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ON

REAL TIME MONITORING OF VITAL SIGNS OF PAEDIATRIC AND TRAUMA PATIENTS USING FITBIT AND XIAOMI WEARABLE DEVICES

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REAL TIME MONITORING OF VITAL SIGNS OF PAEDIATRIC AND TRAUMA PATIENTS USING FITBIT AND XIAOMI WEARABLE DEVICES

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Abstract

REAL TIME MONITORING OF VITAL SIGNS OF PAEDIATRIC AND TRAUMA PATIENTS USING FITBIT AND XIAOMI WEARABLE DEVICES.

This project investigates the effectiveness of wearable devices in continuously monitoring vital signs, specifically heart rate and oxygen saturation, in clinical settings, particularly in resource-limited environments such as Ghanaian hospitals. The increasing demand for accurate and real-time patient monitoring underscores the importance of developing affordable and reliable health technologies that can enhance patient care while minimizing human error associated with manual monitoring.

To address this problem, a web-based system was designed that integrates wearable devices, namely the Fitbit Inspire 3 and Xiaomi Smart Band 8, to provide continuous monitoring of vital signs. The system enables real-time data collection and analysis, facilitating early detection of health issues, especially in trauma and pediatric patients. Testing was conducted in a clinical setting, focusing on the accuracy of the devices and their ability to monitor multiple patients simultaneously.

The results revealed that the Fitbit device achieved a heart rate accuracy of 93.65%, while the Xiaomi device recorded a heart rate accuracy of 90.35% and an oxygen saturation accuracy of 98%. The system successfully monitored two vital signs for seven patients concurrently, demonstrating its effectiveness and scalability. However, challenges such as reliance on smartphones for data synchronization and limitations in the range of vital signs monitored were identified.

In conclusion, the project establishes a foundation for the use of wearable technology in healthcare, offering a more accurate and efficient method of patient monitoring, particularly in resource-constrained environments. The findings suggest potential applications in various clinical scenarios, including remote monitoring and early intervention strategies, thereby contributing to improved patient outcomes and overall healthcare efficiency.

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Chapter 1 - Introduction

1.0 Background

In contemporary healthcare, the monitoring of vital signs is a cornerstone of patient evaluation and management. Vital signs—comprising blood pressure, body temperature, heart rate, respiratory rate, and blood oxygen saturation (SpO2)—are essential physiological indicators that provide critical insights into an individual's overall health status. These parameters are not merely data points; they serve as pivotal indicators for early identification and prediction of health-related issues, enabling healthcare professionals to make timely and informed clinical decisions [1]

The importance of continuous monitoring is particularly pronounced in vulnerable patient populations, such as paediatric and trauma patients. Paediatric patients, due to their developmental stage, often lack the ability to effectively communicate their symptoms, making precise monitoring of vital signs crucial for timely interventions. In the case of trauma patients, continuous observation is vital for understanding the body's physiological responses to injuries, as even minor fluctuations in vital signs can dictate urgent treatment decisions. These factors highlight the critical need for accurate and consistent vital sign measurements in healthcare settings, particularly in high-stakes environments like emergency care [2]

In low- and middle-income countries (LMICs), including Ghana, the challenges surrounding vital sign monitoring are exacerbated. Access to modern monitoring devices is limited due to high costs, maintenance requirements, and unreliable power supply. As a result, traditional manual monitoring has become the standard practice, which introduces subjectivity and potential inaccuracies, especially given the overwhelming workload faced by nursing staff. Studies indicate that the nurse-to-patient ratio can be as high as 15:1, making continuous monitoring often impractical and leading to significant gaps in patient data collection [1], [3].

Recent advancements in technology, particularly through the Internet of Things (IoT) and Information and Communication Technology (ICT), offer promising solutions to these challenges. Wearable technology (WT) has emerged as a transformative tool in healthcare, enabling continuous monitoring of vital signs with the potential to improve patient outcomes significantly. However, integrating wearable devices into clinical practice faces numerous obstacles, including resource constraints and the slow adaptability of healthcare stakeholders to new technologies [4].

The aim of this project was to monitor vital signs of patients in real time using wearable devices, specifically the Fitbit Inspire 3 and Xiaomi Smart Band 8. A critical component of this study involved verifying the concordance of these wearable devices with standard manual monitoring techniques. The project recruited patients aged 3 to 18 years, focusing on 20 participants—10 from the paediatric unit and 10 from the accident and emergency centre at Korle-Bu Teaching Hospital in Ghana.

By evaluating the accuracy and reliability of these wearable health devices in real-world clinical scenarios, we seek to contribute meaningful insights into their utility in enhancing patient care. This project aspires to address both the technological and practical challenges associated with vital sign monitoring, ultimately paving the way for a more efficient and responsive healthcare system that improves health outcomes for the most vulnerable segments of the population.

1.1 Problem definition

The current methods of monitoring vital signs in Ghanaian hospitals face significant challenges that hinder effective patient care. Patient monitors, while essential for assessing vital signs, are prohibitively expensive, averaging $4,173 (₵45,694.35). Many hospitals in Ghana cannot afford these devices, leading to a limited supply of functioning monitors. Often, the available monitors are faulty and require manufacturers for repairs, resulting in inadequate access to reliable monitoring equipment.

Due to the scarcity of functioning monitors, healthcare providers, particularly in the paediatric ward at Korle-Bu Teaching Hospital, resort to manual monitoring of vital signs. This practice is further complicated by the high patient-to-nurse ratio, where nurses are unable to consistently monitor a large number of patients. Consequently, vital signs are typically checked on a four-hour interval schedule, which poses a significant risk for early detection of deterioration and timely treatment.

Additionally, manual monitoring is prone to human error, which can jeopardize patient safety. The lack of continuous monitoring is particularly critical for post-trauma patients, who require constant observation. Furthermore, the data collected through manual monitoring is not digitally available for analysis, limiting effective patient management and intervention strategies. The reliance on manual methods not only increases the workload for nursing staff but also restricts patient movement, further complicating care delivery.

There is, therefore, a pressing need for a more accurate, efficient, and consistent method to continuously monitor the vital signs of patients in Ghanaian hospitals, particularly in high-risk environments where timely intervention is crucial.

1.2 Project Objectives

The main objectives of the project are outlined below:

i. Comprehensive Data Acquisition and Continuous Monitoring: To acquire and continuously monitor values for the five vital signs—heart rate, oxygen saturation (SpO2), temperature, respiratory rate, and blood pressure—from a maximum of 30 patients in a ward. The system should effectively receive signals from all patients without interference or data loss, displaying real-time measurements throughout their hospital stay.

ii. Web Application Development with Interactive Interface: To develop a comprehensive web application that includes an interactive interface for displaying acquired vital sign data. This platform will enable healthcare personnel to easily view, analyse, and interact with real-time signals from patients, ensuring a user-friendly experience.

iii. Multi-Patient Monitoring and Trend Analysis: To monitor the vital signs of multiple patients (up to 30) and perform trend analysis to aid healthcare personnel in identifying patterns and making informed decisions.

iv. Remote Monitoring and Alerts: To implement a system for remote monitoring that provides alerts for any abnormal detection of patients' vital signs, enhancing patient safety and response times.

v. Statistical Analysis of Data: To perform statistical analysis on the received data to describe the concordance of the wearable technologies with traditional modes of vital sign measurement, validating the effectiveness of the wearable devices in clinical settings.

1.3 Relevance of project

The relevance of this project is underscored by several critical factors that address existing challenges in patient care, particularly for post-surgery patients. The implementation of wearable devices for continuous monitoring of vital signs offers numerous benefits:

i. Improved Patient Outcomes: Continuous measurement of vital signs provides real-time data on trends for post-surgery patients, enabling healthcare professionals to detect changes promptly. This early detection helps prevent complications, ultimately reducing the prevalence of post-surgery complications and preventable deaths.

ii. Enhanced Accuracy: Utilizing wearable technology eliminates the inaccuracies associated with manual monitoring, which is often subject to human error. This ensures reliable and continuous records of vital signs, allowing clinicians to make informed and accurate diagnoses.

iii. User-Friendly Web Application: The design of a fully functioning web application displays real-time physiological data measured by wearable devices to clinicians, facilitating better decision-making and patient management.

iv. Reduction of Workload: Implementing wearable devices alleviates the high demand on traditional patient vital sign monitors, reducing the workload on nursing staff. This enables nurses to focus more on patient interactions and overall care, improving the quality of healthcare delivery.

v. Increased Patient Mobility: The portable nature of wearable devices provides greater freedom of movement for patients. This increased mobility enhances comfort and supports rehabilitation practices, leading to more effective recovery processes.

vi. Contribution to Medical Literature: The project contributes valuable information to the existing literature on the effectiveness of wearable devices. By comparing the concordance of these technologies with traditional manual methods, the findings guide the adoption of such devices in Ghanaian hospitals.

vii. Early Alert System: The continuous monitoring capability allows for early prompting of any abnormal vital signs, enhancing patient safety and facilitating timely interventions.

1.4 Scope of the Project

The scope of this project encompasses the development and implementation of a web application designed for the real-time monitoring of vital signs within specific units of Korle-Bu Teaching Hospital, particularly targeting the paediatric ward and the Accident and Emergency centre. Key components include:

i. Vital Signs Monitored: The application will track five critical vital signs: heart rate, oxygen saturation (SpO2), blood pressure, temperature, and respiratory rate, utilizing data from Fitbit and Xiaomi wearable devices.

ii. Patient Capacity: The system will support the simultaneous monitoring of up to 30 patients, enhancing the management of multiple cases in high-demand clinical settings.

iii. Integration and Data Management: The web application will integrate seamlessly with wearable technology to collect and display patient data in real-time. Digital access to this information will improve data management and communication among healthcare personnel.

iv. Graphical Representation: Vital sign data will be presented in an intuitive graphical format, enabling clinicians to easily interpret trends and make informed decisions based on real-time monitoring.

v. Target User Base: The primary users of this application will include healthcare professionals working in the paediatric ward and Accident and Emergency centre at Korle-Bu Teaching Hospital, allowing for improved monitoring capabilities and enhanced patient care.

vi. Limitations: The project will specifically focus on the integration of selected wearable devices (Fitbit and Xiaomi) and will primarily be tested within the units of Korle-Bu Teaching Hospital, recognizing that further research may be needed to validate findings across different patient populations and healthcare settings.

By establishing these parameters, the project aims to enhance patient monitoring and outcomes in Korle-Bu Teaching Hospital, addressing the challenges faced in traditional vital sign measurement methods.

1.5 Outline of the Thesis

To present a systematic and coherent research study, the thesis is organized into five chapters:

- Chapter One – Introduction: This chapter includes the background of the study, the problem statement, project objectives, scope, and significance of the study.

- Chapter Two – Literature Review: This chapter reviews related studies and existing literature relevant to the research topic.

- Chapter Three – System Design and Development: This chapter discusses the methods adopted for real-time and continuous monitoring of patient vital signs, including requirements analysis and specifications of the web application, the system design and development process, system modeling and simulation, and the development tools and materials used.

- Chapter Four – Implementation and Testing: This chapter covers the implementation and testing phases of the project, detailing findings and limitations of the system.

- Chapter Five – Conclusion and Recommendations: This final chapter provides a summary of the study, conclusions, recommendations, and challenges encountered throughout the project.

Chapter 2 – Literature Review

2.0 Introduction

This section evaluates existing literature to justify the need for this project, identifying strengths and weaknesses in current approaches to continuous vital sign monitoring. Effective monitoring is crucial in high-risk clinical settings like surgical wards and emergency departments, yet resource limitations in Ghanaian hospitals often lead to reliance on manual methods, resulting in high costs, inadequate equipment, and potential human errors that hinder timely interventions.

Recent advancements in wearable technology offer innovative solutions for real-time monitoring of vital signs, such as heart rate, oxygen saturation (SpO2), temperature, respiratory rate, and blood pressure. These devices improve accuracy and reduce the burden on healthcare personnel, enhancing patient mobility during recovery.

This chapter reviews research on the effectiveness of wearable technologies in similar clinical contexts, synthesizing findings and exploring trends in their adoption. By highlighting knowledge gaps, this review aims to inform future research and enhance understanding of how wearable technologies can improve vital sign monitoring in resource-limited environments.

2.1 Review of existing works

Below are related works that examine the integration and effectiveness of wearable technologies in healthcare, particularly in monitoring vital signs. These studies provide insights into the established benefits and limitations of wearable devices in clinical settings.

i. In a study conducted by Effah Kaufmann et al. (2024) [5], a web application was developed for integration with the Fitbit Versa 2 and Xiaomi Mi Smart Band 6 to evaluate the validity of heart rate (HR) and oxygen saturation (SpO2) data in a Ghanaian hospital setting. The study compared the performance of these wearable devices against standard monitoring practices, specifically using manual monitoring and the PHILIPS MX 450 patient monitor along with Balance brand BP devices.

   Through the application of Bland-Altman analysis and mean absolute percentage error calculations, the findings revealed that the Fitbit Versa 2 achieved measurement accuracies of 96.87% for HR compared to the PHILIPS MX 450 patient monitor and 96.67% against the Balance brand BP device. Meanwhile, the Xiaomi Mi Smart Band 6 demonstrated 94.24% accuracy for HR against the PHILIPS MX 450 patient monitor and 93.21% against manual monitoring. Notably, the Xiaomi Mi Smart Band 6 achieved a measurement accuracy of 98.79% for SpO2 when compared to the PHILIPS MX 450 patient monitor.

   However, it is important to note that this study was conducted on only one healthy individual over a short time period, which limits its applicability to typical clinical settings.

ii. In the study conducted by Pitt et al. (2024) [6], the Fitbit Inspire 2 was utilized to monitor the step count of patients aged 3 to 17 who had undergone an appendectomy. The researchers tracked the step count over 21 days and compared the trends between patients who experienced complications post-surgery and those who did not. The findings revealed that patients who faced complications demonstrated a slower increase in step count compared to those with normative recoveries. Additionally, the recovery trajectories were found to vary based on the type of complication.
   However, it is important to note that measuring step count may not be ideal for this patient population. Following appendectomy surgery, patients are typically advised to limit physical exertion during their recovery. As a result, relying solely on step count data could

misrepresent their recovery progress, as many patients may not be walking frequently during this critical healing period.

iii. In the study by Breteler et al. (2020) [7], two wearable patch sensors designed for monitoring heart rate (HR) and respiratory rate (RR) were compared to contemporary patient monitors in an intensive care unit setting. The researchers recorded the results from the wearable sensors and assessed their accuracy against the standards set by ICU-grade monitoring. To evaluate the sensors' ability to support correct treatment decisions, Clarke Error Grid analysis was performed.

