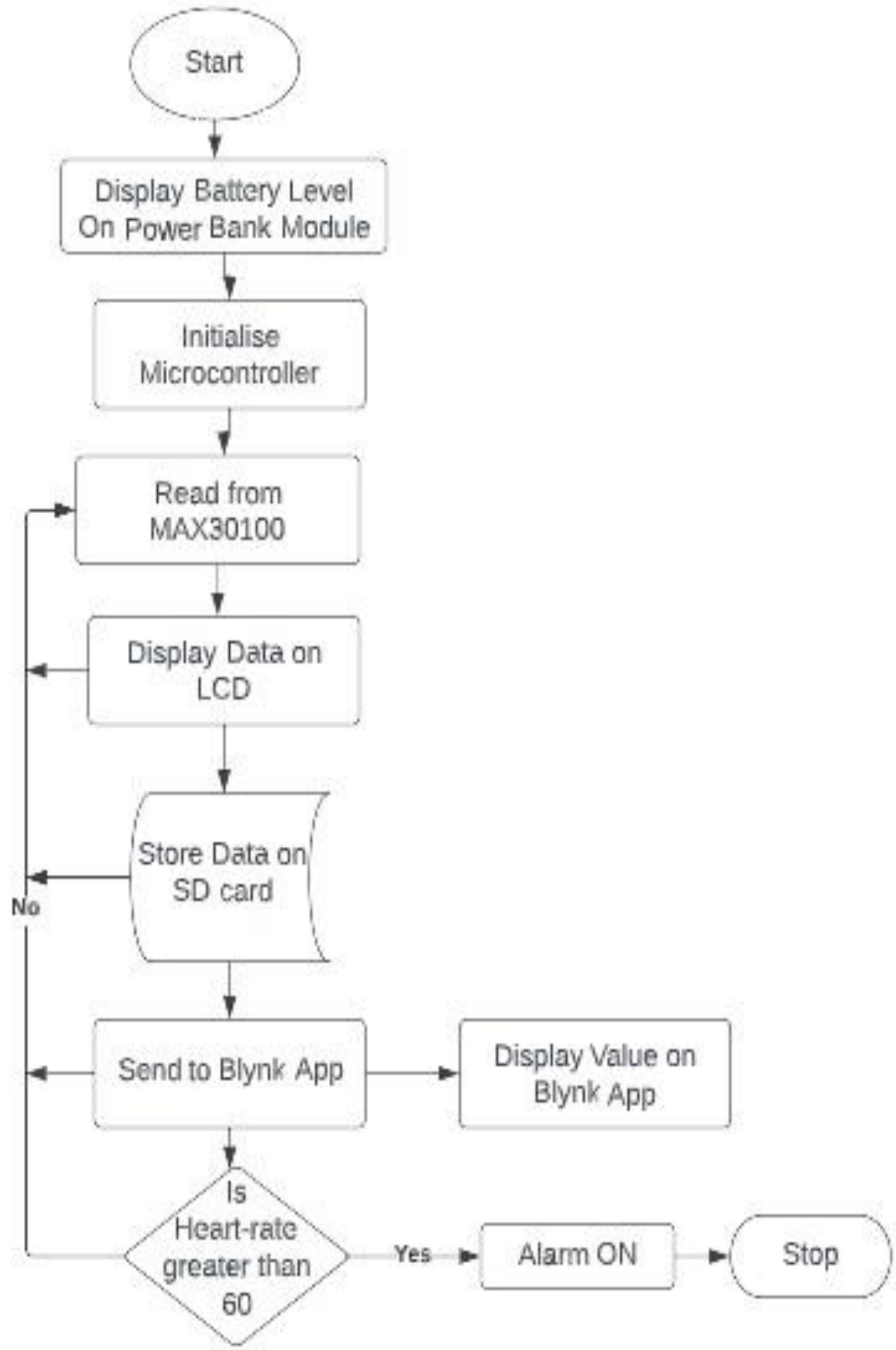


**Figure 10.** MAX30100 based flow chart

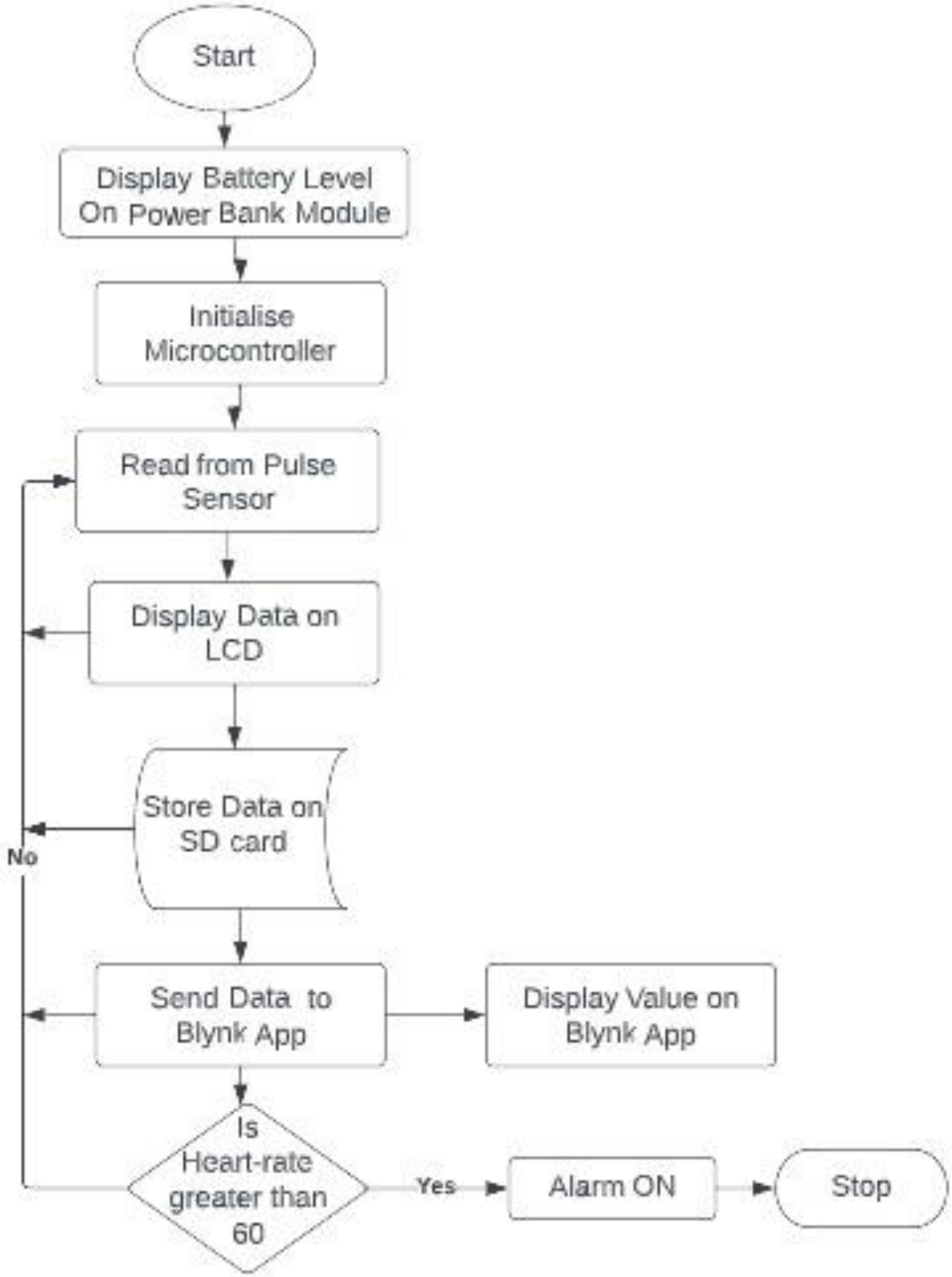


**Figure 11.** Pulse Sensor-based flow chart

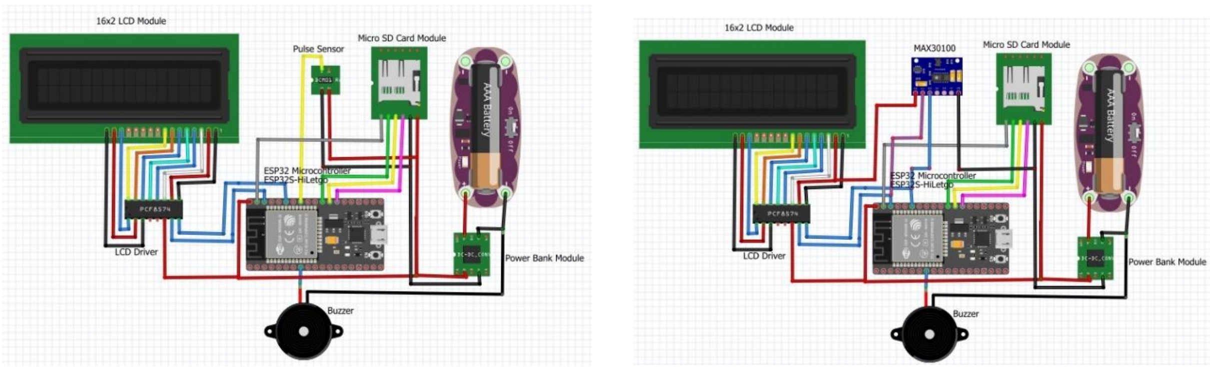