The findings indicated that the wearable sensors demonstrated high accuracy for monitoring both heart rate and respiratory rate. However, data loss was a notable concern, with wireless transmission failures resulting in varying levels of data gaps. Specifically, the study reported data loss rates ranging from 13% (83 of 633 hours) to 34% (122 of 360 hours) for respiratory rate, and from 6% (47 of 727 hours) to 27% (182 of 664 hours) for heart rate.

iv. In the study by Hadiyoso et al. (2021) [8], vital signals—including ECG, SpO2, blood pressure (BP), and heart rate—were monitored using an armband vital sign monitor equipped with a multi-sensor system, control unit, and Bluetooth module capable of interfacing with a mobile application. This innovative design allowed for simultaneous monitoring of multiple parameters through its multisensory system. The results demonstrated impressive accuracy, achieving over 99% accuracy in body temperature measurements, deviation values of ±2 for SpO2 measurements, and systolic and diastolic blood pressure deviations ranging from ±3 to 8 mmHg.

However, it is important to note that this study was not conducted in a clinical setting, which may limit the generalizability of the findings to real-world healthcare environments.

2.2 The proposed work

This project proposes the development of a web application that facilitates the real-time and continuous monitoring of five vital signs—heart rate, oxygen saturation (SpO2), blood pressure, temperature, and respiratory rate—for up to 30 patients simultaneously. The application will integrate data from Fitbit and Xiaomi wearable devices, specifically designed for use in paediatric wards and Accident and Emergency centre.

Key features of the proposed web application include:

i. Real-Time Monitoring: The application will enable healthcare professionals to continuously track and display vital signs for each patient, allowing for prompt detection of any changes in their condition.

ii. Graphical Display: Vital sign data will be presented in an interactive graphical format, making it easier for clinicians to interpret and analyse trends over time.

iii. Digital Data Access: Patient data will be digitally accessible, streamlining record-keeping and enhancing communication among healthcare staff.

iv. Concurrent Data Collection: The system will support the simultaneous monitoring of multiple patients, improving efficiency in high-demand clinical environments.

By implementing this solution, the project aims to enhance patient care through accurate, real-time data collection, ultimately leading to improved clinical decision-making and better patient outcomes.

2.3 Summary

The literature review highlights the critical role of wearable technologies in monitoring vital signs, emphasizing their potential to enhance patient care, particularly in resource-limited settings such as Ghanaian hospitals. Traditional monitoring methods face challenges like high costs and human error, leading to missed opportunities for timely interventions.

Key studies demonstrate the efficacy of wearable devices: Effah Kaufmann et al. (2024) [5] validated the accuracy of Fitbit and Xiaomi devices for heart rate and oxygen saturation, though limited by a small sample size. Pitt et al. (2024) [6] found that step count monitoring in paediatric appendectomy patients revealed slower recovery in those with complications, but this method may not reflect true recovery needs. Breteler et al. (2020) [7] assessed wearable patch sensors against ICU-grade monitors, noting high accuracy but significant data loss. Hadiyoso et al. (2021) [8] developed a multi-sensor armband that achieved impressive accuracy but lacked clinical testing.

In response to these findings, this project proposes a web application for real-time monitoring of five vital signs—heart rate, SpO2, blood pressure, temperature, and respiratory rate—of up to 30 patients using Fitbit and Xiaomi devices. This solution aims to improve clinical decision-making and patient outcomes in paediatric wards and emergency settings.

Chapter 3 – System Design and Development

3.0 Introduction

This chapter focuses on the design and development of the web application for real-time vital sign monitoring at Korle-Bu Teaching Hospital. It begins with an overview of the system and its key functions, emphasizing the integration of wearable technology to enhance patient monitoring.

The chapter then discusses the requirements, analysis, and specifications that informed the development process. It covers the design and development methodologies used, as well as system modeling and simulation techniques employed to evaluate performance.

Finally, the chapter outlines the development tools and material requirements necessary for building the application.

3.1 System overview and functions

This section provides an overview of the web application developed for real-time monitoring of vital signs at Korle-Bu Teaching Hospital. The application is designed to enhance patient care by integrating data from Fitbit and Xiaomi wearable devices, allowing healthcare professionals to monitor vital signs efficiently.

Key Functions:

i. Real-Time Monitoring: The application continuously collects vital sign data, including heart rate, oxygen saturation (SpO2), blood pressure, temperature, and respiratory rate for up to 30 patients simultaneously.

ii. Patient Dashboard: A centralized dashboard displays real-time information for all monitored patients, enabling quick assessments and facilitating timely clinical decisions.

iii. Alerts and Notifications: The system generates alerts for abnormal vital signs, ensuring healthcare providers can respond promptly to potential complications.

iv. Graphical Data Representation: Vital sign data is presented in intuitive graphical formats, making it easy for clinicians to identify trends and anomalies.

v. Reporting Capabilities: The application generates detailed reports on patient vital signs, highlighting abnormalities and trends over time to support clinical decision-making.

vi. Data Security: Patient information is securely stored and accessible only to authorized personnel, ensuring compliance with healthcare data protection regulations.

3.2 Requirements analysis and specifications

3.2.1 Functional Requirements

i. User Authentication: The system must allow healthcare professionals to securely log in and access the application with unique credentials.

ii. Real-Time Data Collection: The application must continuously gather vital sign data from Fitbit and Xiaomi wearable devices for up to 30 patients.

iii. Patient Dashboard: A dashboard must display real-time vital sign information for all monitored patients, enabling quick assessments.

iv. Alerts and Notifications: The system must generate alerts for abnormal vital signs, notifying healthcare professionals immediately.

v. Graphical Data Representation: Vital sign data must be presented in user-friendly graphical formats, such as charts and graphs, for easy interpretation.

vi. Reporting Functionality: The application must generate comprehensive reports on patient vital signs, including historical data and trends.

vii. Data Export: Users should be able to export patient data (e.g. CSV).

viii. User Management: Administrators must be able to manage user accounts, including adding, modifying, and removing users.

3.2.2 Non-Functional Requirements

i. Performance: The system must support real-time data processing with minimal latency to ensure timely monitoring of vital signs.

ii. Scalability: The application must be able to handle an increase in the number of users and devices without degradation in performance.

iii. Usability: The user interface must be intuitive and easy to navigate for healthcare professionals, requiring minimal training.

iv. Security: The system must ensure the confidentiality, integrity, and availability of patient data, complying with relevant healthcare regulations (e.g., HIPAA).

v. Reliability: The application must be reliable, with minimal downtime, to ensure continuous monitoring of patients.

vi. Maintainability: The application must be designed for easy maintenance and updates, allowing for quick bug fixes and feature enhancements.

vii. Accessibility: The system should be accessible from various devices (e.g., desktops, tablets) and support multiple web browsers.

3.2.3 System Requirements

1. **Hardware Specifications**
   a. **Server Requirements**:
      i. **Operating System**: Windows Server 2022
      ii. **Processor**: 8-core processor
      iii. **RAM**: 8 GB
      iv. **Storage**: 100 GB SSD for fast data retrieval
      v. **Network Interface**: Gigabit Ethernet
   b. **Client Requirements**:
      i. **Device**: Desktop, laptop, tablet or smartphone
      ii. **Processor**: Minimum Intel i3 or equivalent
      iii. **RAM**: At least 4 GB
      iv. **Display**: Minimum resolution of 1366 x 768 pixels

2. **Software Specifications**
   a. **Web Server**: IIS (Internet Information Services) on Windows Server
   b. **Database Management System**: MongoDB
   c. **Programming Languages**:
      i. **Backend**: Node.js
      ii. **Frontend**: EJS (Embedded JavaScript), HTML, CSS, JavaScript
   d. **Development Tools**:
      i. Integrated Development Environment (IDE): Visual Studio Code
      ii. Version Control: Git

3. **Network Specifications**
   a. **Network Requirements**: Internet connection for real-time data transmission from wearable devices
   b. **Data Transmission (Protocols)**: HTTPS for secure communication and WebSocket for real-time data updates

4. **User Interface Specifications**
   a. **User Roles**:
      i. Administrator: Full access to manage user accounts and system settings
      ii. Healthcare Professional: Access to patient data, monitoring dashboard, and reporting tools
   b. **Interface Design**:
      i. Responsive design for compatibility with various devices (desktops, tablets)
      ii. Intuitive navigation with clear menus and options
      iii. Graphical representations of vital sign data (charts, graphs)
5. **Security Specifications**
   a. **Authentication**:
      i. Role-based access control to restrict functionalities based on user roles.
   b. **Data Encryption**: Encryption of sensitive data at rest and in transit
   c. **Compliance**: Adherence to healthcare data protection regulations (e.g. HIPAA)

3.3 System design and development process

3.3.1 System Architectural Diagram

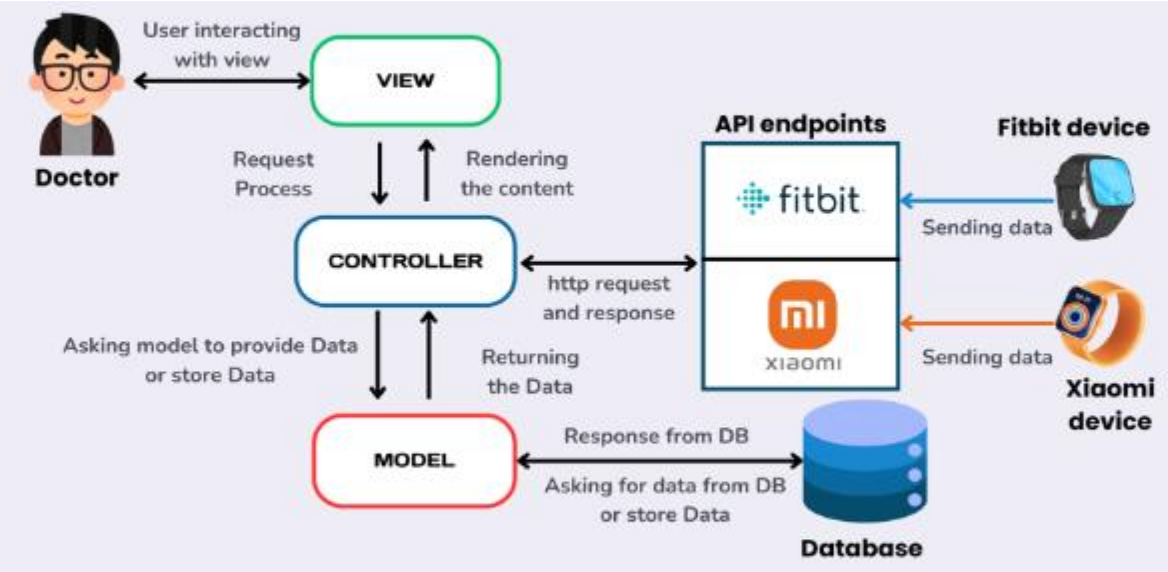


Figure 3.0.1 Architectural diagram of the web application

The web application employs a Model-View-Controller (MVC) architecture, organizing the application into three interconnected components: the Model, the View, and the Controller. This structure enhances modularity and maintainability, allowing for a clear separation of concerns in the application's design.

1. User Interaction with the View

   The View serves as the interface through which doctors interact with the system. It displays real-time information from the Fitbit and Xiaomi devices, enabling healthcare professionals to monitor patient vital signs effectively. The View is designed to render content clearly and intuitively, handling user requests for specific information or data input. This interaction ensures that doctors can access and input vital information seamlessly.

   When registering a new patient, the View allows doctors to input essential details such as the patient's name, patient ID, the device ID identifying the wearable device placed on the patient, and the ward where the patient is located, whether it be Paediatric or Accident and Emergency. Additionally, the View supports data entry for manual monitoring, allowing healthcare professionals to input vital signs collected manually, ensuring comprehensive patient records.

2. Request Processing in the Controller

    The Controller functions as the intermediary between the View and the Model. When a doctor interacts with the View—such as entering patient registration information or requesting vital signs—the Controller processes these interactions. It sends HTTP requests to the API endpoints linked to the wearable devices (Fitbit and Xiaomi), facilitating the retrieval of vital sign data. Additionally, the Controller manages data inputs from the View, directing them to the appropriate Model for storage in the database.

    The Controller effectively handles incoming requests from the View, responding with the necessary data. It communicates with the API endpoints to fetch vital sign information from the devices and returns this data to the View for display.

3. Data Management with the Model

    The Model encapsulates the application's data structure and database schema, defining how data is stored, retrieved, and manipulated. Whenever the Controller needs to access or update data, it interacts with the Model to perform these operations, ensuring efficient data management.

    The Model communicates directly with the database, retrieving patient vital signs or storing new information, such as patient registration details and manually entered vital signs. This interaction guarantees that all data transactions are handled efficiently, maintaining data integrity and consistency.

4. Integration with Wearable Devices

The system integrates with Fitbit and Xiaomi devices through API endpoints, which facilitate data exchange. These devices send vital sign data to the server, where the Controller processes it and updates the Model accordingly. This integration allows for real-time monitoring, ensuring that healthcare professionals have access to the most current patient information, thereby enhancing the overall quality of patient care.

3.3.2 System User Interface and Front-End Design

With the architectural framework established through the Model-View-Controller (MVC) design, the next critical aspect of the system development is the User Interface (UI) and front-end design. This component is essential for facilitating user interactions and ensuring a seamless experience for healthcare professionals.

The UI is designed to be intuitive and user-friendly, enabling doctors to easily access real-time data from wearable devices and input necessary patient information. By focusing on usability and clarity, the front-end aims to enhance the overall effectiveness of the application, ensuring that vital sign monitoring is efficient and straightforward.

The web application, eDOCTOR, can be accessed via edoctor.ug.ed.gh, directing users to the welcome page. Here, users with valid credentials can sign in, while those without can easily sign up.

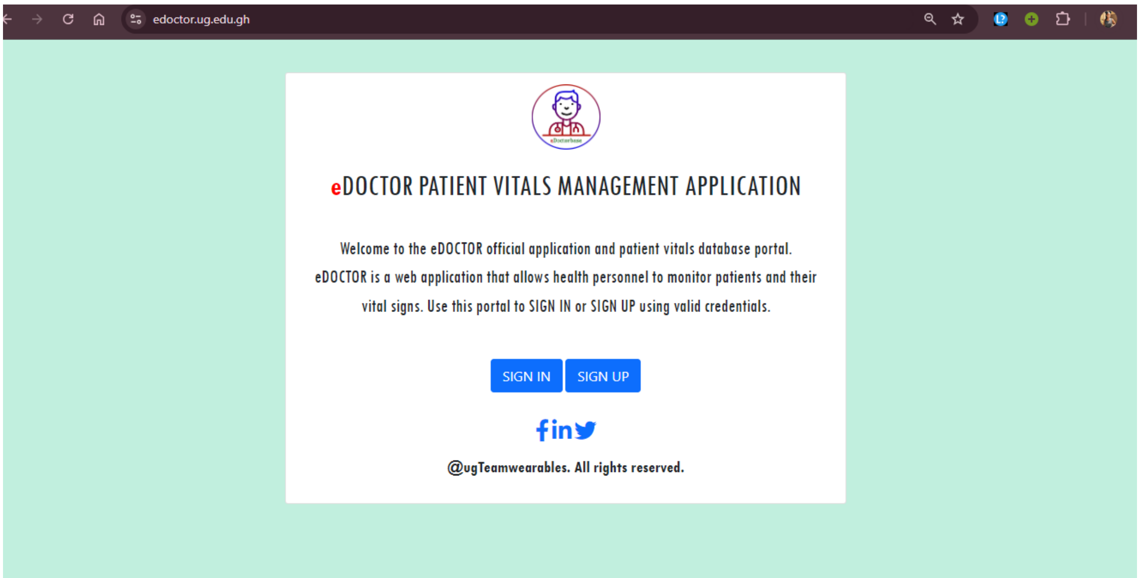


Figure 3.0.2 Welcome Page

To register on eDOCTOR, users must provide essential information, including first and last names, designation (either doctor or nurse), username, and email address.

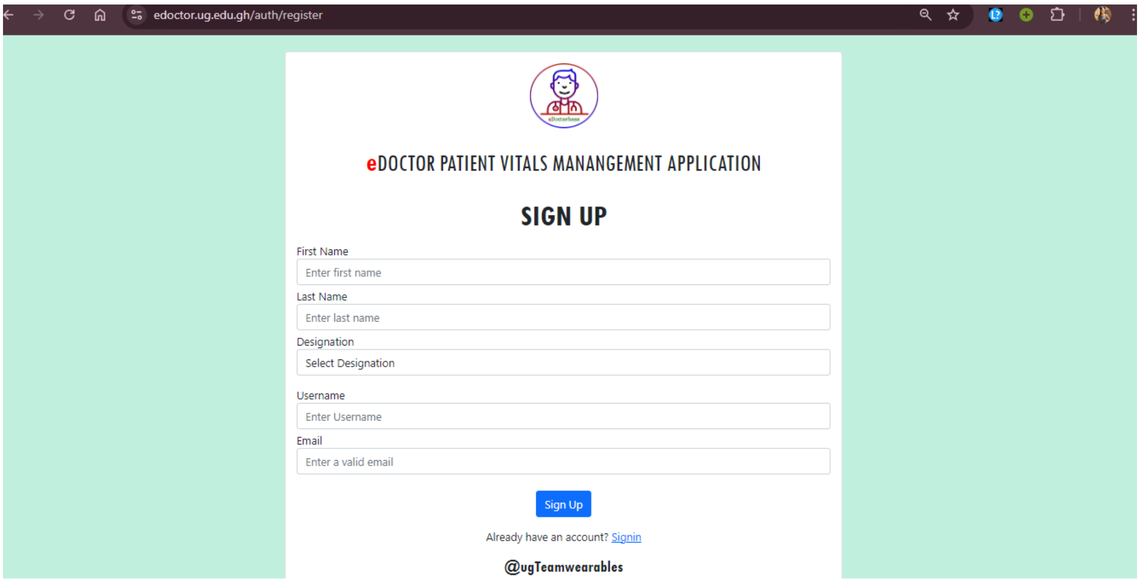


Figure 3.0.3 Sign Up Page

Upon clicking the sign-up button, a confirmation email is sent to the user, notifying them that their application has been submitted to the admin for approval.

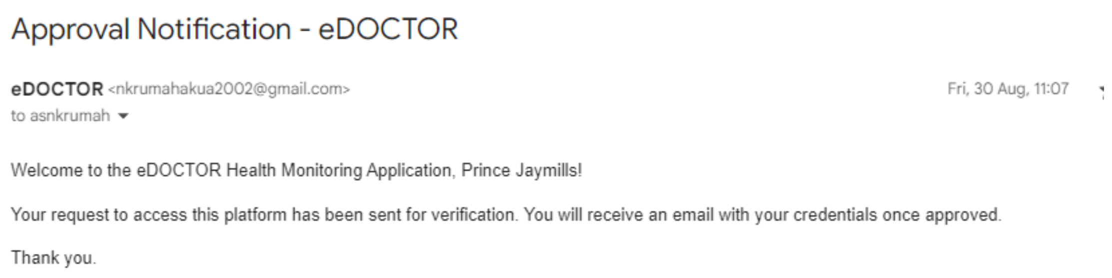


Figure 3.0.4-1 User Approval Notification

Simultaneously, an email is sent to the admin to either accept or decline the application for registration on the platform. This process is implemented to facilitate controlled access to the platform and enhance security, ensuring that only authorized personnel can use the system.

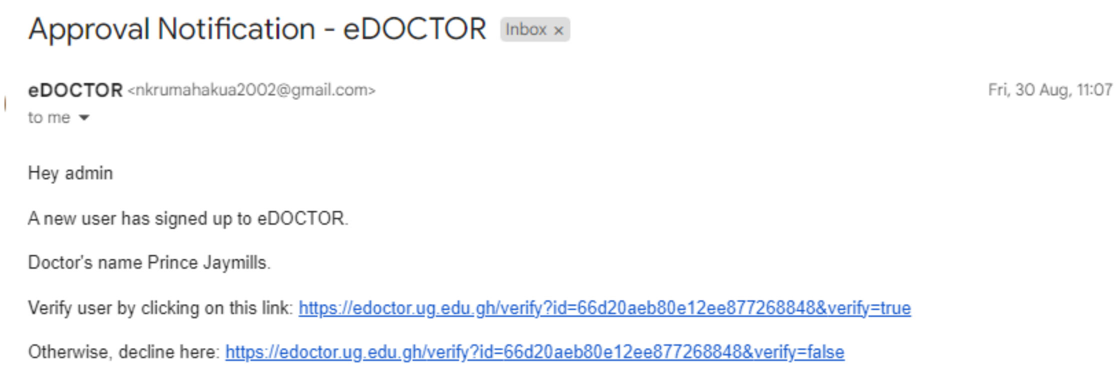


Figure 3-4-2 Admin Approval Notification

When the admin verifies the application, a unique code and password are generated and sent to the user via email. This information is essential for accessing the platform.

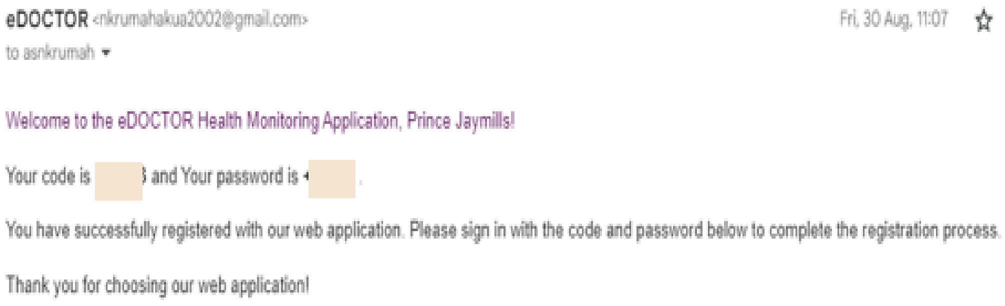


Figure 3-4-3 Code and Password mail

After successful registration and receipt of their login credentials, users are redirected to the Login page, enabling them to access their accounts and navigate to the Dashboard.

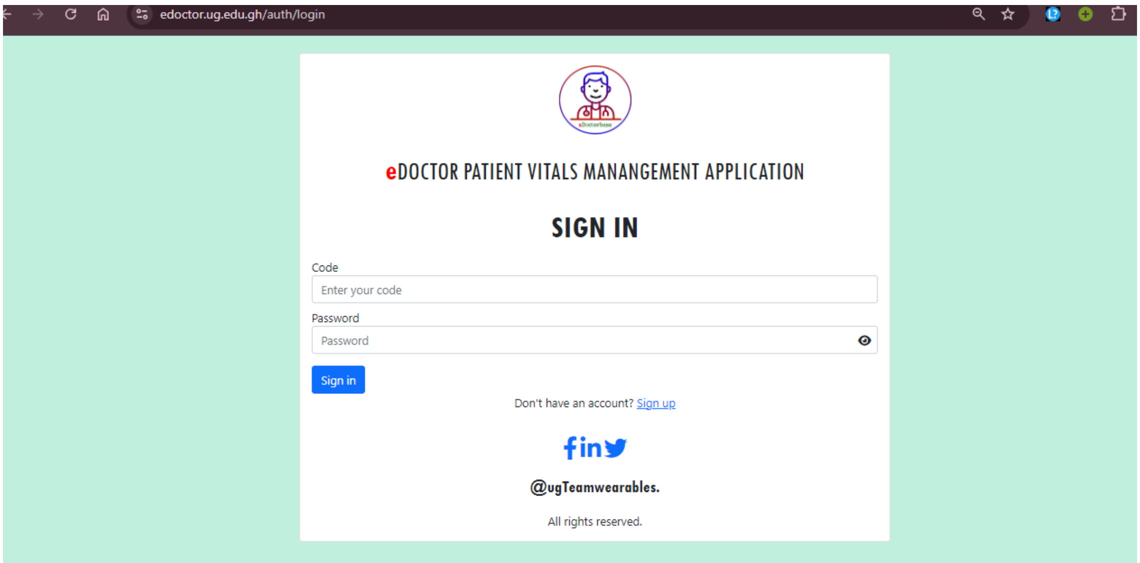


Figure 3-5 Sign In Page

On the Dashboard, the user (doctor) can view a list of currently active patients being monitored. This list includes vital information such as the date of registration, the device assigned to each patient, and the ward they are in (either Paediatric or Accident and Emergency).

The Dashboard features several key functionalities, presented as interactive cards that the doctor can click on to:

View All Patients: Access a comprehensive list of all patients, including both active and inactive ones.

Register New Patient: Easily register a new patient into the system.

View Patient Reports: Obtain detailed reports on active patients.

View Patient Vitals: Monitor real-time vital signs of patients.

Upload Manual Vitals: Input and record vital signs collected manually.

Analyse Vital Signs: Evaluate and analyse the vital signs data for trends and insights.

Export Patient Data: Export patient information, including data from Fitbit, Xiaomi devices, and manually recorded vitals.

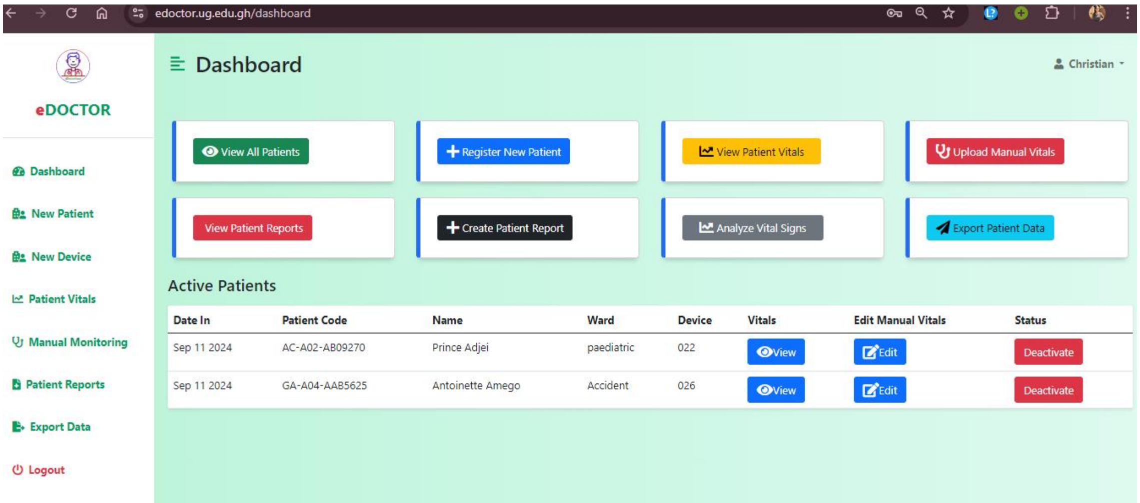


Figure 3-6 Dashboard

Users can also enter patient manual data through the Upload Manual Vitals page, where they can view and edit any previously recorded manual data.

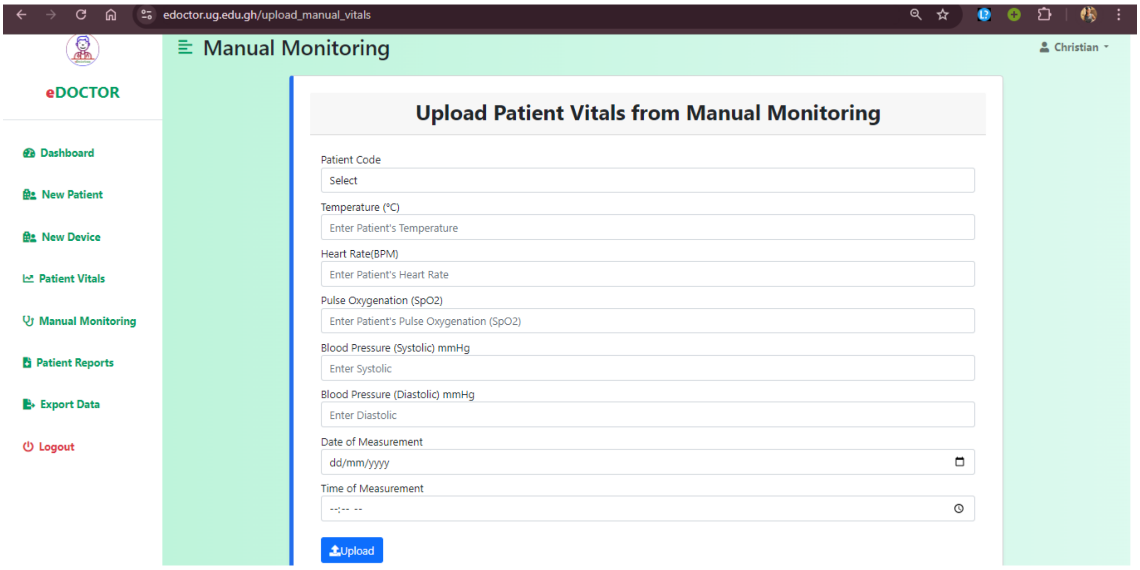


Figure 3-7 Upload Manual Vital Signs Page

Recorded vitals can be displayed graphically on the View Vitals page, accessible to doctors.