**Figure12.** Pulse and Max30100 Sensors' circuit diagrams.

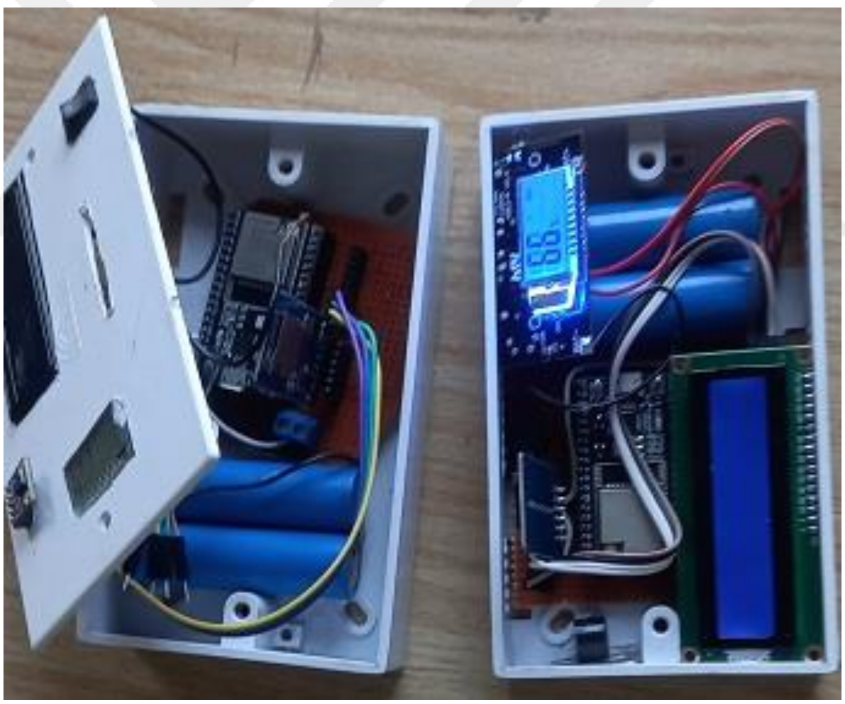

**Figure 13.** Picture of the two heart-rate monitoring devices

## CHAPTER FOUR

## TEST RESULTS AND DISCUSSION

This chapter shows the results of the devices' measurements. The testing covers the step-by-step procedures involved in testing of the devices along with the result obtained. The discussion covers the analysis of the results obtained, comparing the results to other relevant work.