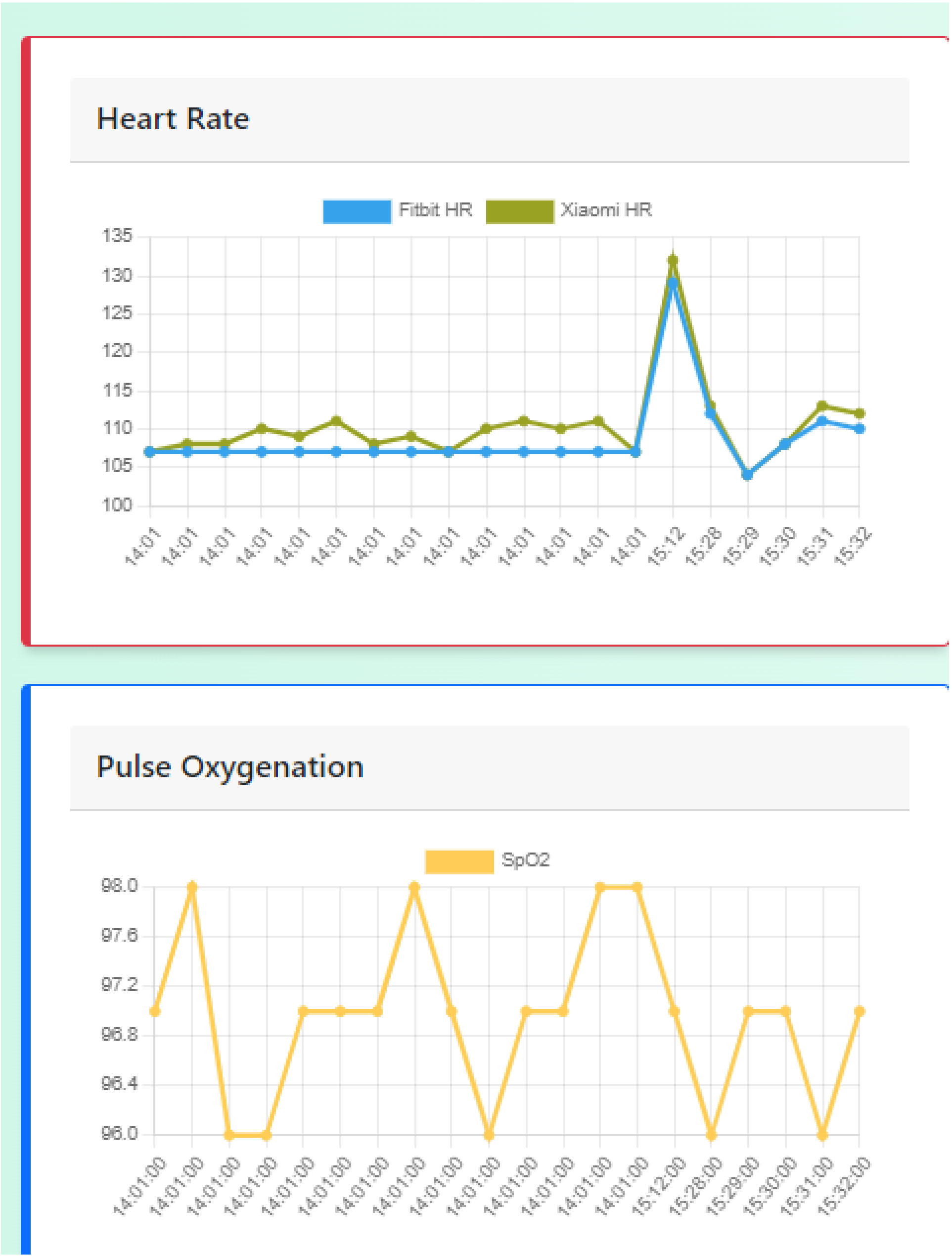


Figure 3-8 Vital Signs Graphs

3.4 System modelling and simulation

3.4.1 Entity Relationship Diagram

The Entity-Relationship Diagram (ERD) provides a structured visual representation of the data architecture within the eDOCTOR system. This diagram captures the entities involved, their attributes, and the relationships between them, serving as a blueprint for the database design.

Key Entities

1. User:
   Attributes:
   - UniqueID: A primary key that uniquely identifies each user.
   - first_name, last_name: Personal identification details.
   - username: A unique identifier for login purposes.
   - email: Contact information for notifications and communication such as login credentials.
   - designation: Role of the user, such as doctor or nurse.
   - code, password: For secure access to the system.

   Description: This entity represents individuals who interact with the eDOCTOR application, ensuring that only authorised personnel can access sensitive patient data.

2. Patient
   Attributes:
   - UniqueID: Primary key for the patient entity.
   - first_name, last_name: Patient's name.
   - patient_code: A unique identifier assigned to each patient.
   - email: Email linked to the wearable device assigned to patient.
   - type_of_patient: ward of the patient (whether paediatric or accident and emergency).
   - is_active: Status indicating whether the patient is currently being monitored.
   - dob: Date of birth.
   - sex: Gender of the patient.

   Description: This entity manages all patient-related information, allowing healthcare providers to monitor and record vital health metrics.

3. Device

Attributes:

deviceID: Unique identifier for each device.
source: Type of device (e.g., Fitbit, Xiaomi).
email: Email associated with the wearable device accounts.
is_active: Status indicating whether the device is currently in use.
access_token, refresh_token, authHeader: Tokens for authenticating device data access.

Description: This entity tracks the wearable devices assigned to patients, enabling the system to gather and manage health data efficiently.

4. Patient Report

Attributes:

deviceID: Foreign key linking to the device used.
patient_code: Links to the patient the report is about.
heart_rate, spo2: Fields for documenting patient abnormal vital signs received.

Description: This entity captures reports generated for patients, allowing healthcare providers to document and analyse patient conditions.

5. Patient Vital

Attributes:

deviceID: Links to the device generating the vital records.
patient_code_id: Foreign key linking to the patient.
heart_rate: Recorded heart rate.
blood_pressure_sys, blood_pressure_dia: Systolic and diastolic blood pressure measurement.
pulse_oxygenation: Recorded pulse oxygenatiom.
temperature: Recorded temperature

Description: This entity stores vital sign data of patients from the manual monitoring.

6. Fitbit Vital and Xiaomi Vital

Attributes:

deviceID: Unique identifier for the device.
patient_code: Links to the relevant patient.
email: Patient's email for record tracking.
time, date: Timestamps for when the data was recorded.
heart_rate, SPO2: Specific health metrics tracked by the respective devices.

Description: These entities specifically handle vital sign data from Fitbit and Xiaomi devices.

7. Procedure

Attributes:

deviceID: Links to the device involved in the procedure.
patient_code: Links to the patient undergoing the procedure.
doctor: Identifies the doctor performing the procedure.
assistant: Additional personnel involved in the procedure.

Description: This entity documents medical procedures conducted on patients, ensuring a comprehensive record of treatment histories.

The relationships depicted in the ERD illustrate how these entities interact with one another:

- User to Patient: A many-to-many relationship, as authorized doctors and nurses can monitor multiple patients, and each patient can be seen by different doctors, requiring an associative entity if necessary.

- Patient to Device: A one-to-many relationship, as each patient can be associated with two devices (Fitbit and Xiaomi) while each device is linked to one patient.

- Patient to Patient Report: A one-to-many relationship, where each patient can have multiple reports documenting their health status.

- Patient Vital Records: Each patient can have multiple entries of vital signs recorded, creating a one-to-many relationship between patients and their vital records.

- Patient to Procedure: A one-to-many relationship, with each patient being able to undergo multiple procedures over time.

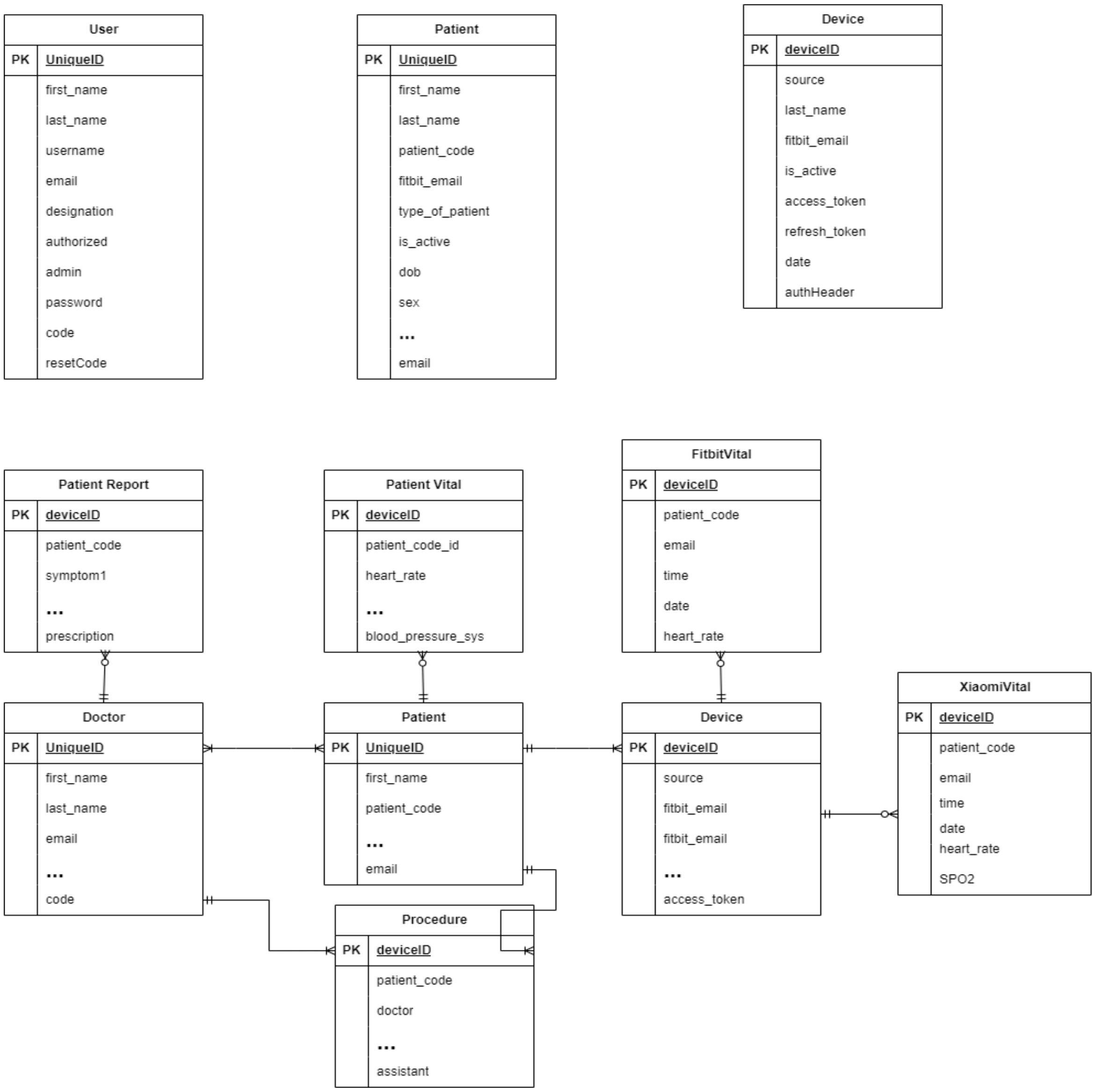


Figure 3-9 Entity Relational Diagram

This ERD serves as a foundational element for the database design within the eDOCTOR system. It ensures data integrity by clearly defining how data entities relate to one another, facilitating efficient data retrieval and management. By structuring the entities and their relationships explicitly, the system can effectively handle patient data, monitor vital signs, and generate reports, ultimately supporting the application's objectives of enhancing patient care and streamlining healthcare processes.

3.4.2 Data Flow Diagram

The Data Flow Diagram (DFD) illustrates the movement of data within the eDOCTOR system, highlighting how information is collected, processed, and delivered to users. The diagram consists of several key components:

Data from Devices: Initial vital sign data is collected from patient to the wearable devices via sensors.

Device Apps on Phones: The data is transmitted to the mobile applications associated with the devices (Mi Fitness for Xiaomi and Fitbit LLC for Fitbit) via a Bluetooth connection.

Fitbit & Xiaomi Servers: The data is sent to the respective servers of Fitbit and Xiaomi over the internet, where it is stored and managed via internet connection.

Server: The database server of the eDOCTOR application retrieves the data from the Fitbit and Xiaomi servers. This server acts as a mediator, ensuring that the data is correctly formatted and ready for use.

eDOCTOR: Finally, the processed data is transmitted to the eDOCTOR application, where healthcare professionals can access and analyse it in real-time.

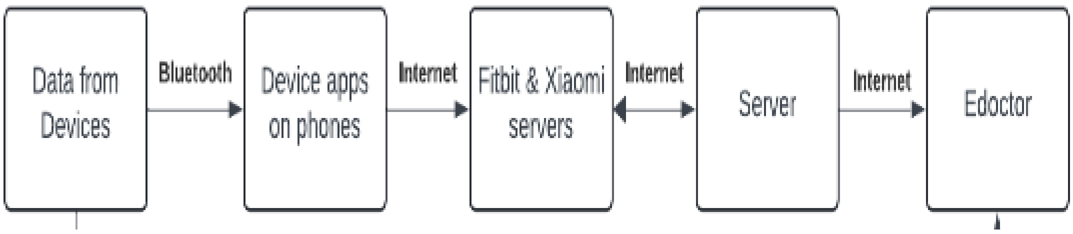


Figure 3-10 Data flow from devices to web application

This flow of data ensures that vital patient information is efficiently collected, stored, and made accessible to authorised users, facilitating timely medical interventions and enhancing patient care.

```
const axios =require('axios');
const FitbitVital = require('../models/FitbitVital');

async function fitbitFetch(device,patient){
    try {
      // Get Fitbit heart rate data
    const url = `https://api.fitbit.com/1/user/${device.device_id}/activities/heart/date/today/today/1min/time/
00:00/23:59.json`;
    const headers = {
      'Accept': 'application/json',
      'Authorization': `Bearer ${device.access_token}`,
    };

    const response = await axios.get(url, { headers });
    const data = response.data['activities-heart-intraday']['dataset'];


  console.log('->',patient.is_active ? patient.patient_code :'not active',patient.is_active ? data: 'inactive');
    for (const item of data) {
      const exists = await FitbitVital.findOne({
        patient_code:patient.patient_code,
        email: patient.fitbit_email,
        time: item.time,
        heart_rate: item.value,
      });

      if (!exists) {
        await FitbitVital.create({
```

Figure 3-11 Code snippet for fetching Fitbit data

```
const { google } = require('googleapis');
const User = require("../models/user");
const fitness = google.fitness({ version: 'v1', auth: oauth2Client });
async function fetchHeartRateData(fitness, User) {
    const dataSourcesResponse = await fitness.users.dataSources.list({
        userId: 'me',
    });
    const heartRateSource = dataSourcesResponse.data.dataSource.find(source =>
        source.dataType.name === 'com.google.heart_rate.bpm'
    );
    if (!heartRateSource) {
        console.error('Heart rate data source not found');
        return;
    }
    const dataSourceId = heartRateSource.dataStreamId;
    const startTime = Date.now() - 1 * 24 * 60 * 60 * 1000; // 7 days ago
    const endTime = Date.now();
    const datasetId = `${startTime * 1e6}-${endTime * 1e6}`; // Convert to nanoseconds
    console.log(datasetId);

    const heartRateResponse = await fitness.users.dataSources.datasets.get({
        userId: 'me',
        dataSourceId: dataSourceId,
        datasetId: datasetId,
    });

    console.log('Heart Rate Data:', heartRateResponse.data);
}
//Fetch data for a single user
  async function fetchUserData(clientId) {
    const user = await getUserById(clientId);
    const fitness = google.fitness({ version: 'v1', auth: user.accessToken });
```

Figure 3-12 Code snippet for fetching Xiaomi Data

3.5 Development tools and material requirements

In this section, we outline the development tools, technologies, and materials required to build the eDOCTOR application, highlighting the specific choices made during the development process.