Heart-rate measurement is essential for various reasons, such as an early cardiovascular disease diagnosis. However, the average resting heart-rate can change depending on the age in beats per minute (BPM): Infants 80 - 160, Children 80-130, under 9-year-old 70 - 110, 10 years and above 60 - 100, athletes - 40 – 60 (Pulse: MedlinePlus Medical Encyclopedia, n.d.). In general, pulse measurements ranges between 60-100 bpm (Suprayitno et al., 2019)..

The device can be used to test on any part where arteries pass, like neck and wrist and also tip of the index fingers.

### 4.1. Testing

The devices are tested in two phases: MAX30100-based and Pulse Sensor-based devices.


**Figure 14.** MAX30100 Sensor-based device (left) and Pulse Sensor-based device (right)

#### 4.1.1. MAX30100 Sensor Base Device Testing

Below are the phases of MAX30100 based-device's heart rate monitor testing:

##### 4.1.1.1. MAX30100 Sensor Base Device Testing and Result

The MAX30100 sensor module takes at least 10 seconds before its reading normalizes (Instructables, 2022). Index finger is placed on the MAX30100 and held 10 seconds for the reading to normalize. The ESP32 gets the value from the sensor and sends it to be displayed on the different LCD, SD card, and Blynk applications. Each measurement of MAX30100 is confirmed with the commercial Pulse Oximeter as seen in **Figure 14.**


**Figure 15.** MAX30100 Sensor based-device showing a heart-rate value on LCD

##### 4.1.1.2. MAX30100 Sensor Base Device Data on the SD Card and Result

The data read from the MAX30100 is sent to the microcontroller. The microcontroller sends the data to the SD card, which is stored in CSV format. The SD card is removed from the SD card module, inserted into an SD card reader and accessed through a computer. Table 1 shows each measurement.

**Table 1.** MAX30100 heart-rate values in bpm

| Measurements | MAX30100 Heart Rate (bpm) |
|---|---|
| 1 | 98 |
| 2 | 97 |
| 3 | 98 |
| 4 | 98 |
| 5 | 97 |
| 6 | 98 |
| 7 | 97 |
| 8 | 98 |
| 9 | 97 |
| 10 | 98 |

#### 4.1.1.3. MAX30100 Sensor Base Device Blynk Application Testing and Result

To monitor heartbeat results from the MAX30100 remotely, a user must create a free account with the Blynk application for heartbeat monitoring with MAX30100 (Figure 16).

The steps are:

- Open the Blynk platform and register as a user
- Add your ESP32 to the environment
- Select the analog value widget and select the virtual pin1 to stream the data
- Input the write hotspot details in your sketch, and the ESp32 will connect automatically with the Blynk app.
- Place your finger on the MAX30100 sensor and monitor the reading on the platform.