3.5.1 Development Tools

Programming Languages and Frameworks

Frontend:

EJS (Embedded JavaScript): Used for templating to generate dynamic HTML content, enabling the creation of interactive and responsive user interfaces.

CSS: Employed for styling the user interface, ensuring a responsive and visually appealing design. Bootstrap was also used to enhance the efficiency of UI design with pre-designed components and a responsive grid system.

Backend:

Node.js: Chosen for server-side programming, enabling a non-blocking, event-driven architecture that is essential for handling real-time data processing.

Express: A web framework for Node.js that simplifies routing and middleware management, facilitating the development of web servers and APIs.

Database Management

MongoDB: A NoSQL database used for storing user, patient, and device data, allowing for flexible data models and scalability. It is well-suited for applications requiring high scalability and flexibility in data management.

Development Environment

Visual Studio Code (VSCode): The primary IDE used for coding, offering a range of extensions and features to enhance productivity. Sublime Text is also utilized for writing, editing, and debugging code.

Version Control

Git: Utilised for version control, enabling collaboration among developers by tracking changes in the codebase.

GitHub: Used for repository hosting and managing code contributions, ensuring all team members work with the most up-to-date code.

Documentation Tools

Google Docs: Utilised for project documentation, collaboration, and version control of written materials. It facilitates easy sharing and editing among team members.

Figma: Employed for designing the user interface and user experience (UI/UX) of the web application. Figma allows multiple team members to collaborate in real-time, streamlining the design process [9].

3.5.2 Material Requirements

Hardware Requirements

Development Machine: A computer with a multi-core processor, at least 8GB of RAM, and sufficient storage to support development tools and databases.

Wearable Devices: Thirty devices each: Fitbit Inspire 3 and Xiaomi Smart Band 8, for testing and data collection.

Networking Equipment

Router and Internet Connection: A reliable internet connection is needed for cloud services, API interactions, and remote collaboration.

Hosting Services

University Server: The application is hosted on the university server, ensuring reliable access and support from the institution.

Testing and Collaboration Tools

Postman: Used for testing APIs and ensuring proper data flow between the frontend and backend, facilitating efficient debugging and communication.

Design and Collaboration Tools

Figma: For user interface design and prototyping, enabling a collaborative approach to UI development.

Google Docs: For collaborative documentation and project tracking, maintaining clarity and cohesion among team members.

Chapter 4 – Implementation and Testing

4.0 Introduction

This chapter focuses on the implementation and testing of the eDOCTOR application. It begins with the system implementation process, which includes a pilot study conducted at Korle-Bu Teaching Hospital. This phase involved the recruitment of patients and the monitoring of their health metrics using wearable devices.

Following the implementation, the chapter discusses the testing and results, detailing the methodologies applied to assess the application's functionality and performance. The analysis of these results will be examined in the subsequent section, highlighting their significance in the context of patient monitoring and healthcare delivery.

Lastly, the chapter addresses the performance evaluation and limitations of the system, identifying challenges encountered during implementation and offering insights for future enhancements.

4.1 System implementation process

4.1.1 Pilot Study

The pilot study aimed to evaluate how data is transmitted and received from the Fitbit and Xiaomi devices, focusing on the volume of data transmitted and the mechanisms of data transmission to their respective services.

For this study, we selected six patients, comprising three from the paediatric unit and three from the Accidents and Emergencies centre. Each unit was assigned three devices: Xiaomi Smart Band and two Fitbit devices.

The devices were placed on the patients for a duration of three days, allowing for continuous data collection and monitoring of vital signs, including heart rate and oxygen saturation. The Fitbit devices primarily measured heart rate, while the Xiaomi Smart Band monitored both heart rate and oxygen saturation.

After three days, the research team returned to the hospital to retrieve the devices. The devices were then synced with the respective Mi Fit and Fitbit apps, enabling the data collected over the monitoring period to be transmitted to the Xiaomi and Fitbit servers.

To export the data collected from the Fitbit devices, the following steps were completed:

Access the Fitbit Dashboard by navigating to fitbit.com/dashboard and log in using the specific email associated with the device from which the data was accessed.
Go to Settings: Once logged in, I clicked on the settings icon located in the top right corner of the dashboard.
Select Data Export: In the settings menu, I found and selected the Data Export option.
Choose Export File Type: After selecting data export, I chose the export file type, which was .zip.
Receive Data via Email: The data was then compiled and sent to the email addresses associated with the devices.

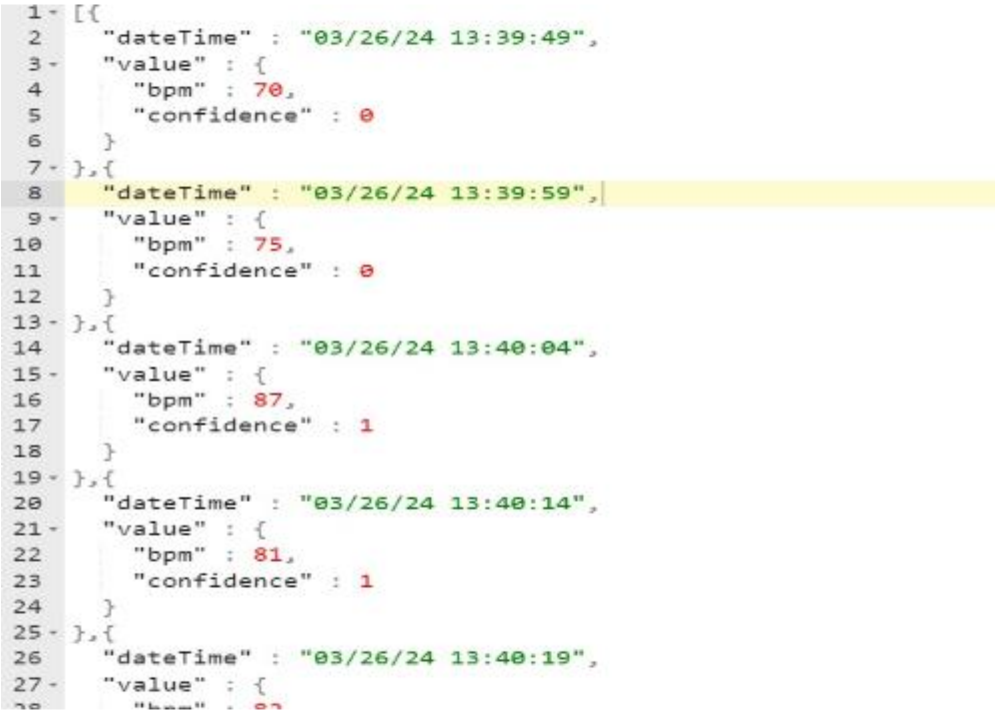


Figure 4-0.1 Snippet of exported Fitbit data

To export the data collected from the Xiaomi devices, the following steps were completed:

Access the Xiaomi Website by navigating to mi.com/global and log in using the email associated with the device.
Go to My Account: Once logged in, click on My Account.
Select Privacy: In the account settings, select the Privacy option.
Authenticate Data: A verification mail will be sent to authenticate user.
Manage Data: Select manage data and download.
Receive Data via Email: The exported data was sent to the registered email address associated with the device.

Time	Value	Date edited	Time edite	BPM
1711720320	{"time":1711720320,"bpm":95}	29/03/2024	1:52 pm	95
1711720260	{"time":1711720260,"bpm":82}	29/03/2024	1:51 pm	82
1711720200	{"time":1711720200,"bpm":84}	29/03/2024	1:50 pm	84
1711720140	{"time":1711720140,"bpm":93}	29/03/2024	1:49 pm	93
1711720080	{"time":1711720080,"bpm":96}	29/03/2024	1:48 pm	96
1711720020	{"time":1711720020,"bpm":94}	29/03/2024	1:47 pm	94
1711719960	{"time":1711719960,"bpm":86}	29/03/2024	1:46 pm	86
1711719900	{"time":1711719900,"bpm":91}	29/03/2024	1:45 pm	91
1711719840	{"time":1711719840,"bpm":95}	29/03/2024	1:44 pm	95
1711719780	{"time":1711719780,"bpm":92}	29/03/2024	1:43 pm	92
1711719720	{"time":1711719720,"bpm":94}	29/03/2024	1:42 pm	94
1711719660	{"time":1711719660,"bpm":94}	29/03/2024	1:41 pm	94
1711719600	{"time":1711719600,"bpm":92}	29/03/2024	1:40 pm	92
1711719540	{"time":1711719540,"bpm":91}	29/03/2024	1:39 pm	91
1711719480	{"time":1711719480,"bpm":94}	29/03/2024	1:38 pm	94
1711719420	{"time":1711719420,"bpm":94}	29/03/2024	1:37 pm	94
1711719360	{"time":1711719360,"bpm":85}	29/03/2024	1:36 pm	85
1711719300	{"time":1711719300,"bpm":97}	29/03/2024	1:35 pm	97
1711719240	{"time":1711719240,"bpm":101}	29/03/2024	1:34 pm	101
1711719180	{"time":1711719180,"bpm":94}	29/03/2024	1:33 pm	94
1711719120	{"time":1711719120,"bpm":90}	29/03/2024	1:32 pm	90
1711719060	{"time":1711719060,"bpm":93}	29/03/2024	1:31 pm	93
1711719000	{"time":1711719000,"bpm":104}	29/03/2024	1:30 pm	104
1711718940	{"time":1711718940,"bpm":94}	29/03/2024	1:29 pm	94

Figure 4-0.2 Snippet of exported Xiaomi data

4.1.2 Recruitment of Patients

After analysing the content of the data and understanding how it is transmitted and stored, the eDOCTOR web application was designed to efficiently retrieve, process, and present this data in a viewable and accessible format. This functionality ensures that the exported data can be easily utilized for further analysis.

Following the data processing setup, the recruitment phase commenced. So far, 23 patients have been recruited onto the eDOCTOR platform. During this recruitment process at Korle-Bu Teaching Hospital, research staff presented consent forms to the guardians of the patients, ensuring that both the patients and their guardians were informed participants in the study. Ethical clearance had been obtained prior to this recruitment, allowing the project to move forward.

The consent process was particularly important for minors. For children unable to provide verbal consent, their guardians signed the consent forms on their behalf. For older children capable of understanding the study, both the minors and their guardians signed the consent forms before any devices were placed on them.

4.1.3 Data Integration and Device Linking

For the recruited patients, email addresses were created and associated with the IDs assigned to each pair of Fitbit and Xiaomi devices, following the convention of IDs ranging from 001 to 030. This setup facilitated the integration of the wearable devices with the eDOCTOR platform.

Both the Fitbit and Xiaomi devices were placed on the same wrist of each patient, allowing for simultaneous monitoring. The devices were synced with the Mi Fit and Fitbit apps via Bluetooth, ensuring continuous data transmission from the devices to the respective applications. With a reliable internet connection, data was transported to the Fitbit and Xiaomi services over the duration of the patient's stay.

During this process, the eDOCTOR platform made calls every 15 seconds to retrieve data from the devices. The Fitbit device provided heart rate readings, while the Xiaomi Smart Band monitored both heart rate and oxygen saturation.

It is important to note that the devices were linked to the eDOCTOR application using access tokens which are used to obtain data from the Fitbit and Xiaomi servers. This authentication process ensured secure and efficient data access, allowing for real-time monitoring of the patients' vital signs.

The access tokens used to link the Fitbit and Xiaomi devices to the eDOCTOR application have an expiration period of 8 hours. After this time, the tokens become invalid, requiring a refresh to maintain continuous data access.

To manage this, the system is designed to automatically call a function after a period of 7 hours and 30 minutes. This function requests refresh tokens, which are then used to obtain new access tokens. The refresh tokens allow the application to request new access tokens without requiring the user to log in again, ensuring seamless data retrieval from the devices.

This token management process is crucial for maintaining uninterrupted access to the health data collected from the wearable devices, enabling the eDOCTOR platform to continuously monitor patients' vital signs in real-time. By automating the refresh process, the system enhances user experience and ensures that the data flow remains uninterrupted throughout the duration of patient monitoring.

The nursing staff performed normal manual monitoring and recording of vital signs at 4-hour intervals as part of the implementation process. Each patient trial had an average duration of about two to four days, during which data was collected from the wearable devices alongside manual recordings.

For each patient, the data from the Fitbit, Xiaomi devices, and manual monitoring were exported as .CSV files. This data collection approach allowed for a comprehensive comparison between the readings obtained from the wearable devices and the traditional manual monitoring methods.

4.2 Testing and results

Following the data collection, a detailed analysis was conducted to compare the device readings with the manual readings. The focus was specifically on the vital signs captured by the devices: the Fitbit measured heart rate, while the Xiaomi Smart Band monitored both heart rate and oxygen saturation.

This analysis provided a clearer picture of how well the wearable devices performed in comparison to standard manual monitoring.

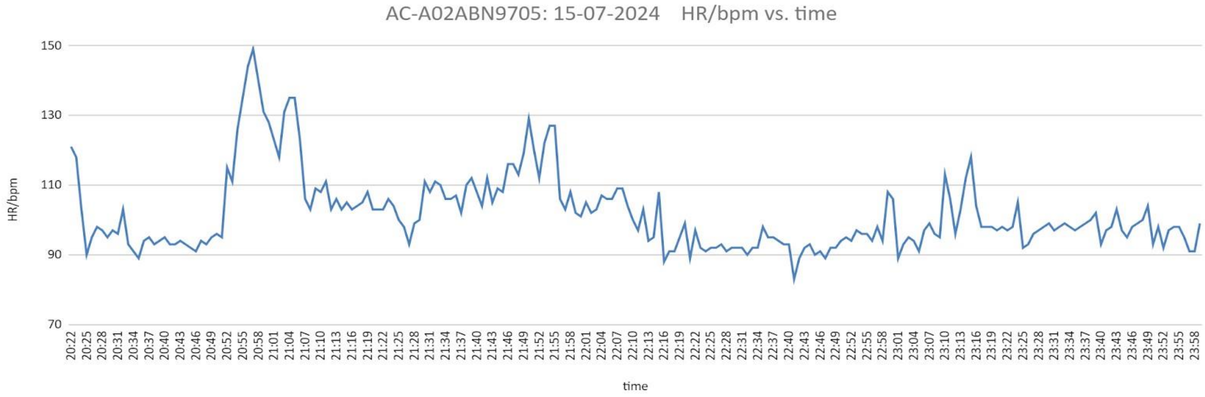
Out of the 23 patients recruited for the study, the results for two patients are presented to illustrate the data collected from the Fitbit and Xiaomi devices. The following tables and graphs display the vital signs monitored during the trial period, highlighting the comparative readings between the wearable devices and manual monitoring.

Patient 1: Data Summary

- **Patient ID**: AC-A02ABN9705
- **Duration of Stay**: From 15th July 2024, 8:22 PM to 18th July 2024, 10:33 AM

The following graph displays the heart rates recorded from the Fitbit device throughout the patient's stay.

Figure 4-0.3 Heart rate vs time plot from Fitbit for patient AC-A02ABN9705 on 15/07/2024



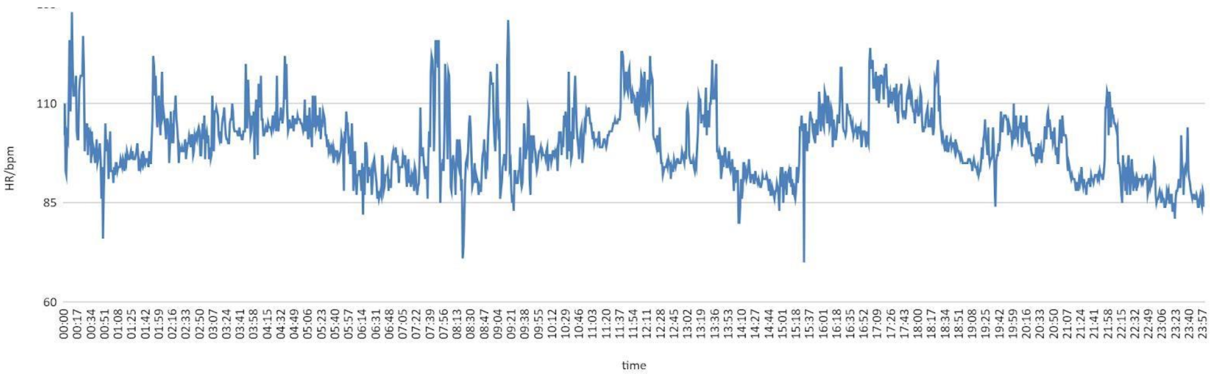


Figure 4-0.4 Heart rate vs time plot from Fitbit for patient AC-A02ABN9705 on 16/07/2024

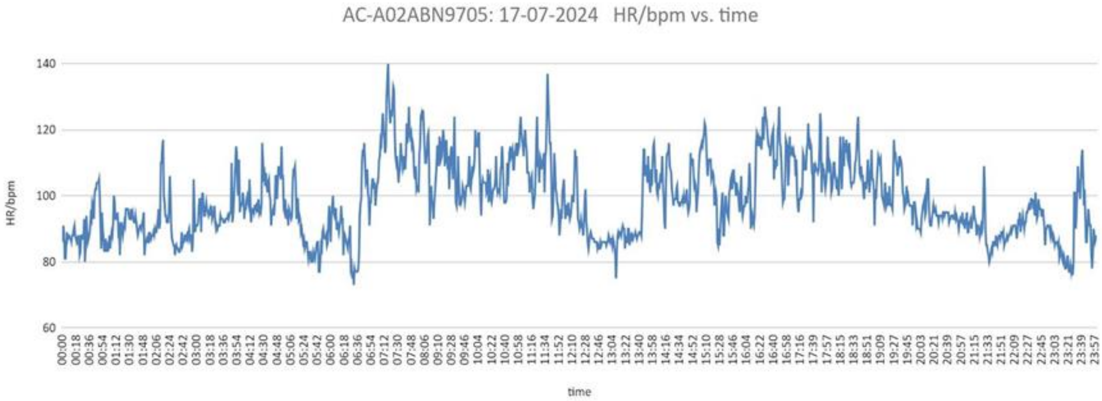


Figure 4-0.5 Heart rate vs time plot from Fitbit for patient AC-A02ABN9705 on 17/07/2024

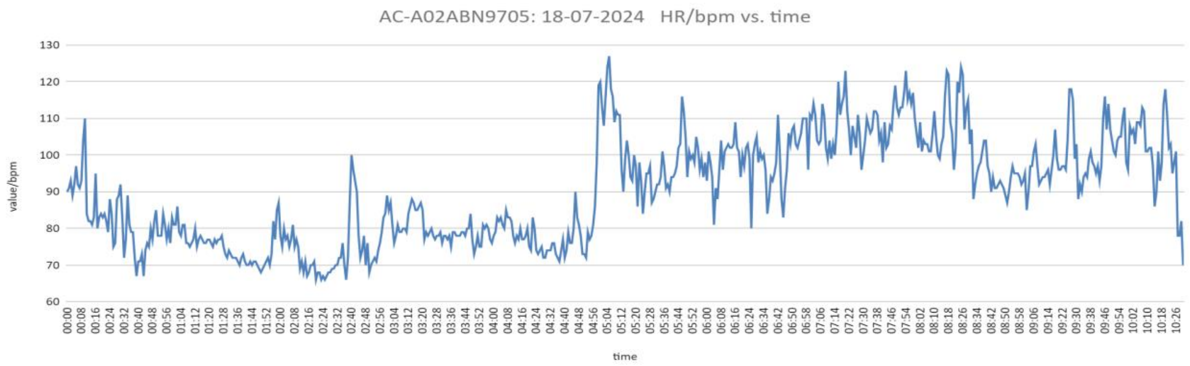


Figure 4-0.6 Heart rate vs time plot from Fitbit for patient AC-A02ABN9705 on 18/07/2024

Table 4-0-1 Combined data from fitbit, xiaomi and manual data for patient AC-A02ABN9705

Date	Time	Heart Rate_manual	Heart Rate_fitbit	Heart Rate_Xiaomi	Pulse Oxygenation_manual	SPO2_Xiaomi
15/07/2024	20:20	120	120		96	
15/07/2024	22:30	121	92	88	99	98
16/07/2024	00:25	128	119	106	98	98
16/07/2024	03:30	110	106	104	98	97
16/07/2024	06:00	110	95	103	98	97
16/07/2024	08:30	103	104	121	98	97
16/07/2024	10:27	98	107	103	97	97
16/07/2024	13:16	111	112	99	98	98
16/07/2024	16:00	128	110	124	98	98
16/07/2024	18:00	112	107	92	98	98
16/07/2024	22:00	121	113	111	99	98

17/07/2024	06:00	100	86	105	99	97
17/07/2024	08:00	121	115	104	100	98
17/07/2024	10:43	99	110	86	98	99
17/07/2024	14:00	78	116	117	99	
17/07/2024	18:00	96	107	102	99	
17/07/2024	22:00	97	87	86	99	
18/07/2024	00:00	120	90	84	100	
18/07/2024	02:00	80	78	84	98	
18/07/2024	04:00	96	78	84	99	
18/07/2024	06:00	108	93	84	99	
18/07/2024	08:00	100	106	85	99	

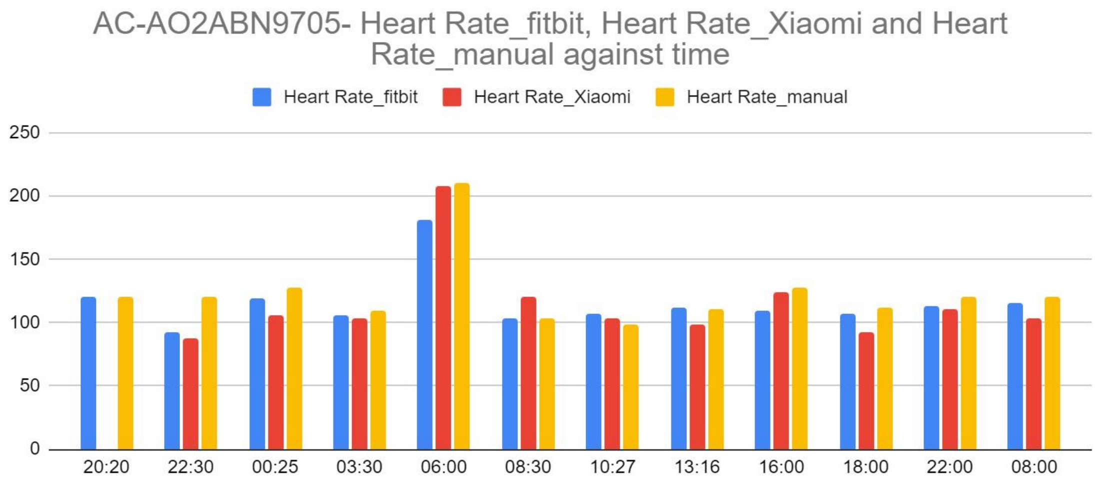


Figure 4-0.7 Heart rate vs time plot from Fitbit and Xiaomi against manual readings for patient AC-A02ABN9705

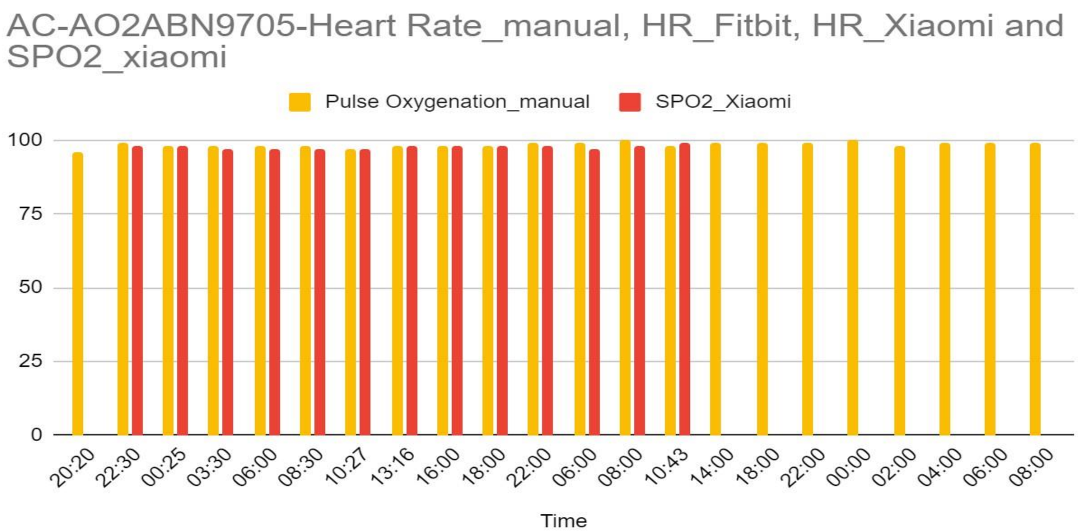


Figure 4-0.8 Oxygen Saturation from Xiaomi and manual readings against Time for patient AC-A02ABN9705

Table 4-.0-2 Heart rate comparison between Fitbit, Xiaomi, and manual monitoring for patient AC-A02ABN9705

Heart_Rate_manual	**Heart_Rate_fitbit**	**Fitbit_Percentage_Error**	**Heart_Rate_Xiaomi**	**Xiaomi_Percentage_Error**
120	120	0.00	100	16.67
121	97	19.83	88	27.27
128	127	0.78	106	17.19
110	109	0.91	104	5.45
110	98	10.91	103	6.36
103	105	1.94	121	17.48

98	96	2.04	103	5.10
111	111	0.00	99	10.81
128	114	10.94	124	3.13
112	111	0.89	92	17.86
121	116	4.13	111	8.26
100	91	9.00	105	5.00
121	121	0.00	104	14.05

For Fitbit Heart Rate

- MAPE (Mean Absolute Percentage Error): 4.72%
- RMSE (Root Mean Squared Error): 8.91
- R-squared (Coefficient of Determination): 0.13 (indicating a weak positive correlation)

For Xiaomi Heart Rate:

- MAPE (Mean Absolute Percentage Error): 11.89%
- RMSE (Root Mean Squared Error): 16.13
- R-squared (Coefficient of Determination): -1.83 (indicating a poor fit and potentially an inverse relationship)

Table 4- 0-3 Oxygen Saturation comparison between Xiaomi, and manual monitoring for patient AC-A02ABN9705

Pulse_Oxygenation_manual	SPO2_Xiaomi	SPO2_Percentage_Error
96	96	0.00
99	98	1.01
98	98	0.00
98	97	1.02
98	97	1.02
98	97	1.02
97	97	0.00
98	98	0.00
98	98	0.00
98	98	0.00
99	98	1.01
99	97	2.02
100	98	2.00

Xiaomi SPO2:

- MAPE (Mean Absolute Percentage Error): 0.70%
- RMSE (Root Mean Squared Error): 1.0
- R-squared (Coefficient of Determination): -0.11 (indicating a poor fit)

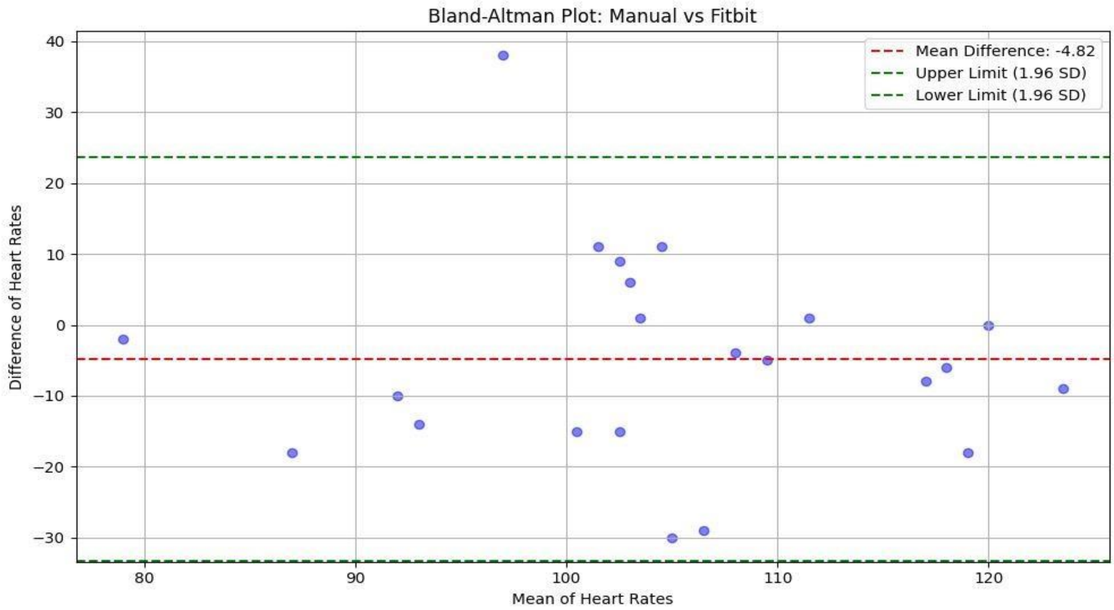


Figure 0.9 Bland-Altman Plot of manual vrs fitbit heart rate for patient AC-AO2ABN9705