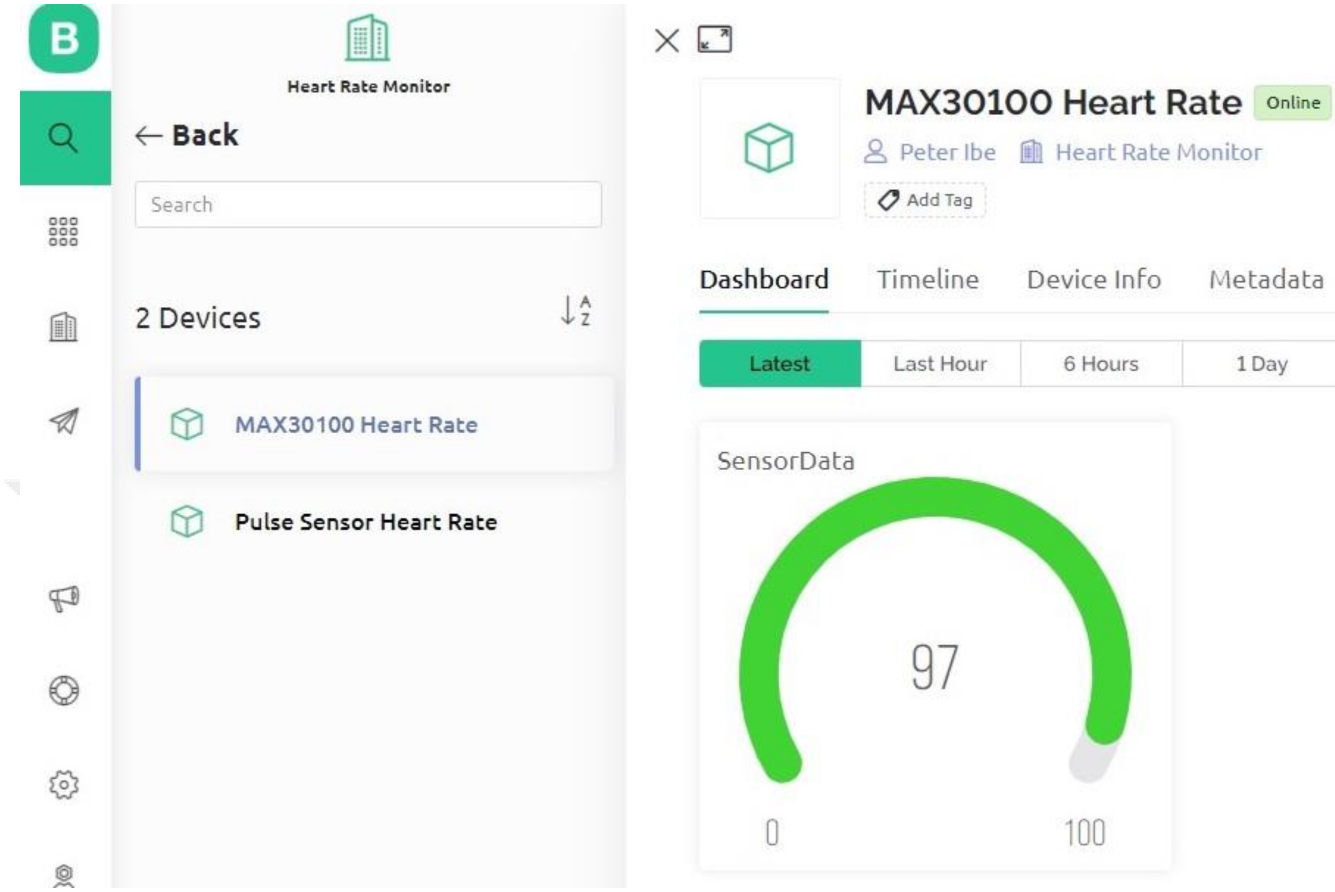


**Figure 16.** MAX30100 value on Blynk App

### 4.1.2. Pulse Sensor Base Device Testing

Below are the phases of Pulse Sensor based-device's heart rate monitor testing:

#### 4.1.2.1. Pulse Sensor Base Device Testing and Result

For the measurement, a finger is placed on the Pulse Sensor-based device. The ESP32 gets the value from the sensor and sends it to be displayed on the different LCD, SD card, and Blynk Application. Each measurement of Pulse Sensor is confirmed with the commercial pulse oximeter as seen in Figure 17.


**Figure 17.** Pulse Sensor Base Device showing Heart rate value on LCD

#### 4.1.2.2. Pulse Sensor Base Device Data on the SD Card and Result

The data read from the Pulse Sensor is sent to the microcontroller. The microcontroller sends the data to the SD card, which is stored in CSV format. The SD card is removed from the SD card module, inserted into an SD card reader and accessed through a computer. Table 2 shows each measurement with the Pulse Sensor-based device.

**Table 2.** Pulse Sensor heart-rate values of in bpm

| **Measurements** | **Pulse Sensor Heart Rate (bpm)** |
|---|---|
| 1 | 96 |
| 2 | 98 |
| 3 | 97 |
| 4 | 99 |
| 5 | 97 |
| 6 | 97 |
| 7 | 97 |
| 8 | 99 |
| 9 | 97 |
| 10 | 96 |

#### 4.1.2.3. Pulse Sensor base-device Blynk Application testing and result

To monitor heartbeat results from the Pulse sensor remotely, a user needs to create a free account with the Blynk application for heartbeat monitoring (Figure 18). The steps are:

- Open the Blynk platform and register as a user
- Add your ESP32 to the environment
- Select the analog value widget and select the virtual pin1 to stream the data.
- Input the write hotspot details in your sketch, and the ESp32 will connect automatically with the Blynk app; place your finger on the pulse sensor and monitor.

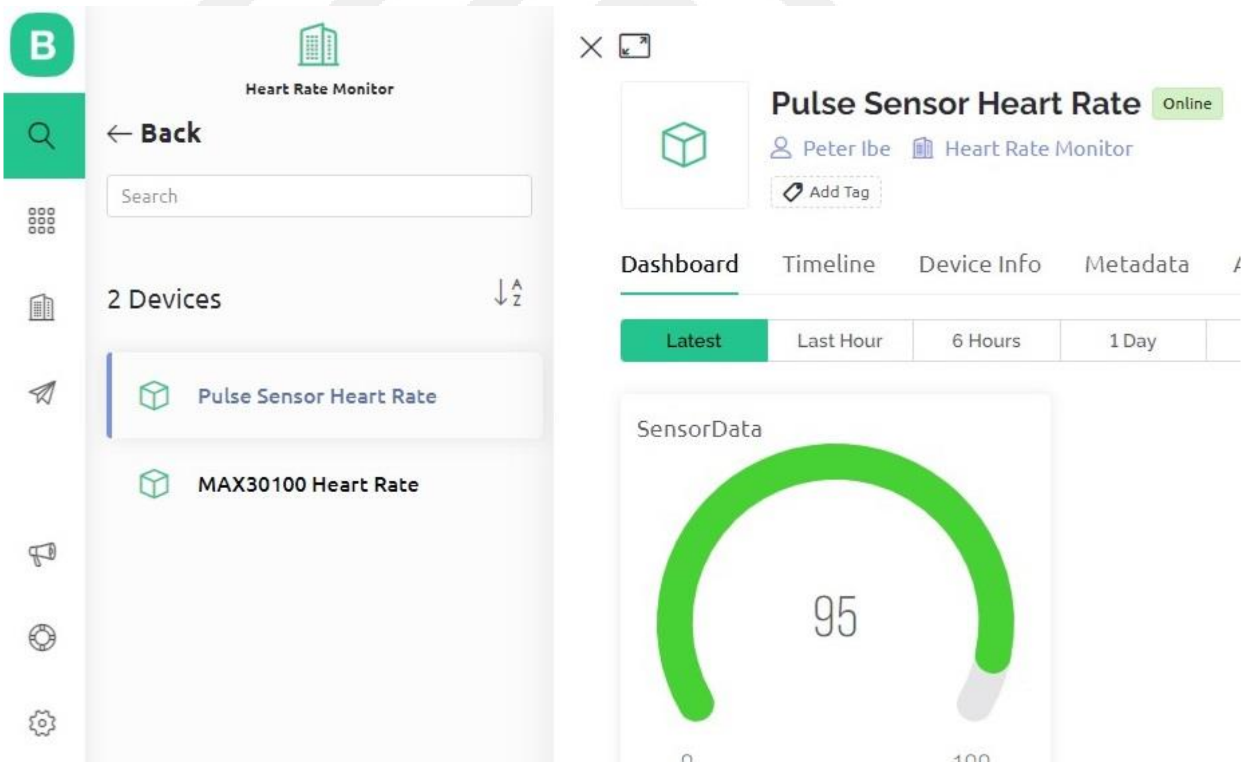


**Figure 18.** Pulse Sensor Value on Blynk App

### 4.2. Power Consumption Results

From the datasheet of MAX30100, the sensor uses 1.8 V and 3.3 V. It has a current consumption of around 0.02A when in active operation (MAX30100 Pulse Oximeter and Heart-Rate Sensor Module | Ampere Electronics, 2023).