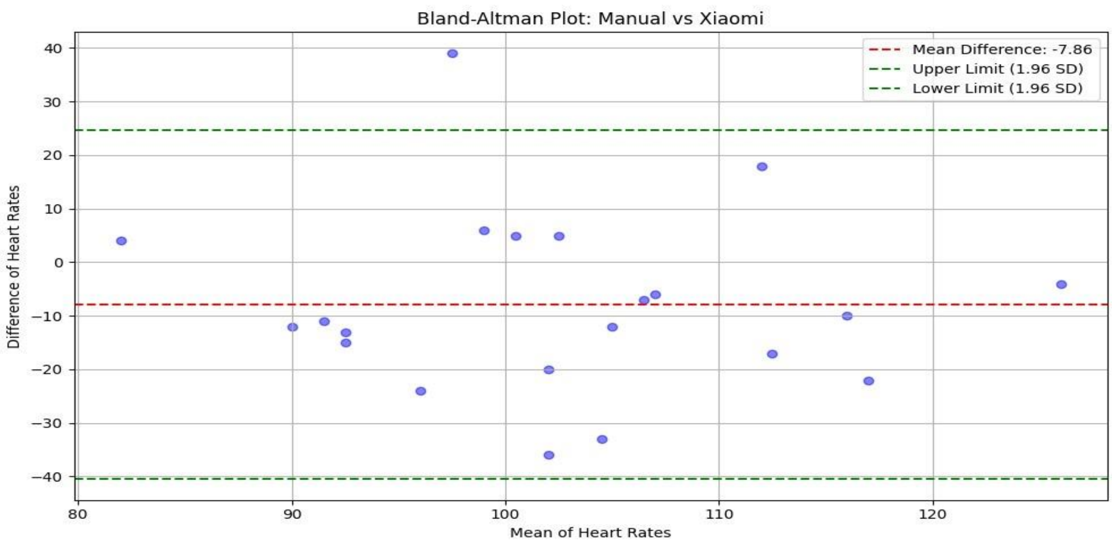


Figure 0.10 Bland-Altman Plot of manual vrs xiaomi heart rate for patient AC-AO2ABN9705

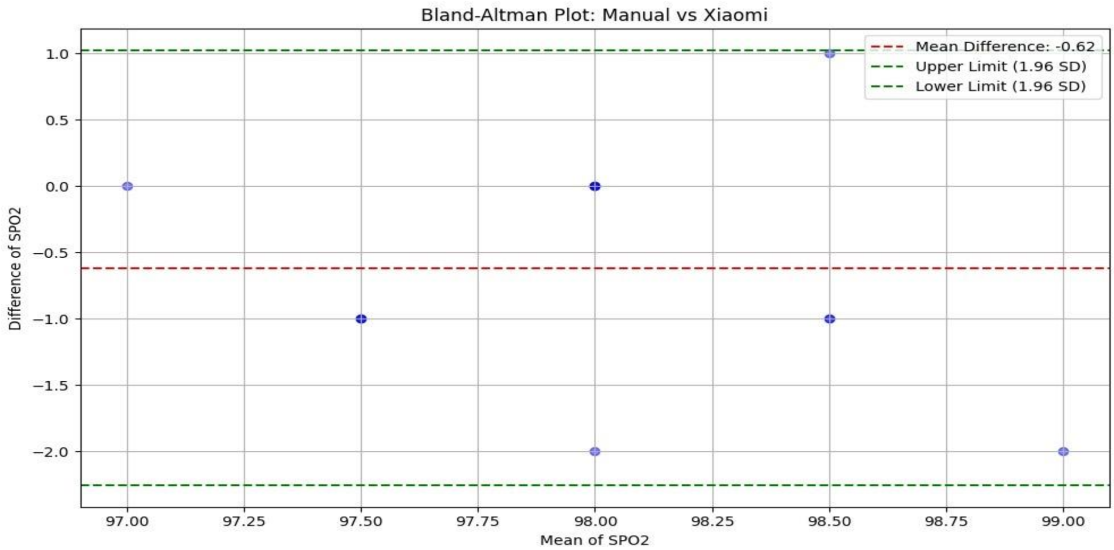


Figure 4.11 Bland-Altman Plot of manual vrs xiaomi oxygen saturation for patient ACAO2ABN9705

Patient 2: Data Summary

- **Patient ID**: AC-A02ABN7994
- **Duration of Stay**: From 5th July 2024, 5:45 PM to 8th July 2024, 10:45 AM

  The following graph displays the heart rates recorded from the Fitbit device throughout the patient's stay.

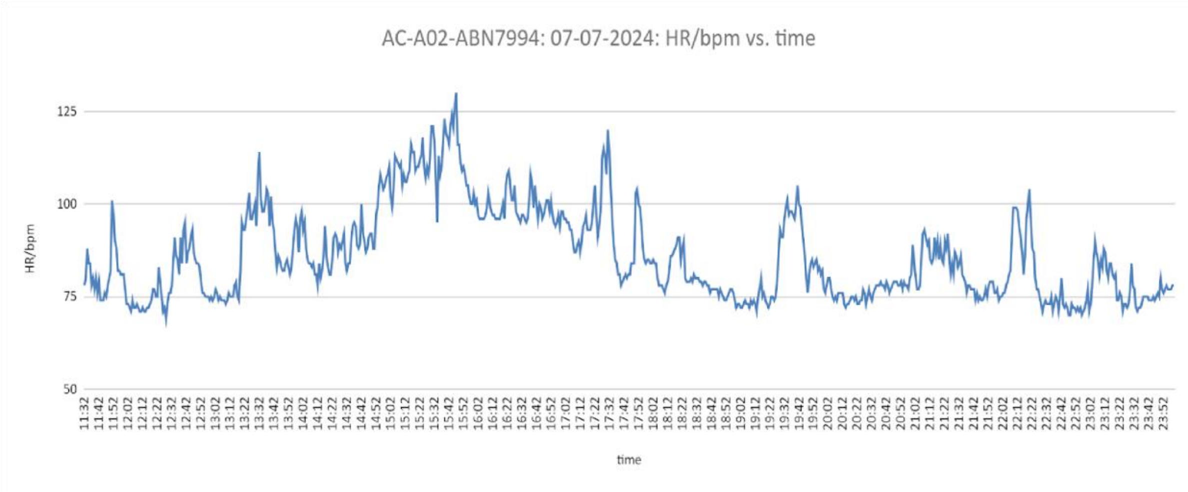


Figure 0.11 Heart rate vs time plot from Fitbit for patient AC-A02-ABN7994 on 7/07/2024

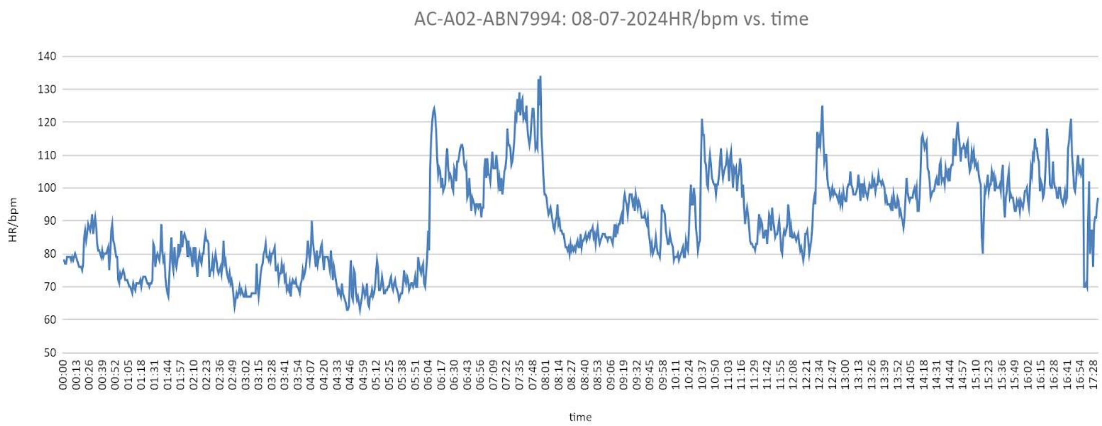


Figure 0.12 Heart rate vs time plot from Fitbit for patient AC-A02-ABN7994 on 8/07/2024

Table 4-0-4 Combined data from fitbit, xiaomi and manual data for patient AC-A02-ABN7994

Date	**Time**	**Heart Rate_manual**	**Heart Rate_fitbit**	**Heart Rate_xiaomi**	**Blood Oxygenation_manual**	**Blood Oxygenation**

05/07/2024	18:00	96	95	100	98	98
05/07/2024	20:00	104	101	111	96	98
05/07/2024	22:00	108	102	115	98	97
06/07/2024	00:00	76	80	100	98	98
06/07/2024	02:00	90	92	103	98	98
06/07/2024	04:00	102	94	100	97	95
06/07/2024	06:00	76	82	80	98	95
06/07/2024	20:00	90	89	94	98	96
06/07/2024	22:00	104	103	112	98	98
07/07/2024	00:00	98	99	102	97	96
07/07/2024	02:00	98	98	102	99	99
07/07/2024	04:00	97	96	98	99	97
07/07/2024	10:00	117	117	115	96	95
07/07/2024	12:00	86	77	89	97	94
08/07/2024	10:30	97	97	99	99	98

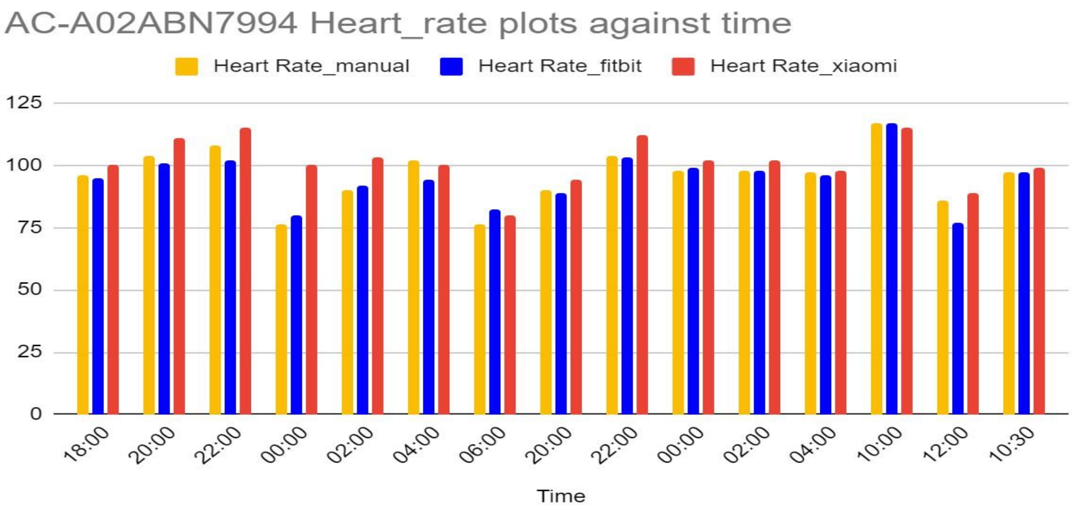


Figure 0.13 Heart rate vs time plot from Fitbit, Xiaomi and Manual readings against Time for patient AC-A02-ABN7994

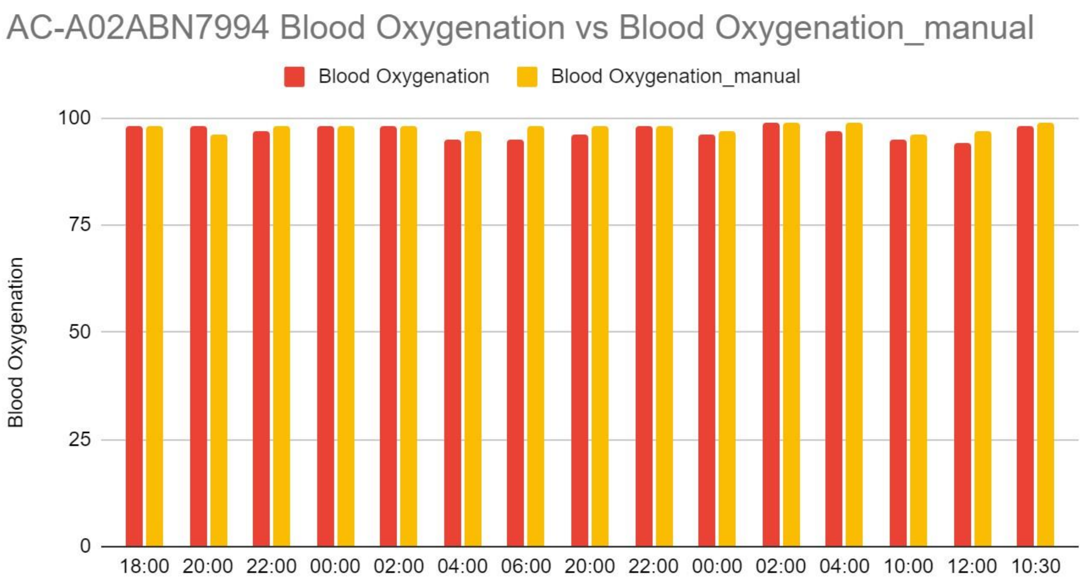


Figure 0.14 SPO2 vs time plot from Xiaomi and Manual readings against Time for patient AC-A02-ABN7994

4.3 Discussion of results and analysis

Figures 4.3 to 4.8 and Tables 4.1 to 4.3 provide a comprehensive analysis of patient ACA02ABN9705 over three days, focusing on heart rate and oxygen saturation measurements.

4.3.1 Continuous Heart Rate Monitoring

Figure 4.3 depicts the continuous heart rate graph, which begins at 20:22 and ends at 23:58. The initial heart rate was approximately 120 beats per minute (bpm). At around 20:55, there was a sudden spike to 150 bpm, followed by a rapid decrease. Fluctuations were observed between 21:15 and 22:15, suggesting periods of activity and potential stress, with heart rates ranging between 90 and 110 bpm.