The datasheet parameters, therefore, imply the maximum power consumption of MAX30100 when it operates at full voltage:

Power = Current x Voltage (EQ 2)

I = 0.02 A

V = 3 V

Power = 0.02x3.3

**P = 0.06 Watts**

The minimum power consumption when it is not active in operation is

Power = IV

I = 0.02

V= 1.8

Power = 0.02 x 1.8

**Power = 0.036 Watts.**

From the Pulse Sensor datasheet, the sensor operates from 3.3 V and 5 V and has a current of consumption of about 0.004 A in active operation (Pulse Sensor, n.d.).

The maximum power consumption of the sensor is using EQ1:

I = 0.004 A

V = 5 V

Power = 0.004 x 5

**Power = 0.02 Watts**

The minimum power consumption when it is not in active operation is:

I = 0.004 A

V = 3.3

Power = 0.004 x 3.3

**Power = 0.0132 Watts**

The power consumption resulting from the two devices suggests that MAX30100, which draws 0.06 watts when it operates at full voltage, consumes more power than the Pulse Sensor which draws 0.021 watts when it operates at full voltage. There is a difference of 0.039 watts when considering the two devices. The result shows that the MAX30100 consumes about 0.039 watts more than the Pulse Sensor.

Also, from the observation of the two devices designed to monitor the heart rate using MAX30100 and a Pulse Sensor, the power consumption over the same period for MAX30100 is more than that of Pulse, as shown on the power bank module of the two devices **(Figure 17.)**


**Figure 19.** MAX30100 and Pulse Sensor based heart-rate devices showing different battery levels

### 4.3. Comparison of MAX30100 and Pulse Sensor with Pulse Oximeter

Measurements of MAX30100, Pulse Sensor, and a commercial Pulse Oximeter (DetelPro, India) rmeasurements at rest, after light walk and after exercise were compared.

**Table 3.** MAX30100 & Pulse Sensor-based devices' and pulse oximeter's measurements at rest, after light walk and exercise

| | STATE | MAX30100 (bpm) | PULSES SENSOR (bpm) | PULSE OXIMETER (bpm) |
|---|---|---|---|---|
| 1 | **Resting** | 70 | 72 | 65 |
| | | 69 | 77 | 65 |
| | | 68 | 68 | 65 |
| | **Mean** | **69** | **72.3** | **65** |
| | **SD** | **1** | **4.26** | **0** |
| 2 | **EXERCISE** | 95 | 98 | 93 |
| | | 93 | 100 | 94 |
| | | 97 | 95 | 95 |
| | **Mean** | **95** | **97.67** | **94** |
| | **SD** | **2** | **2.52** | **1** |
| 3 | **LIGHT WALK** | 78 | 80 | 76 |
| | | 77 | 79 | 76 |
| | | 76 | 82 | 76 |
| | **Mean** | **77** | **80.33** | **76** |
| | **SD** | **1** | **1.53** | **0** |

As seen in Table 3, heartbeat measurements in bpm from MAX30100 and the Pulse Sensor-based devices and commercial pulse oximeter were obtained at rest, after light walking, and exercise. The standard deviations of these values are calculated for each device at the specific state.

The commercial pulse oximeter is accepted as the more reliable device in this study since it is sold as a POC device in the market. Our study also showed that the pulse oximeter had low standard deviations (Table3). When compared with our devices, commercial pulse oximeter readings were generally lower than both the Pulse Sensor and MAX30100, with lower standard deviations. The measurements of MAX30100 based-device were closer to the commercial pulse oximeter. The Pulse Sensor measurements were slightly higher than MAX30100 device and the pulse oximeter.

Moreover, results showed that the MAX30100 based-device has a standard deviation of 1 at rest and light walk and a value of 2 at exercise. The Pulse Sensor has a standard deviation value of 4.26 at rest, 1.53 at light walking, and 0.52 during exercise. The standard deviation of the commercial pulse oximeter is slightly between 0 and 1 for the three scenarios. The standard deviation of MAX30100 at rest and after a light walk is lower than that of the Pulse Sensor at rest and after a light walk. According to Suprayitno et al. (2019), it can be inferred that the MAX30100 sensor, with a lower deviation value, has higher closesness to the pulse oximeter when compared to the Pulse Sensor which has a higher deviation value (Suprayitno et al., 2019). As mentioned above MAX30100 sensor based device's measurements are determined to be closer to the commercial pulse oximeter, making it more reliable than the Pulse Sensor.

When Suprayitno et al. (2019) did a research to compare the accuracy of the MAX30100 sensor to standard industrial measurement with an oximeter, their result showed that MAX30100 has an accuracy rate of 99.62% for oxygen saturation and 97.55% for heart rate (Suprayitno et al., 2019).

Another work by Puspitasari et al. (2020) compared oxygen level saturation using the MAX30100 and commercial fingertip pulse oximeter readings. Their data showed the highest deviation of MAX30100 was 3.03%, a minor deviation of 1.01%, and the average deviation of 1.62% for oxygen saturation when compared with the commercial pulse oximeter readings.

The results from the Table 3 also suggest that the Pulse Sensor accuracy increases at higher heartbeat values when compared to its mesurements during resting and light walk. At the same time, MAX30100 and the Pulse Oximeter give more stable results at lower heartbeat values since their standard deviations are lower when compared to the each deviecs' standard deviation during exercise.

From the parameters investigated in this study, which are power consumption and accuracy, MAX30100 consumes more power. Still, it is more accurate than the Pulse Sensor since it has lower standard deviation among its measurements and has measurements closer to the commercial pulse oximeter. Pulse Sensor consumes less power but has its measurements are less closer to the commercial oximeter. Hence it can be inferred that MAX30100 is more effective as its reliability is superior to more power consumption as in biomedical point of view and MAX30100 based-device can be accepted as a better candidate for a POC device which can be used by patients at home.

Also, it is determined that, the Blynk application was very effective in the remote monitoring of both MAX30100 data and Pulse Sensor data for biotelemetry applications. The communication is only affected by the network of the user's internet service provider.

## CONCLUSION AND RECOMMENDATIONS

This research determined the most effective, power efficient, and accurate heart rate sensor between MAX30100 and Pulse sensor. Standard deviation was used to analyze the heart-rate data obtained from the devices. The analysis showed that, MAX30100 has an average standard deviation of 1.33 (as calculated from Table 3), while the Pulse Sensor has an average standard deviation of 2.77 (as calculated from Table 3), among its measurements. According to a report by Suprayitno et al. (2019), where they compared MAX30100 to a standard medical heart-rate instrument (oximeter), they concluded that the smaller the standard deviation, the more accurate the device. Accordingly, this study showed that the MAX30100 based-device had a lower standard deviation value among its measurements, therefore, it is a better sensor for measuring heart rate when compared with the Pulse Sensor.

Moreover, when compared with the commercial pulse oximeter device, it was observed that the measurements of MAX30100 based-device were closer to the commercial device than the Pulse Sensor based-device's measurements (Table 3).

The Blynk application remotely monitored the heart parameters from the MAX30100 and the Pulse sensor-based heart rate monitoring devices. The Blynk platform was effective, fast, and seamless in transmitting heart rates. One significant advantage of the application is that users can create a personal account with private access and the biomedical data are secured.

The power consumption was estimated based on their datasheet power rating and the devices' battery drain simultaneously. From their datasheet, it was calculated that MAX30100 drained more power compared to the Pulse Sensor. Also, the MAX30100 based-device consumed more battery over the same period and usage when compared to the Pulse Sensor-based device.

The effectiveness of the MAX30100 based and the Pulse Sensor-based devices were evaluated on the power consumption and accuracy. Since accuracy is more critical in biomedical data acquisition, the conclusion is that MAX30100 is more effective than the Pulse Sensor. Therefore, the MAX30100 based-device is a better candidate for a POC testing device to be used at home for also biotelemetric measurements.

For future work, the design of both of these devices can be implemented to be used as wearable devices. Also the accuracy of the devices can be further determined by using a medical grade pulse oximeter device.

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