Figure 4.4 shows the continuous heart rate data for the following day over a 24-hour period, with significant fluctuations between 60 and 135 bpm. Notable peaks above 120 bpm occurred before 1:30 AM, followed by a more stable heart rate between 2:00 AM and 6:00 AM, indicating sleep and rest. The period from 7:00 AM to 5:00 PM displayed fluctuations likely related to daily activities, while from 6:00 PM onward, the heart rate began to stabilize, reflecting relaxation or preparation for sleep.

Figure 4.5 illustrates another 24-hour heart rate graph, with values varying from 60 to 140 bpm. In the early morning hours before 6:00 AM, stable heart rates were recorded between 80 and 100 bpm. A rise was noted from 7:00 AM to 8:00 AM, with peaks near 140 bpm, indicating increased activity. From 8:00 AM to 1:00 PM, frequent peaks above 120 bpm were observed, suggesting heightened activity levels.

4.3.2 Comparative Data Analysis

Table 4.1 presents the manual measurements of heart rate and oxygen saturation alongside the corresponding Fitbit and Xiaomi values. These data points were used to create a histogram of heart rate measurements in Figure 4.7 and a histogram of oxygen saturation measurements in Figure 4.8.

It is important to note that the Xiaomi device did not record values at certain times for both heart rate and oxygen saturation. This absence could be attributed to the device losing contact with the skin, which is particularly critical for measuring oxygen saturation, as the patient must remain still for accurate readings. Any movement during the measurement process may interfere with the Xiaomi sensor's ability to capture these vital signs effectively.

Error Analysis of Heart Rate and Oxygen Saturation Measurements
Heart Rate Measurement Accuracy
Table 4.2 presents the percentage error for each heart rate measurement taken by the wearable devices compared to the manually measured heart rate, which serves as the reference. The analysis includes the Mean Absolute Percentage Error (MAPE), Root Mean Squared Error (RMSE), and Coefficient of Determination (R-squared) for both the Fitbit and Xiaomi devices.

Fitbit Performance: MAPE: 4.72%, RMSE: 8.91, R-squared: 0.13
Xiaomi Performance: MAPE: 11.89%, RMSE: 16.13, R-squared: -1.83

From these values, it is evident that the Fitbit outperforms the Xiaomi device in terms of heart rate measurement accuracy, as indicated by the lower MAPE and RMSE values. The Fitbit also shows a positive, albeit weak, correlation with the manual readings, as reflected in the R-squared value. In contrast, the Xiaomi device exhibits a negative R-squared value, indicating a poor alignment with the manual measurements, suggesting that its heart rate readings are less reliable.

Oxygen Saturation Measurement Accuracy

Table 4.3 details the percentage error of oxygen saturation measurements recorded by the Xiaomi device, again using the manually measured oxygen saturation as the reference. The corresponding statistical metrics are as follows:

Xiaomi Oxygen Saturation Performance: MAPE: 0.70%, RMSE: 1.0, R-squared: -0.11

The MAPE for the Xiaomi oxygen saturation readings is notably low, indicating minimal percentage errors in the measurements. However, the RMSE and negative R-squared value suggest that there is a poor fit between the Xiaomi SpO_2 readings and the manual measurements, indicating inconsistencies in the data captured by the device.

4.3.3 Bland-Altman Analysis of Heart Rate and Oxygen Saturation Measurements

Heart Rate Comparison

Figure 4.9 presents a Bland-Altman plot comparing the manual heart rate values with those recorded from the Fitbit device. The mean difference, indicated by the red dashed line, is -4.82 bpm, suggesting that the Fitbit device readings are on average lower than the manual values.

The plot also shows that most points fall within the region of agreement defined by the upper and lower limits of 1.96, as indicated by the green dashed lines. This indicates only slight deviations from the manual readings. The clustering of data points around the red dashed line suggests that the Fitbit data is less biased and more reliable, reinforcing its accuracy in heart rate measurement compared to manual assessments.

Xiaomi Device Comparison

Figure 4.10 displays a Bland-Altman plot comparing manual heart rate values with those recorded from the Xiaomi device. The mean difference observed is -7.86 bpm, indicating that the Xiaomi device readings are also lower than the manual values.

Similar to the Fitbit plot, most points are located within the region of agreement defined by the green dashed lines, indicating slight deviations from the manual values. However, the greater mean difference suggests that the Xiaomi device is less accurate compared to the Fitbit. The clustering of points around the red dashed line indicates that while the data is less biased, it still lacks the reliability seen with Fitbit, confirming that the Fitbit device offers higher accuracy in heart rate measurement.

Oxygen Saturation Comparison

In Figure 4.11, the mean difference of 0.62 suggests that the Xiaomi device values are generally lower than the manual values, but the proximity of most points within the agreement limits indicates that the readings are close to the manual measurements.

The clustering of points around the red dashed line implies that, while there are some discrepancies, the deviations are relatively minor, suggesting a degree of reliability in the Xiaomi device's oxygen saturation readings. This means that, despite some limitations, the Xiaomi device provides oxygen saturation values that are fairly consistent and less biased compared to the manual measurements.

4.3.4 Data Loss Analysis

The analysis of data loss for both the Fitbit and Xiaomi devices provides insight into the reliability of the measurements collected during the monitoring period.

Fitbit Data Loss

On average, the Fitbit experienced a data loss of approximately 2.07 hours out of a total expected duration of 63.22 hours. This translates to a loss of about 3.27% of the heart rate data collected.

Xiaomi Data Loss

In contrast, the Xiaomi device showed a significantly higher average data loss of approximately 18.78 hours (or 1126.5 minutes) out of an average total expected duration of 64.36 hours (or 3861.5 minutes). This results in an average data loss of approximately 29.19%.

4.4 Performance evaluation and limitations of system

4.4.1 Performance Evaluation

The eDOCTOR project aimed to assess the effectiveness of wearable devices in monitoring 5 vital signs, in a clinical setting. Based on the data collected from the Fitbit and Xiaomi devices, several key findings can be highlighted:

Accuracy of Measurements:

The Fitbit device demonstrated higher accuracy in heart rate measurements, with a lower Mean Absolute Percentage Error (MAPE) of 4.72% and a positive R-squared value of 0.13, indicating a weak correlation with manual readings.

In contrast, the Xiaomi device had a higher MAPE of 11.89% and a negative R-squared value of -1.83, suggesting poorer alignment with manual measurements.

Data Loss:

The Fitbit showed minimal data loss (3.27%), reflecting its reliability in continuous monitoring.

The Xiaomi device experienced significant data loss (29.19%), raising concerns about its effectiveness for consistent health monitoring.

Bland-Altman Analysis:

The Bland-Altman plots indicated that the Fitbit data was less biased and more reliable compared to the Xiaomi device's measurements. The mean differences suggested that while both devices recorded lower values than manual measurements, the Fitbit had a smaller mean difference, indicating better performance.

Oxygen Saturation Readings:

The Xiaomi device's oxygen saturation readings showed relatively low MAPE (0.70%) and were close to manual measurements, but the negative R-squared value indicated inconsistencies.

4.4.2 Limitations of the System

The system under discussion has several limitations that affect its functionality:

Limited Vital Sign Monitoring:

The system is only able to track heart rate and oxygen saturation. As a result, the wearable devices can only monitor these two vital signs in patients. While significant, these measurements represent only a fraction of overall health. There is a lack of monitoring for other vital signs like blood pressure, body temperature, and respiration rate, which severely restricts the wearable device's utility in clinical situations that require comprehensive monitoring. Relying solely on heart rate and SpO2 may cause early warning signs of conditions such as fever or respiratory issues to go unnoticed, delaying appropriate medical responses.

Dependence on Smartphones:
The devices require linked smartphones to sync data, which must be turned on and connected to the internet. This dependency means that if the smartphone is turned off, unplugged, or out of range, data synchronization may be disrupted, resulting in interruptions in real-time monitoring.

Improper Device Fitting:
If the wearable devices are not properly fitted, any movement by the patient can lead to the sensors losing contact with the skin, preventing accurate recording of vital signs. This issue emphasizes the importance of ensuring that devices are correctly worn for effective monitoring.

Sample Size and Generalizability:
The study involved a limited sample size of 23 patients, which may not be representative of the broader population. Future studies should include a larger and more diverse group to enhance generalizability.

Short Monitoring Duration:
The average duration of stay for patients was relatively short (two to four days), potentially limiting the understanding of long-term performance and reliability of the wearable devices.

Technological Constraints:
Technical issues, such as the loss of sensor contact with the skin, particularly affected the Xiaomi device's ability to capture accurate readings. These constraints highlight the need for improvements in wearable technology design.

Data Integration Challenges:

Integrating data from various sources (manual, Fitbit, Xiaomi) posed challenges in ensuring consistency and accuracy, indicating a need for better interoperability between devices and systems.

Chapter 5 – Conclusion and Recommendation

5.0 Introduction

This chapter summarizes the findings of the eDOCTOR project, which investigated the effectiveness of wearable devices in continuously monitoring vital signs, specifically heart rate and oxygen saturation, in a clinical setting. Based on the analysis, the project highlights the performance of the Fitbit and Xiaomi devices and emphasizes their contributions to advancing continuous vital sign monitoring, as well as the recommendations, observations, and challenges faced throughout the study.

5.1 Conclusions

This project represents a significant advancement in healthcare technology, particularly for settings with limited resources, such as hospitals in Ghana. By designing a web-based system for continuous vital sign monitoring using wearable devices like the Fitbit Inspire 3 and Xiaomi Smart Band 8, this project aims to reduce human error in manual monitoring and address key challenges like the high costs and maintenance requirements associated with conventional patient monitors. The ability to monitor oxygen saturation and pulse rate in real-time provides continuous data streams that are vital for the early detection of issues, particularly in trauma and paediatric patients.

The project achieved several key outcomes, including the ability to continuously monitor two vital signs for more than one patient (seven in total), creating reports on abnormal vital signs measured, and analysing the accuracy of heart rate measurements—93.65% for the Fitbit and 90.35% for the Xiaomi device—along with an oxygen saturation accuracy of 98% for the Xiaomi device. Additionally, the implementation of this system at Korle-Bu Hospital facilitates remote monitoring of vital signs, enhancing patient care.
However, the testing revealed several constraints that need to be addressed. The system's reliance on smartphones for data

synchronization poses a risk of data loss if the phone is turned off or disconnected from the internet. Additionally, the limited functionality in monitoring only heart rate and oxygen saturation highlights the need for incorporating other vital signs such as blood pressure, temperature, and respiration rate. Inadequate device fitting also emerged as a potential cause of false readings or data gaps, particularly in oxygen saturation measurements.

To fully realize the technology's potential, future enhancements should focus on ensuring proper device fitting and expanding monitoring capabilities. Integrating features like LTE connectivity could eliminate the need for smartphones, thereby improving reliability. Overall, despite current limitations, this project establishes a foundation for the use of wearable technology in medical settings, providing a more accurate and efficient method of patient monitoring, especially in resource-constrained environments. The performance evaluation underscores the advantages of wearable technology for monitoring vital signs, with the Fitbit device demonstrating superior accuracy and reliability. Addressing the identified limitations will be crucial for maximizing the effectiveness of such health monitoring systems in the future.

5.2 Recommendations

To improve the functioning of the eDOCTOR system, several actions can be taken:

Enhanced Wearable Devices: To maximize the system's utility and enable comprehensive monitoring of a patient’s health, it is essential to utilize wearable devices capable of capturing multiple vital signs, including respiratory rate, heart rate, body temperature, blood pressure, and blood oxygen saturation. This holistic approach will facilitate the early detection of potential complications, allowing for timely interventions.

Independent Data Transmission: Implementing built-in LTE connectivity in wearable devices would enable them to independently send data to cloud services or the application. This enhancement would eliminate the reliance on smartphones, allowing for continuous and uninterrupted monitoring of patients, thereby improving data reliability.

Proper Device Fitting: Ensuring that wearable devices are well-fitted to the patient is crucial to prevent data loss due to poor sensor placement. Training healthcare staff on proper fitting techniques and providing clear guidelines for patients can help achieve accurate and consistent readings.

5.3 Observations and challenges

5.3.1 Key Observations

1. Effectiveness of Wearable Technology: The project demonstrated that wearable devices like the Fitbit and Xiaomi can effectively monitor vital signs in real-time, providing critical data for early detection of health issues.

2. Data Accuracy: The accuracy analysis revealed that the Fitbit device had a heart rate accuracy of 93.65%, while the Xiaomi device had a heart rate accuracy of 90.35% and an oxygen saturation accuracy of 98%. This indicates a generally high level of reliability in the data collected.

3. Feasibility in Resource-Limited Settings: The implementation of the eDOCTOR system at Korle-Bu Hospital highlighted the feasibility of using wearable technology in low-resource environments, addressing the need for affordable patient monitoring solutions.

4. Continuous Monitoring of Multiple Patients: The system successfully monitored two vital signs for multiple patients simultaneously, demonstrating its scalability and potential for broader application in clinical settings.

5.3.2 Challenges

1. Reliance on Smartphones: The system's dependency on smartphones for data synchronization posed a significant risk of data loss if the phone

was turned off or disconnected from the internet, affecting real-time monitoring capabilities.

2. Limited Vital Sign Monitoring: The current setup only monitors heart rate and oxygen saturation, which restricts comprehensive patient assessments. There is a need for devices that can also track additional vital signs such as blood pressure, temperature, and respiration rate.

3. Device Fitting Issues: Inadequate fitting of wearable devices was identified as a challenge, leading to potential false readings or gaps in data, particularly for oxygen saturation measurements. Ensuring proper fitting is essential for accurate monitoring.

4. Technical Limitations: Issues related to the loss of sensor contact with the skin, especially during patient movement, affected data collection and reliability, highlighting the need for design improvements in wearable technology.

5. User Training and Compliance: Ensuring that healthcare staff and patients understand how to properly use and fit the devices was crucial. User training programs need to be developed to enhance compliance and data accuracy.

These observations and challenges provide valuable insights into the implementation and operation of wearable technology in clinical settings, guiding future improvements and research in this area.

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Appendices

Appendix A: Terminologies

- Percentage error is an expression of the difference between an obtained value from an actual value expressed as a percentage of the actual value.

$$percentage\ error = \frac{obtained\ value - actual\ value}{actual\ value} \times 100\%$$

- Mean Absolute Percentage Error (MAPE) is the average of the absolute percentage errors between the actual and obtained values.

$$M = \frac{1}{n} \sum_{t=1}^{n} \left| \frac{A_t - F_t}{A_t} \right|$$

Where

M = mean absolute percentage error

n = number of times the summation iteration happens

A_t = manually measured values

F_t = wearable device values

- Root Mean Squared Error (RMSE) is the square root of the average of the squared discrepancies between the obtained and actual values.

- Coefficient of Determination (R-squared) quantifies the percentage of the actual value's variance that can be predicted from the obtained value.